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Effects of capture, marking, and tracking on the welfare of wild birds

Katrine Eldegard, Marianne W. Furnes, Matthew J. Grainger, Børge Moe, Brett K. Sandercock, Geir A. Sonerud, Bjørnar Ytrehus, Eli Rueness, Amin Sayyari, Lawrence Kirkendal, Erik Granquist, Kyrre Kausrud

Scientific Opinion of the Norwegian Scientific Committee for Food and Environment

Abstract: Capture, handling and marking of wild birds requires ethical considerations of the risk of possible harm to individual birds, and the need to acquire the necessary knowledge as a basis for the management and conservation of bird populations. The effects on the welfare of individuals vary between methods and bird groups. This report provides an updated knowledge base and an overview of risk-reducing measures.

Keywords: animal welfare, attachment, capture, free-living birds, handling, marking, Norwegian Scientific Committee for Food and Environment, Norwegian Food Safety Authority, Norwegian Environment Agency, risk assessment, sampling, tagging, tracking, VKM, wild birds

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Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion. The project group consisted of four VKM members, one VKM staff and three external experts. Three referees commented on and reviewed the draft opinion. An interdisciplinary VKM approval group appointed specifically for the assignment, assessed and approved the final opinion.

Authors of the opinion

The authors have contributed to the opinion in a way that fulfils the authorship principles of VKM (VKM, 2019). The principles reflect the collaborative nature of the work, and the authors have contributed as members of either the project group or an interdisciplinary VKM approval group appointed specifically for the assignment.

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Project leader Danica Grahek-Ogden (VKM secretariat) is acknowledged for coordinating the work with the opinion.

Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

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Summary

Background. Ethical considerations with respect to the capture, handling, and marking of wild birds must balance the risk of potential harm to individual birds against the need to obtain the necessary data to address goals in basic science, and conservation targets for species and ecosystems. The Norwegian Environment Agency and the Norwegian Food Safety Authority requested an updated knowledge base on methods for capture, handling, and marking of wild birds for scientific and management purposes, and associated risk-reducing measures. Under the terms of reference (ToR) for the project, VKM was commissioned to: (1) Describe new knowledge for the methods presented in a previous report from 2013 (hereafter referred to as VKM 2013), and any updates or changes that lead to a reassessment of the potential risk level when capturing, handling, and marking wild birds; (2) Describe new methods and technological developments in the field, which are relevant to the conditions regulated by Norwegian law; (3) Consider the risk of reduced animal welfare when using the methods mentioned in points 1 and 2, both the direct effects and the consequences from a lifespan perspective as part of the 3R method based on Replacement, Reduction, and Refinement; and (4) Describe risk-reducing measures that can improve outcomes for animal welfare. The ToR were to update VKM 2013 and assess new methods that were not evaluated in 2013, but the current evaluation does not directly build upon VKM 2013. We have prepared risk assessments for a wide range of new advances for marking and tracking of wild birds but have nevertheless ensured that all methods evaluated by VKM 2013 were also included in the current report. For the subset of methods previously evaluated by VKM 2013, we have included information on whether the risk assessment has been downgraded, confirmed, or upgraded based on new research findings from the past decade.

Methods. *Limitations.* The assessment includes any bird species belonging to the orders of birds that are represented on the Norwegian mainland, other land areas where Norwegian law applies, or in Norwegian territorial waters; and methods that require an animal care permit from the National Animal Research Authority, or a bird ringing license or a wildlife permit from the Norwegian Environment Agency. In addition to impacts of handling *per se*, assessments of potential impacts of physical sampling methods were included, while risks to animal welfare related to ecological manipulations or experimental approaches and keeping birds in captivity for an extended period beyond marking, were not included. The assessment of methods that involve anesthesia or surgical procedures were restricted to the impacts of abdominal implantation of tracking devices. Regarding the 3Rs approach, the risk assessments focused on the refinement of methods in cases where marking is regarded as the most appropriate and adequate method, and use of new marking and tracking devices that provide detailed movement data from a reduced sample of marked birds, rather than whether field studies of wild birds should be replaced with alternative approaches.

Definition of animal welfare. Before initiating the literature search, the VKM project group established a common understanding of animal welfare and its indicators in free-living wild birds. We adopted an approach that synthesized the guidance on animal welfare risk assessment from the European Food Safety Authority with the Five Domains Model framework. The Five Domains approach assesses impacts on welfare from factors concerning 1: nutrition, 2: physical environment, 3: health, 4: behavioural

interactions, and 5: mental state. The mental state is deduced from the assessment of welfare indicators and welfare-alerting factors in the other domains. We have used the following definition of animal welfare: "*The welfare of an individual is its state as regards its attempts to cope with its environment*". Furthermore, our assessment is based on the view that the subjective feelings of an animal are an essential part of its welfare, and characteristic of an individual animal during a certain time interval, but still possible to assess in a scientific manner.

Evidence base. Initially, a comprehensive list of 92 benchmark papers was compiled for the capture, handling, sampling, and marking of wild birds. Due to resource constraints and a lower priority for updating the risk assessment for capture and handling methods, a full systematic literature search was only conducted for marking and tracking methods. The search was conducted by targeting peer-reviewed articles indexed in three major platforms: Web of Science (Core Collection), Biological Abstracts, and Scopus. The final search yielded 17,995 unique citations after removal of duplicate records. To further streamline the process, we undertook Topic Modelling to aid in screening. We screened articles based on defined criteria for inclusion and exclusion, considering only articles published after the year 2000 that evaluated methods for marking and tracking of wild birds, and provided some assessment of animal welfare in response to marking and tracking in either an observational study or in relation to a suitable control group. Metadata were extracted from 190 included articles, comprising 732 studies. Evidence of the impacts of capture, handling, and sampling was based on information from VKM 2013, the initial list of benchmark papers, the extensive libraries and first-hand experience of project group members, and additional literature searches for relevant articles.

Risk assessment method. We employed the Five Domains model as a conceptual framework for evaluating risks to animal welfare and developed rubrics and score sheets for a systematic approach. Assessments were conducted separately for each capture, handling, sampling, and marking method, utilizing the Five Domains rubric and score sheets. If a method has varying effects on different groups of birds, separate assessments have been conducted for each group of birds. For each method, the overall risk was assessed as either Low, Moderate, or High, and depicted in a matrix, with the probability of negative impact on the x-axis and the potential magnitude of negative impact on the y-axis. Additionally, the level of confidence in each assessment is indicated, after considering the quality and quantity of the available evidence for different groups of birds.

Results. In most of the methods described in this report, the birds must experience being captured and handled by humans. Apart from reports describing physical and behavioural responses to capture, there has been little research investigating the impact of such experiences on the mental state of wild birds. Nevertheless, it is plausible that the birds experience capture and handling as a life-threatening situation that elicits fear and alarm. As such, the risk of immediate harm to mental states from capturing and handling could be high in some cases. In this report, we have developed short descriptions of what we consider best practices for capturing and handling and we describe mitigation measures to improve animal welfare. During marking birds may go through an immediate, but presumably transient and intense experience. However, there is little scientific evidence to evaluate immediate effects on mental states of wild birds. Thus, the current report focuses on the short-term and long-lasting effects of capture, handling, marking, and tracking on risk of harm to animal welfare. This limitation does not mean that we consider the bird's experience of being captured unimportant. To write a scientific report that provides a foundation for improvement of animal welfare based on the current level of knowledge, we have concentrated on the short-term and long-lasting effects and less on the immediate effects.

For the 12 main capture methods evaluated, the risk of short-term or long-lasting harm to animal welfare was consistently assessed as Low, except for net guns and rocket/cannon nets, for which the risk was assessed as Moderate under certain conditions. Compared to VKM 2013, we downgraded the risk of short-term or long-lasting harm to animal welfare for mist netting. No formal risk assessment of the other capture methods was conducted in VKM 2013. For handling, the risk of short-term or long-lasting harm was assessed as Moderate. For sampling techniques, risk was assessed as Low for the methods evaluated if best-practice guidelines are followed. The previous report of VKM 2013 did not evaluate methods for handling and sampling of wild birds.

Regarding marking for individual identification (no tracking or logging) only temporary feather dyes were assessed as Low risk regardless of group of birds, and our assessment confirmed the evaluation in VKM 2013. For flipper bands on penguins, the risk was assessed High, which was an upgrading compared with VKM 2013. For five other marking methods, the risk was assessed as Low to High, depending on group of birds, and these risk assessments confirmed or upgraded the risk.

Regarding marking for tracking and logging, we have described the main *types of tags* used in ornithological studies. The evaluation of impacts on animal welfare from equipping wild birds with such tags are dealt with in the assessments of the modes of attachment. However, we provide a general description of how the impact of marking will depend on the weight, size, and shape of the device, as well as position on the body. For the *modes of attachment* of the tracking and logging devices, our evaluation revealed there was a great heterogeneity in the impacts on animal welfare. Subcutaneous PIT tags were assessed as Low risk. Glue and tape methods, tail mounts, necklace collars, and surgical implants, were assessed as Low to Moderate risk, depending on group of birds. Sutures and subcutaneous anchors, leg mounted tags, leg-loop harness, and backpack (thoracic) harness, were assessed as Low to High risk, depending on group of birds. Compared with VKM 2013, the assessment of PIT tags was confirmed, the assessments of backpack (thoracic) harness and surgical implants were confirmed or downgraded, and the assessment of glue and tape methods was confirmed or upgraded. VKM 2013 did not include a formal assessment of risk for sutures and subcutaneous anchors, tail mounted tags, leg mounted tags, leg-loop harness, or necklace collars.

Confidence in the evaluations varied among methods and groups of birds, mainly due to variation in the number and quality of primary studies. Overall, the evaluations are associated with low confidence for short-term effects on mental state, and variable levels of confidence for long-term effects on behavior, physiology, demography, and other domains.

Risk-reducing measures are provided for each specific method assessed. Additionally, we have identified five key measures that would significantly reduce the probability of adverse impacts on animal welfare: (1) follow best practises; (2) conduct pilot and effect studies; (3) ensure training routines; (4) standardise assessments and encourage reporting of animal welfare effects; and (5) continuing efforts to address the 3Rs with *refinement* and *reduction* to improve animal welfare.

Uncertainty. Wild birds are difficult to track, and monitoring any effects on welfare is challenging. Behavioural signs associated with state of welfare can vary greatly between species and are rarely well described in the literature. This is particularly true for capture, handling, and sampling situations, where normal behaviour is restricted, and some birds could be in a state of fear. Among studies reporting impacts on animal welfare, there are often significant variations in the approach, including the choice between observational or experimental study design, challenges in selected appropriate reference levels, and differences in measured animal welfare indicators and sample sizes. In addition to differences among the methods, impacts on animal welfare are influenced by factors such as species, age, sex, and physical condition and environmental variability. The risk of harm to animal welfare will also depend on the training and skills of the individual researchers employing different field methods.

Data gaps. There is a growing foundation of documentation in the scientific literature on the impacts on animal welfare of the capture, handling, sampling, and marking of wild birds relative to the extensive use of various techniques. Nevertheless, many field studies do not include a control group to evaluate marking or tagging methods and negative effects from pilot studies may remain unpublished. Avian responses can also be heterogeneous and field techniques that work well for one group of birds can have negative effects on other birds that differ in morphology, behaviour, or ecology. Some behavioural, physiological, or demographic responses are easier to observe and record for free-living birds under field conditions than are others. There is a lack of scientific knowledge on the effects of capture, handling and sampling on the mental state of birds, partially caused by lack of standardized studies including interpretation of bird behaviour during these events.

Conclusions. If conducted by trained personnel following best practices, all the methods for capture, handling, or sampling evaluated in this report were assessed as low or moderate risk for short-term or long-lasting harm to animal welfare. Among the different methods for marking and tagging of wild birds, temporary feather dyes and PIT tags were assessed as low risk, while glue and tape methods, tail mounted tags, necklace collars, and surgical implants were assessed as low or moderate risk, and flipper tags on penguins as high risk. Metal and colour rings, leg flags, patagial wing and web tags, neck bands, nasal discs and saddles, sutures and subcutaneous anchors, leg mounted tags, leg-loop and backpack (thoracic) harness were assessed as low, moderate, or high risk, depending on group of birds. The substantial heterogeneity in the impacts on animal welfare among methods and different groups of birds means that thorough pre-investigation, planning, and preparations are required for safe capture, handling, sampling, and marking of wild birds.

Sammendrag på norsk

Bakgrunn. Etiske vurderinger knyttet til fangst, håndtering og merking av ville fugler må balansere risikoen for mulig skade på enkeltfugler mot behovet for å skaffe nødvendige data for å besvare grunnleggende forskningsspørsmål, og for å nå forvaltnings- og bevaringsmål for arter og økosystemer. Miljødirektoratet og Mattilsynet har bedt om et oppdatert kunnskapsgrunnlag om metoder for fangst, håndtering og merking av ville fugler til vitenskapelige og forvaltningsmessige formål, samt tilhørende risikoreduserende tiltak. I henhold til prosjektets mandat (Terms of Reference, ToR) fikk VKM i oppdrag å: (1) Beskrive ny kunnskap om metodene presentert i en tidligere rapport fra 2013 (heretter referert til som VKM 2013), og eventuelle oppdateringer eller endringer som fører til revurdering av potensielt risikonivå ved fangst, håndtering og merking av ville fugler; (2) Beskrive nye metoder og teknologiske utviklinger på feltet som er relevante for forhold regulert av norsk lov; (3) Vurdere risikoen for redusert dyrevelferd ved bruk av metodene nevnt i punkt 1 og 2, både de direkte effektene og konsekvensene i et livsperspektiv som en del av 3R-metoden basert på Erstatning (Replacement), Reduksjon (Reduction) og Forbedring (Refinement); og (4) Beskrive risikoreduserende tiltak som kan forbedre utfallet for dyrevelferd. Oppdraget var å oppdatere VKM 2013 og vurdere nye metoder som ikke ble vurdert i 2013, men den nåværende vurderingen bygger ikke direkte på VKM 2013. Vi har utarbeidet risikovurderinger for en rekke nye metoder innen merking og sporing av ville fugler, men vi har likevel sørget for at alle metodene som ble vurdert av VKM i 2013 også ble inkludert i vår rapport. For de metodene som tidligere ble vurdert av VKM i 2013, har vi inkludert informasjon om hvorvidt risikovurderingen har blitt nedjustert, bekreftet eller oppjustert basert på nye forskningsfunn fra det siste tiåret.

Metoder. *Avgrensinger*. Vurderingen inkluderer alle fuglearter tilhørende fugleordenene som er representert på norsk fastland, andre landområder hvor norsk lov gjelder, eller i norsk territorialfarvann; og metoder som krever tillatelse fra Mattilsynet, eller en ringmerkingslisens og/eller en fangsttillatelse fra Miljødirektoratet. I tillegg til effektene av håndtering i seg selv, inkluderte vi vurderinger av mulige virkninger av fysiske prøvetakingsmetoder (sampling). Risiko knyttet til økologiske manipulasjoner eller eksperimentelle tilnærminger, og oppbevaring av fugler i fangenskap i en utvidet periode utover varigheten av selve merkeprosedyren, ble ikke inkludert. Vurderingen av metoder som involverer anestesi eller kirurgiske prosedyrer ble begrenset til effektene av abdominal implantasjon av sporingsenheter. Når det gjelder tilnærmingen med 3R, fokuserte risikovurderingene på *forbedring* (*refinement*) av metoder i tilfeller der merking er vurdert å være den mest hensiktsmessige og passende metoden, samt bruk av nye merke- og sporingsenheter som gir detaljerte bevegelsesdata fra et *redusert* utvalg av merkede fugler. Rapporten vurderer ikke hvorvidt feltstudier av ville fugler bør erstattes med alternative tilnærminger.

Definisjon av dyrevelferd. Før vi startet litteratursøket etablerte VKM-prosjektgruppen en felles forståelse av begrepet dyrevelferd og dyrevelferdsindikatorer hos frittlevende ville fugler. Vi valgte å bruke en tilnærming der vi benyttet veiledningen fra European Food Safety Authority for risikovurdering av dyrevelferd sammen med rammeverket til den såkalte 'Five Domains-modellen'. I 'Five Domains-modellen' vurderes effekten på dyrets velferd innenfor fem hovedområder 1: ernæring, 2: fysisk miljø, 3: helse, 4: atferdsinteraksjoner og 5: mental tilstand. Den mentale tilstanden angis på grunnlag av vurderingen av dyrevelferdsindikatorer og varslingsindikatorer for dyrevelferd fra de andre områdene. Vi har brukt følgende definisjon av dyrevelferd: "Individets velferd er dets tilstand med hensyn til dets mulighet til å mestre sitt miljø". Videre er vår vurdering basert på synet at et dyrs subjektive følelser er en essensiell del av dets velferd, og et karaktertrekk ved det enkelte dyret i en gitt tidsperiode, men som likevel vil være mulig å vurdere på en vitenskapelig måte.

Kunnskapsgrunnlag. Som en start ble det utarbeidet en omfattende liste med 92 nøkkelreferanser (benchmark papers) for fangst, håndtering, prøvetaking og merking av ville fugler. På grunn av begrensede ressurser og lavere prioritet for oppdatering av risikovurderingen for fangst- og håndteringsmetoder, ble det utført et fullstendig systematisk litteratursøk bare for merkings- og sporingsmetoder. Søket ble innrettet for å fange opp fagfellevurderte artikler indeksert i tre store plattformer: Web of Science (Core Collection), Biological Abstracts og Scopus. Det endelige søket resulterte i 17 995 unike artikler etter fjerning av duplikater. For ytterligere å strømlinjeforme prosessen gjennomførte vi temamodellering (Topic modelling) som en hjelp i screeningen av artiklene. Vi gjennomgikk artikler basert på definerte kriterier for inkludering og ekskludering. Vi vurderte bare artikler som var publisert etter år 2000, og bare artikler som evaluerte metoder for merking og sporing av ville fugler, og som ga en viss vurdering av dyrevelferd som respons på merking og sporing, enten i en observasjonsstudie eller i forhold til en egnet kontrollgruppe. Metadata ble hentet ut fra 190 inkluderte artikler som omfattet 732 studier. Kunnskapsgrunnlaget for effektene av fangst, håndtering og prøvetaking var basert på informasjon fra VKM 2013, den opprinnelige listen over nøkkelreferanser, de omfattende private bibliotekene og førstehåndserfaringen til prosjektgruppens medlemmer, og tilleggslitteratursøk etter relevante artikler.

Risikovurderingsmetode. Vi benyttet 'Five Domains' modellen som et konseptuelt rammeverk for å evaluere risiko for negative effekter på dyrevelferd, og vi utviklet en dreiebok/sjekkliste og et tilhørende poengskjema for å sikre en systematisk tilnærming. Vurderingene ble gjennomført separat for hver fangst-, håndterings-, prøvetakings- og merkemetode, ved hjelp av 'Five Domains' sjekklisten og tilhørende poengskjema. Hvis en metode har ulik effekt på ulike fuglegrupper, har separate vurderinger blitt gjennomført for hver relevant fuglegruppe. For hver metode ble den overordnede risikoen vurdert som enten Lav, Moderat eller Høy, og visualisert i en matrise, med sannsynligheten for negativ effekt på x-aksen og mulig grad/styrke av negativ innvirkning på y-aksen. I tillegg er nivået av tillit (confidence) knyttet til hver vurdering oppgitt, basert på kvaliteten og omfang av datagrunnlaget for ulike fuglegrupper.

Resultater. For de fleste metodene beskrevet i denne rapporten må fuglene oppleve å bli fanget og håndtert av mennesker. Bortsett fra rapporter som beskriver fysiske og atferdsmessige reaksjoner på fangst, har det vært lite forskning som undersøker effekten av slike opplevelser på den mentale tilstanden til ville fugler. Likevel er det mulig at fuglene opplever fangst og håndtering som en livstruende situasjon som vekker frykt og alarm (beredskap). Som sådan kan risikoen for umiddelbar negativ effekt på mental tilstand forårsaket av fangst og håndtering være høy i noen tilfeller. I denne rapporten har vi utarbeidet korte beskrivelser av hva vi anser som beste praksis for fangst og håndtering, og vi beskriver tiltak for å forbedre dyrevelferden. Ved merking kan ville fugler gjennomgå en umiddelbar, men antakeligvis forbigående og intens opplevelse, men det finnes lite vitenskapelig belegg for å evaluere umiddelbare effekter på deres mentale tilstand. Derfor har vi fokusert vår evaluering på de kortsiktige og langvarige effektene av fangst, håndtering, merking og sporing på risikoen for negative effekter på dyrevelferden. Denne avgrensningen betyr ikke at vi anser fuglens opplevelse av å bli fanget som uviktig. Men for å skrive en vitenskapelig rapport som gir grunnlag for forbedring av dyrevelferden, basert på dagens kunnskapsnivå, har vi valgt å fokusere på de kortsiktige og langvarige effektene og mindre på de umiddelbare effektene.

For de tolv hovedtypene av fangstmetoder som ble evaluert, ble risikoen for kortsiktig eller langvarig skade på dyrevelferden gjennomgående vurdert som Lav, bortsett fra for nettgevær og rakett-/kanonnett, der risikoen ble vurdert som Moderat under visse forhold. Sammenlignet med VKM 2013, nedgraderte vi risikoen for kortsiktig eller langvarig skade på dyrevelferden for 'mistnett'. Det ble ikke gjennomført noen formell risikovurdering av de andre fangstmetodene i VKM 2013. For håndtering ble risikoen for kortsiktig eller langvarig skade vurdert som Moderat. For metoder for prøvetaking ble risikoen vurdert som Lav for de evaluerte metodene, hvis beste praksis retningslinjer følges. Den forrige rapporten fra VKM i 2013 vurderte ikke metoder for håndtering og prøvetaking av ville fugler.

Når det gjelder merking for individuell identifikasjon (uten sporing eller logging) ble kun midlertidig farging av fjær vurdert som lav risiko uavhengig av fuglegruppe, og vår vurdering bekreftet evalueringen i VKM 2013 for denne metoden. For 'flipper bands' på pingviner ble risikoen vurdert som høy, noe som er en oppgradering sammenlignet med VKM 2013. For fem andre merkemetoder ble risikoen vurdert som lav til høy, avhengig av fuglegruppe, og disse risikovurderingene bekreftet eller oppgraderte risikoen sammenliknet med VKM 2013.

Når det gjelder merking for sporing og logging, har vi beskrevet de viktigste typene av merker (tags) og loggere som brukes i ornitologiske studier. Vurderingen av konsekvensene for dyrevelferd som følge av å utstyre ville fugler med slike merker, er i hovedak behandlet i vurderingene av festemetoder. I tillegg gir vi en generell beskrivelse av hvordan effektene av merking på dyrevelferd vil avhenge av vekt, størrelse og utformingen av merkeenheten, samt plasseringen på kroppen. Når det gjelder metodene som brukes for å feste sporings- og loggingsenheter til fuglen, avdekket vår evaluering at det var stor variasjon (heterogenitet) i konsekvensene for dyrevelferd. Subkutane PIT-merker ble vurdert å medføre lav risiko. Lime- og teipemetoder, halemontering, halsbånd og kirurgiske implantater ble vurdert å medføre lav til moderat risiko, avhengig av fuglegruppe. Suturer og subkutane ankere, merker festet på fuglens ben, benløkke (leg-loop) sele og ryggsekk/kroppssele, ble vurdert å medføre lav til høy risiko, avhengig av fuglegruppe. Sammenlignet med VKM 2013, ble vurderingen av PIT-merker bekreftet, vurderingene av ryggsekk/kroppssele og kirurgiske implantater ble bekreftet eller nedgradert, og vurderingen av lime- og teipemetoder ble bekreftet eller oppgradert. VKM 2013 inkluderte ikke en formell vurdering av risiko ved bruk av suturer og subkutane ankere, eller halemonterte, benmonterte, halsbånd eller benløkke (leg-loop) sele for festing av sporingsenheter.

Tilliten (confidence) til vurderingene varierer mellom metoder og grupper av fugler, hovedsakelig på grunn av variasjon i antallet og kvaliteten på primærstudiene som vurderingene er basert på. Generelt sett er vurderingene assosiert med lav tillit når det gjelder kortsiktige effekter på mental tilstand, og variable nivåer av tillit når det gjelder langsiktige effekter på atferd, fysiologi, demografi og andre områder

Riskoreduserende tiltak er oppgitt for hver enkelt av metodene som er evaluert. I tillegg har vi identifisert fem nøkkeltiltak som i betydelig grad kan redusere sannsynligheten for negative effekter på dyrevelferd: (1) følge beste praksis; (2) gjennomføre pilot- og effektstudier; (3) sikre opplæring og rutiner; (4) standardisere vurderinger og oppfordre til rapportering av dyrevelferdseffekter; og (5) fortsette innsatsen med å anvende de 3R-ene med *forbedring* (Refinement) og *reduksjon* (Reduction) for å bedre dyrevelferden.

Usikkerhet. Ville fugler er vanskelige å spore, og det er utfordrende å overvåke eventuelle effekter på velferden deres. Atferdsmessige tegn knyttet til velferdstilstand kan variere betydelig mellom arter, og er sjelden tilstrekkelig godt beskrevet i litteraturen. Dette gjelder særlig for fangst, håndtering og prøvetakningssituasjoner, der normal atferd er begrenset, og der noen fugler kan være i en tilstand av frykt. Blant studiene som rapporterer om effekter på dyrevelferd er det ofte betydelige variasjoner i metodetilnærming, inkludert valget mellom observasjonsstudier eller eksperimentell studiedesign, utfordringer med å velge passende referansegruppe(r), og forskjeller i målte dyrevelferdsindikatorer og utvalgsstørrelse. I tillegg påvirkes effekter på dyrevelferd av faktorer som fuglens art, alder, kjønn og fysisk kondisjon/tilstand, samt miljømessig variasjon. Risikoen for negativ effekt på dyrevelferd vil også avhenge av opplæringen og ferdighetene til de enkelte forskerne som bruker ulike feltmetoder.

Kunnskapshull. Det er en stadig økende mengde dokumentasjon i den vitenskapelige litteraturen knyttet til effektene på dyrevelferd av fangst, håndtering, prøvetaking og merking av ville fugler, sett i forhold til den omfattende bruken av ulike teknikker. Likevel inkluderer mange feltstudier ikke en kontrollgruppe for å evaluere merkemetoder, og negative effekter fra pilotstudier kan forbli upubliserte. Fuglenes respons kan også være heterogen, og feltteknikker som fungerer bra for én gruppe fugler, kan ha negative effekter på fugler som har en annen morfologi, atferd eller økologi. Noen atferdsmessige, fysiologiske eller demografiske responser er enklere å observere og registrere enn andre for frittlevende fugler under feltforhold. Det mangler vitenskapelig kunnskap om effektene av fangst, håndtering og prøvetaking på fuglenes mentale tilstand, delvis forårsaket av mangel på standardiserte studier som inkluderer tolkning av fuglenes atferd under disse hendelsene.

Konklusjoner. Forutsatt at de blir utført av opplært personell som følger beste praksis, er alle metodene for fangst, håndtering eller prøvetaking vurdert i denne rapporten å medføre lav eller moderat risiko for kortvarig eller langvarig negativ effekt på dyrevelferd. Blant de ulike metodene for merking av ville fugler ble midlertidig fjærfarging og PIT-merker vurdert å medføre lav risiko, mens lime- og teipemetoder, halemontering, halsbånd(sendere), og kirurgiske implantater ble vurdert å medføre lav eller moderat risiko, og 'flipper bands' på pingviner å medføre høy risiko. Metall- og fargeringer, benflagg, 'patagiale' vingemerker, halsbånd (individmerking av vannfugl), neseskiver og -sadler, suturer og subkutane ankere, benmonterte merker, benløkke- og ryggsekk (kropps-) sele ble vurdert å medføre lav, moderat eller høy risiko, avhengig av fuglegruppe. Den betydelige heterogeniteten i effekter på dyrevelferd mellom metodene og forskjellige grupper av fugler betyr at grundig forundersøkelse, planlegging og forberedelser er nødvendig for trygg fangst, håndtering, prøvetaking og merking av ville fugler.

1 Background as provided by the Norwegian Food Safety Authority and Norwegian Environment Agency

Assessment of the risks of reduced animal welfare due to capture, handling and marking of wild birds

The Norwegian Food Safety Authority (Mattilsynet) and the Norwegian Environment Agency (Miljødirektoratet) refer to their respective cooperation agreements with the Norwegian Scientific Committee for Food and Environment (VKM), and hereby request VKM to conduct an updated risk assessment related to animal welfare when capturing, handling, and marking wild birds.

Background

In 2012, the Norwegian Food Safety Authority asked VKM for a risk assessment of animal welfare when marking selected wild species of terrestrial and marine mammals, and birds. The Norwegian Food Safety Authority asked VKM to investigate how the most used methods of capture and handling, as well as methods for marking and tagging, will affect the welfare of these species. The report "Risk assessment concerning the welfare of certain free ranging wild mammals and birds subjected to marking" was published by VKM in 2013 (VKM Report 2013: 26).
The report gave the management authorities an updated knowledge base for risk and risk-reducing measures when capturing, handling, and marking wild mammal and bird species for scientific and management purposes.

Updated knowledge about animal welfare impacts on birds

All capture, handling, and marking of birds will influence the affected individuals. Capture, handling, and marking for scientific and management purposes contribute to increased knowledge and thus also have societal value. Efforts must always be made to use the best possible methods and minimize the risk of negative effects on animal welfare. In this commission, the Norwegian Environment Agency and the Norwegian Food Safety Authority request an updated knowledge base for:

- Capture and handling methods
- Marking and tagging methods
- Risk-reducing measures

2 Terms of reference as provided by the Norwegian Food Safety Authority/ Norwegian Environment Agency

The Norwegian Food Safety Authority and the Norwegian Environment Agency ask VKM to address the following:

1. Describe new knowledge for the methods presented in the report from 2013, and any changes that lead to an altered risk level when capturing, handling and marking wild birds
2. Describe new methods (not mentioned in the report from 2013) and technological developments in the field, which are relevant to the conditions regulated by Norwegian law
3. Consider (if possible) the risk of reduced animal welfare when using the methods mentioned in points 1 and 2, both the direct effects and the consequences from a lifespan perspective as part of the 3R method; replacement, reduction, and refinement (such as effects on behavior and demography)
4. Describe (if possible) measures that can reduce the risks (e.g., by use of best practice protocols) of reduced animal welfare when using methods described in points 1 and 2.

Conditions

The risk assessment report should be written in English with a Norwegian summary.

The deadline for delivery of the report will be the end of January 2024.

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3 Aim, objectives, and research questions

The research questions matched the Terms of Reference (ToR) as provided by the Norwegian Food Safety Authority (Mattilsynet) and the Norwegian Environment Agency (Miljødirektoratet) (see Chapter 2). The current risk assessment was restricted to wild birds under natural conditions and provides a major update and expansion to a previous report from VKM (2013): 'Risk assessment concerning the welfare of certain free-ranging wild mammals and birds subjected to marking' (hereafter 'VKM 2013'). The task set by the ToR was to update VKM 2013 and assess new methods that were not evaluated in 2013, but the current evaluation does not directly build upon VKM 2013. We have prepared risk assessments for a wide range of new advances for marking and tracking of wild birds but have nevertheless ensured that all methods evaluated by VKM 2013 were also included in the current report. For the subset of methods previously evaluated by VKM 2013, we have included information on whether the risk assessment has been downgraded, confirmed, or upgraded based on new research findings from the past decade. Before developing a final strategy for the literature search and risk assessment approach, the project team, in consultation with the Norwegian Food Safety Authority and the Norwegian Environment Agency, held regular meetings to agree on the target populations and some further limitations and clarifications of the assignment.

The project team recognizes that the risk assessment will serve as a reference document during the evaluation of applications for permits to the Norwegian Food Safety Authority and the Norwegian Environment Agency to capture, handle, and mark wild birds. We have endeavoured to create a user-friendly document for case managers within the National Animal Research Authority and the Norwegian Environment Agency. The description of each method and the assessment of the risk of negative effects on animal welfare associated with each method can be found in the following five chapters: 8: Capture of wild birds, 9: Handling and sampling, 10: Marking for individual recognition, 11: Marking for tracking and logging, and 12: Mode of attachment.

Legal context

The Norwegian Food Safety Authority is the National Animal Research Authority in Norway. The Norwegian Food Safety Authority is the national authority responsible for the implementation of Directive 2010/63/EU on the protection of animals used for scientific purposes (data.europa.eu/eli/dir/2010/63/2019-06-26) which has been implemented in Norway with the Norwegian Regulation on Animal Experimentation (FOR-2015-06-18-761 Forskrift om bruk av dyr i forsøk, lovdata.no/dokument/SF/forskrift/2015-06-18-761). Within the Norwegian Food Safety Authority, the National Animal Research Authority (Forsøksdyrforvaltningen) has responsibility for enforcement of the terms of the directive and the national legislation. Use of animals in research is also regulated under legislation for damage control of nuisance animals, dead wildlife, and use of wildlife in production facilities, research, and zoological parks (FOR-2020-04-01-565 Viltforskriften, lovdata.no/dokument/SF/forskrift/2020-04-01-565). Here, the Norwegian Environment

Agency is the responsible authority for decisions regarding authorizations to capture wildlife for scientific purposes.

Threatened species are specifically mentioned in the national legislation for requirements on the use of animals in research (forsøksdyrforskriften: §4g and §19). In principle, the use of threatened species is prohibited. However, the prohibition does NOT apply if the purpose of the experiment is research to conserve the animal species, and it is scientifically justified that the purpose of the experiment cannot be achieved by using species other than threatened ones (cf. §19 and 10e of forsøksdyrforskriften). The purpose of the Nature Diversity Act adopted in 2009 (LOVDATA, 2009b) was to halt biodiversity loss. The management goal for species in §5 is that the species and their genetic diversity should be safeguarded in the long term, and that the species should occur in viable populations within their natural distribution areas. To the extent necessary to achieve this goal, the ecological functional areas of the species and the other ecological conditions on which they depend should also be safeguarded. The Nature Diversity Act also established the principle that management decisions should be knowledge-based (§8).

According to EU legislation, i.e., EU Commission Implementing Decision 2020/569, Annex III, Part B, pkt. 9.4, (EC, 2020) about reporting use of animals in procedures, including information on the actual severity (EC, 2010), the stress associated with capture and transport should not be included in the assessment of severity unless the scientific purpose of the experiment is to evaluate the capture method itself. These terms can be interpreted to mean that animal welfare authorities do not have a legal basis to include animal welfare impacts of capture and transport in their cost-benefit analyses of animal research applications. In practice, however, the EU decision applies for the severity assessment, while Norwegian animal research authorities will include animal welfare impacts from capture and transport in their cost-benefit analyses, referring to the more general legal competence given in the Animal Welfare Act ("Animals shall be treated well and be protected from danger of unnecessary stress and strains.") (NMD, 2009). Consequently, and in line with the Terms of Reference, we have assessed the potential for negative impacts on animal welfare from standard capture methods that are commonly used with wild birds.

In summary, three areas of legislation affect fieldwork with wild animals for scientific purposes in Norway: 1. Authorization from the National Animal Research Authority at the Norwegian Food Safety Authority to use animals for scientific purposes. 2. Authorization from the Norwegian Environment Agency to capture or collect wild animals for scientific purposes. 3. Specific legislation may apply to the location where the experiment will take place with special requirements for field projects at Svalbard, national parks, and other protected areas.

Target populations

The assessment of animal welfare impacts in this report includes impacts on any bird species belonging to bird orders that are represented on the Norwegian mainland, other land areas where Norwegian law applies, or in Norwegian territorial waters (Figure 1). Chapter 4 provides a concise overview of the orders and species of wild birds included in the report. Impacts on bird species were not assessed for taxa belonging to bird orders that are not represented in areas where Norwegian law applies, such as ratites, bustards, tropical trogons, hornbills, and parrots.

Figure 1. The current assessment also includes bird species that do not occur in Norway, if they belong to orders represented in Norway. The bird released in the photo is a North American passerine, the Northern Cardinal (*Cardinalis cardinalis*) and the focus of a previous risk assessment (VKM et al., 2023a). Photo: B.K. Sandercock.

Limitations

The assessment of the impacts of capture and handling was focused on methods that require permits from the National Animal Research Authority and the Norwegian Environment Agency for marking or tagging of individual birds. Currently, ringing of birds with metal leg rings only or up to two colour bands does not require approval from the National Animal Research Authority. Obtaining a formal license from the Norwegian Environment Agency is a prerequisite for bird ringing. A bird ringing license is granted upon completion of mandatory courses and practical training. Ringing with metal bands also requires filing of annual reports on ringed birds to the Norwegian Bird Ringing Centre at the Stavanger Museum. Use of metal and colour rings alone may not require an animal care permit, but we included an evaluation of the impacts of bird ringing in the current risk assessment because birds marked with metal rings were often used as a control group to evaluate the effects of different marking and tagging treatments.

In addition to evaluating the effects of handling itself, the project team also examined the potential impacts of methods for collecting physical samples from live birds, including blood sampling, feather plucking and cloacal swabs. Sampling procedures are often conducted while marking individual birds for ecological studies. The procedures often require small increases in handling time in addition to the time required for individual marking of birds. For both physical sampling and marking, the current risk assessment covered impacts on welfare arising from the procedures themselves, prolonged handling time, and post-release effects.

We did not assess the potential risks to animal welfare for wild birds kept in captivity for a significantly longer duration than that required for marking. Furthermore, we did not assess the potential risks associated with various ecological manipulations or experimental approaches, such as vaccination, hormone augmentation, alterations of plumage brightness, food supplementation, experimental changes in clutch size, playback of predator calls, or exposure to anthropogenic noise.

The evaluation of impacts resulting from attachment methods and marking technology involving general anaesthesia and surgical procedures was confined to the assessment of the effects of abdominal implantation of tracking devices. Methods for euthanasia were not addressed in this report.

3Rs approach in wild animal research

According to the Terms of Reference (ToR), the risk of reduced welfare, both direct impacts – and impacts in a life-cycle perspective – should be assessed as part of a 3Rs approach based on the concepts of Replacement, Reduction, and Refinement. The 3Rs approach was originally developed for laboratory animal research (Russell & Burch, 1992). The usefulness and challenges of applying the 3Rs approach in studies of free-ranging wild birds was discussed by the project team before the literature search was designed and performed. The project team concluded that to answer the ToR on this point, it is important to recognize that implementing the 3R approach has a different set of challenges for field studies of wild, free-living birds under natural conditions than in lab studies of captive populations of wild or domesticated birds (Lindsjo et al., 2016). See also Chapter 5 Animal welfare in wild birds.

In the current assessment, we evaluate the risk of harm to animal welfare for wild birds in field studies. Replacement is typically not an option for field studies of wild birds because it is the demography or movements of target species are often the key data needed for effective conservation or management actions (Box 1).

Box 1. Striking a balance between animal welfare considerations and addressing important knowledge gaps.

Many populations of wild birds are declining with negative trends in population numbers. Declines in bird populations are often caused by exposure to anthropogenic factors and to environmental change. Ecological studies of birds aim to describe, understand, and predict the interactions between birds and their abiotic and biotic environments. Effective conservation efforts require fundamental knowledge about ecological interactions, including information on movements, habitat preferences, migration patterns, breeding success, body condition, and survival of individuals, to understand effects of environmental conditions on individuals as well as populations and entire species. Collection of individual-level data requires capture, handling, collection of samples, and marking of wild birds. Advances in tracking technologies allow collection of detailed movement and physiological data from individual birds, thereby reducing the number of individuals needed for research purposes. Ethical considerations regarding capture, handling, collection of samples, and marking of wild birds must balance the risk of potential harm to individual birds against a need to obtain the necessary data to address goals in basic science and conservation targets for species and ecosystems. Under the Kunming-Montreal Global Biodiversity Framework, adopted by Conference of the Parties (COP15) to the UN Convention on biological diversity, Norway has recently committed to protect 30% of both its terrestrial and inland water areas, as well as marine and coastal areas, by 2030. At the same time, Norway aims to substantially increase energy production from renewable resources, which will require large areas of land and at sea. Hence, there is a societal need for tracking individual birds for mapping habitat use of bird populations, and for siting new anthropogenic developments to areas with the lowest possible impact on biological diversity. Uninformed societal decisions that lead to loss and degradation of critical habitats will negatively affect individual animal welfare and population viability. Additionally, having individually identifiable birds helps build public empathy for birds and conservation actions. Individual marking can increase the understanding of bird personalities and abilities, which resonates with the general public.

Options for replacement are limited in field studies of wild birds. Population viability models and epidemiological models of disease dynamics can be used to explore the consequences of different management scenarios but usually require field estimates of vital rates for wild birds as a model input. Behaviour and local movements can be measured by direct observation of unmarked birds or by indirect methods including video cameras at nests or roosts but usually do not allow evaluation of individual variation. In some case, non-invasive sampling with recordings of unique songs of territorial males or collection of shed feathers at nests may allow individuals to be monitored without a need for physical capture and marking (Kleven et al., 2016). Individual birds can be identified by natural variation in plumage coloration in a few species but that is a rare situation (Whitfield 1986).

Reductions in the number of animals used in scientific research can often be realized with improvements in marking and tracking techniques. Estimates of annual survival based on ring-marking alone typically require large samples of marked birds because individuals must be recaptured to retrieve ring numbers (Sandercock et al. 2000). Colour-banding can provide better data on live encounters from a smaller sample of birds because individuals can be resighted without handling (Martin et al. 2017). Accordingly, the Norwegian Food Safety Authority stated that amateur bird ringers may use one metal ring and up to two colour rings per bird without needing approvals under an animal care permit. Miniature tracking devices have revolutionized the study of bird migration because they provide high resolution data on timing, routes, site use, and migratory connectivity (McKinnon and Love 2018). New tracking technologies also offer dramatic reductions in the number of birds that must be marked to obtain high quality movement data and often provide new insights that cannot be obtained with less advanced methods, for example ringing alone (Strandberg et al. 2009). Reductions can also be realized by combining data from tracking studies with data from non-invasive methods so that fewer birds need to be marked to obtain robust results. Reductions in number of animals can also be realized with an improved experimental design based on a preliminary power analysis to determine optimal sample sizes, pilot studies to determine if a project is feasible, and pooling of data among different research groups to test for possible effects on animal welfare.

Our assessment is primarily a contribution to the concept of Refinement because we review the best practices and pitfalls known for existing methods and compare options among standard and new techniques to facilitate choice of the best possible method when planning, performing, evaluating, and reporting on the marking and tracking of wild birds. Our assessment does not address whether field studies of wild birds should be replaced with alternate approaches – and places less emphasis on whether the number of marked birds should be reduced – but instead focuses on the refinement of methods for research questions where marking or tracking are regarded as the most appropriate methods. Many of the refinements are based on reducing capture and handling times such as continuous monitoring of trap sets and improved procedures for safe handling and marking of wild birds. Refinement of field protocols for use of wild birds in research will often contribute to replacement and reduction, as field studies with minimal harm on animal welfare of common species can provide a large amount of knowledge that is applicable to multiple species and settings, thereby replacing and reducing the need for additional field studies. In cases where marking or tracking tags must be used, new techniques can be tested and developed with captive birds held in aviaries before field applications to wild birds (Green et al., 2004; Kesler et al., 2014; Lamb et al., 2016; Weiss & Cristol, 1999). Similarly, individuals of common, robust, and easily observed birds may be used for field tests prior to deployment on more sensitive species, to enable prediction of potential adverse effects both at an individual level for animal welfare or at population effects of reproductive performance and survival. Glue techniques for attaching tracking devices were initially developed with common species of waders (Warnock & Warnock, 1993) before the same method was implemented for tracking of Spoon-billed Sandpipers (*Calidris pygmaea*) as a Critically Endangered species (Chang, 2020).

General considerations

When conducting studies on wild birds, it is essential to ensure that the capturing, handling, sampling, or marking procedures do not negatively impact the behavior, physiology, reproductive success, or survival of the marked individuals (Fair et al., 2023). Minimizing impacts is essential not only for the welfare of the birds but also for the integrity of the research or investigation in line with the 3Rs (Zemanova, 2021) and for continued public support and social acceptance (Beausoleil et al., 2018). Since 2010, several review papers and meta-analyses have been published for some marking methods and tracking devices – and some groups of birds – which investigate impacts on body condition, reproductive success, movements, and survival (Barron et al., 2010; Bodey et al., 2017; Brlík et al., 2020; Costantini & Moller, 2013; Geen et al., 2019; Lameris & Kleyheeg, 2017; McKinnon & Love, 2018; Vandenabeele et al., 2011; Weiser et al., 2016; White et al., 2012). The reviews have demonstrated that impacts vary substantially between methods, as well as within and among bird species. Due to the widespread practices of capturing birds and marking them for individual recognition, or fitting them with tracking devices, systematic investigations into the potential adverse effects on animal welfare have been increasing. The challenges for evaluating field methods include establishing suitable controls and the complexities involved in observing and measuring impacts on animal welfare in the field, where individuals may be observed only sporadically. Moreover, such studies often contend with small sample sizes that result in low statistical power (see Box 1 in Chapter 7). Furthermore, an assessment of impact on animal welfare includes an evaluation of an individual's affective experiences (mental state). While we cannot definitively determine what each individual bird experiences, we can strive to make such an assessment as objective as possible, by inferring assessments of mental state from recognized observable welfare indicators (see Chapters 5: Animal Welfare in Wild Birds and 7: Risk Assessment Method).

4 Ecology and status of species included

The worldwide diversity of birds (Class Aves) includes 44 orders and a total of 11,161 extant species according to the World Bird List of the International Ornithologist's Union (Gill et al., 2023). The national bird list for Norway is maintained by the Norwegian Fauna Committee for Birds (NFKF) for BirdLife Norway. The most recent list includes a total of 528 species that have been registered in Norway (BirdLife Norge, 2022). The bird list includes 517 species that have been reported at least once since 1950 (Category A), 5 species with historic records from the period 1800-1949 (Category B) and 6 exotic species that now have free-living populations in Europe (Category C). Two appendices include 10 species of uncertain origin that could have been derived either from a wild population or escaped cage birds (Category D), and another 99 species considered likely to be escapees (Category E). For example, populations of Common Pheasant (*Phasianus colchicus*) in Norway are thought to be maintained by releases of captive bred birds. About half of the birds registered on the national bird list (255, 48.2%) are vagrant species with <100 records in Norway.

Bird species that regularly occur in Norway include 274 species evaluated by the Norwegian Biodiversity Information Centre for inclusion in the 2021 Red List of species of conservation concern (Table 1), with separate lists maintained for mainland Norway and Svalbard (Artsdatabanken, 2021). The four criteria for ranking including population trends, changes in range, total population size, and species range. A subset of 43 species were evaluated for both Red Lists and we report the highest conservation ranking if a species was under threat in either area. The 274 species include 31 species where ranking was Not Applicable because the species was alien or a sporadic visitor (NA, 11.3%), 139 species ranked of Low Concern (LC, 50.7%), 30 species that are Near Threatened (NT, 10.9%), 39 species that are Vulnerable (VU, 14.2%), 21 species that are Endangered (EN, 7.7%), and 11 species that are Critically Endangered (CR, 4.0%). In addition, three species are considered to have been Regionally Extirpated from Norway (RE, 1.1%), including Grey Partridge (*Perdix perdix*), Crested Lark (*Galerida cristata*), and Corn Bunting (*Emberiza calandra*). The avifauna of Norway includes representatives from 19 orders of birds and the three lineages with the most species in Norway include waterfowl (Anseriformes, 35 spp.), waders, gulls and seabirds (Charadriiformes, 59 spp.), and songbirds (Passeriformes, 107 spp.).

The risk assessment applies not only to Norway, Svalbard and Jan Mayen, but also Norwegian territories in the southern polar region. Research scientists from Norway are leading ongoing research and monitoring efforts in Dronning Maud Land in Antarctica, with a focus on Antarctic Petrels (*Thalassoica antarctica*), Snow Petrels (*Pagodroma nivea*) and South Polar Skuas (*Catharacta macormicki*). Future work may expand to include more species, for instance penguins. Thus, key groups of Antarctic birds including skuas (Charadriiformes), petrels (Procellariformes) and penguins (Sphenisciformes) were included in the assessment.

Table 1. Conservation status of 274 species of birds in Norway and Svalbard from the 2021 Red List. Conservation categories include: NA = not applicable, LC = least concern, NT = near threatened, VU = vulnerable, EN = endangered, CR = critically threatened, and RE = regionally extirpated. Species/groups from Norwegian territories in the southern polar region are not included in this table, but they are part of this assessment.

Order/Common names	NA	LC	NT	VU	EN	CR	RE	Total
Anseriformes/Waterfowl	6	13	4	8	3	1		35
Galliformes/Gamebirds	1	5		1			1	8
Caprimulgiformes/Nightjar		1						1
Apodiformes/Swift			1					1
Cuculiformes/Cuckoo			1					1
Columbiformes/Doves and pigeons	1	2	1					4
Gruiformes/Crane, coot and rails		1		3	1	1		6
Podicipediformes/Grebes	3	1		1	1			6
Charadriiformes/Waders and gulls	7	18	9	13	7	5		59
Gaviiformes/Divers	1	2		1				4
Procellariiformes/Fulmar and petrels		1		1	1			3
Suliformes/Gannet and cormorants		2	1					3
Pelecaniformes/Heron		1						1
Accipitriformes/Eagles and hawks	1	5	2	2	1			11
Strigiformes/Owls		6		1	2	1		10
Coraciiformes/Kingfisher	1							1
Piciformes/Woodpeckers		7	1					8
Falconiformes/Falcons		3	1	1				5
Passeriformes/Songbirds	10	71	9	7	5	3	2	107
Totals	31	139	30	39	21	11	3	274

Seabirds in marine habitats

Seabirds are defined as those bird species of which a large part of the population rely on the marine environment for at least part of the year (Croxall et al., 2012; Dias et al., 2019; Fauchald, 2023). Following Dias et al. (2019), there are 359 seabird species worldwide from nine orders, including Anseriformes (seaducks), Podicipediformes (grebes), Charadriiformes (auks, skuas, gulls, terns, phalaropes), Phaethontiformes (tropicbirds), Gaviiformes (divers), Sphenisciformes (penguins), Procellariiformes (albatrosses, petrels and shearwaters), Suliformes (cormorants, shags, frigatebirds, gannets, boobies), and Pelecaniformes (pelicans). Seabirds include species that feed at the surface or by diving, and they are classified as pelagic or coastal if they primarily use deep marine water or inshore areas, respectively (Dias et al. 2019). For example, all the Procellariiformes are pelagic seabirds, but some species are surface feeders whereas others feed by diving. Penguins are diving and flightless seabirds. All of the 18 species of penguins are restricted to the southern Hemisphere, but this group of birds is relevant for the current risk assessment because on ongoing research and monitoring in Norwegian territories in the southern polar region.

Norwegian conservation management has classified 54 species as Norwegian seabirds due to breeding or wintering in Norway, including Svalbard and Jan Mayen (Fauchald, 2023). The total includes 25 species of Charadriiformes: 11 gulls, 2 terns, 6 auks, 4 skuas and 2 phalaropes. All auk species are diving seabirds, and most are pelagic. All gulls, terns and skuas are surface-feeding seabirds. Skuas and gulls are categorized as pelagic and coastal seabirds, respectively (Dias et al., 2019), but species from both groups may use inshore and offshore waters. The phalaropes are the only wader species classified as seabirds because they are pelagic and winter offshore during the nonbreeding season. Seaducks, grebes and divers are defined as seabirds based on their use of marine habitats during winter, but we describe their breeding ecology separately in the next section for Waterbirds in Aquatic Habitats.

Globally there are 147 species of Procellariiformes, all classified as seabirds, but only five are Norwegian seabirds. The Northern Fulmar (*Fulmarus glacialis*), European Storm Petrel (*Hydrobates pelagicus*) and the Leach's Storm Petrel (*H. leucorhous*) all breed in Norway, while two shearwater species are vagrants and do not. Three Suliformes species breed in Norway, including Northern Gannet (*Morus bassanus*), Great Cormorant (*Phalacrocorax carbo*), and European Shag (*Gulosus aristotelis*). Four species of Gaviiformes are considered Norwegian seabirds, with two species breeding in Norway and two only wintering. The four Norwegian grebe species in Podicipediformes breed in freshwater lakes but then move to marine habitats during the non-breeding season.

Thirteen Norwegian seaducks in the Anseriiformes are defined as seabirds. Some rely on the marine environment year-round such as the Common Eider (*Somateria mollissima*) while others use marine habitats during the non-breeding season such as the Velvet Scoter (*Melanitta fusca*). All seaducks breed in Norway, except Steller's Eider (*Polysticta stelleri*) which breeds in Russia and winters in Norwegian waters.

Norway hosts large and important seabird populations. However, populations have decreased substantially, and the conservation statuses are alarming. Among the 54 Norwegian seabird species, 34 species are currently listed as species of conservation concern on the Norwegian Red List (Artsdatabanken, 2021). Population declines have several causes, including anthropogenic factors (Dias et al., 2019). In 2008, a global map of the vast human impact on marine ecosystems was published (Halpern et al., 2008). The global impacts have not decreased in recent decades, and new human activities such as offshore wind energy developments are now emerging. Tracking is an important tool to map the marine habitats and the overlap with potential threats, and the need to protect the species and their marine habitats is more important than ever. Early tracking devices such as satellite transmitters (PTTs) used to be large and heavy some 25–30 years ago. Tag size initially restricted tracking studies to albatrosses, large petrels, and other large-bodied seabirds. Continuing technological developments have produced new tracking devices that are much smaller. The development of light-level geolocators (GLS), as well as small GPS-devices and refined attachment methods have enabled tracking of medium and small-bodied seabirds, as weight of the smallest devices is now <1 gram.

Leg bands are used to individually mark seabirds. The leg bands can also be used to attach RFID tags, geolocators (GLS), TDR loggers, GPS tags, and other small tracking devices. Permanent leg bands are not used to individually mark penguins, but custom-made leg bands have been used to successfully attach geolocators for 6–24 months in some species (Bost et al. 2009). Devices and attachment methods have become much refined over the last decades and tracking devices can be deployed on the smallest (~25 grams) and largest species of seabirds (>10 kg). In addition to leg bands, devices are commonly attached with glue or tape to back- or tail feathers. Harnesses are associated with higher risks of impact on most seabirds and are not used in diving seabirds. Harness applications are generally avoided for use with most seabird groups, but with some notable exceptions. Where harnesses have been used, the risk of impact seems to be lower with leg-loop harnesses. Both thoracic wing and leg-loop harnesses have been used with success on different species of gulls and terns.

Seabirds are a diverse group of birds with considerable variation in key features such as morphology, mode of locomotion, behaviour, and use of a wide range of breeding and wintering habitats in different environments. Therefore, extensive consideration must be used to select the best method of attachment and optimal size of tracking device to ensure good animal welfare.

Waterbirds in aquatic habitats

Waterfowl (Anseriformes, 35 spp.)

Waterfowl are a diverse lineage with 178 species found worldwide (Gill et al. 2023). A total of 35 species of waterfowl regularly occurs in Norway, including geese, swans and shelducks (14 spp.), dabbling ducks (8 spp.), and diving ducks (13 spp.) (BirdLife Norge, 2022). Three species are red-listed as Endangered including Taiga Bean Goose (*Anser fabalis*), Garganey (*Spatula querquedula*), and Greater Scaup (*Athya marila*), and the Lesser White-fronted Geese (*Anser erythropus*) is listed as Critically

Endangered (Artsdatabanken, 2021). A subset of 11 species are quarry birds that are legal to hunt during the fall and spring hunting seasons (Miljødirektoratet, 2022). Overharvest and exposure to lead shot in wetland habitats can be risk factors for sensitive species. On the other hand, wildlife conflicts can arise with overabundant populations where foraging activity of migratory or wintering geese cause agricultural losses. Finally, three exotic species have established free-living populations in Norway including Canada Goose (*Branta canadensis*), Bar-headed Goose (*Anser indicus*), and Mandarin Duck (*Aix galericulata*).

Waterfowl are large-bodied and heavy birds and often have a coarse diet of plant material, invertebrates, or fish (Sedinger, 1997). Diversity in beak shape is linked to variation in foraging modes which include grazing for geese and swans, dabbling in freshwater for ducks, or diving in large lakes or coastal marine areas (Olsen, 2017). Many species are highly migratory with breeding grounds in the arctic or mountain areas and nonbreeding sites at coastal or southerly sites. Wild populations of waterfowl can be a reservoir and source of transmission for zoonotic diseases, including highly pathogenic avian flu and avian cholera. The sexes are similar in geese and swans, but many ducks are dichromatic and can be sexed and aged by plumage. Variation in life-history includes short-lived species with large clutches such as teal, and long-lived species with low fecundity and high survival such as sea ducks and geese (Krementz et al., 1997). Nest sites are often ground nests in wetland areas but a subset of species are adapted to using natural cavities or nest boxes. Incubation is often by the female and broods of precocial young may be alone or attended by multiple females (Eadie et al., 2011). Pair formation in waterfowl often occurs in the nonbreeding season so that patterns of natal philopatry in waterfowl are opposite to other birds with females returning to natal sites at higher rates than males (Robertson & Cooke, 1999).

Several features of the morphology, physiology, and behavior of waterfowl are relevant to selection of capture and marking methods. Waterfowl are unusual among birds because some species undergo simultaneous molt of flight feathers resulting in periods of flightlessness after breeding (Brennan et al., 2007; Sjöberg, 1988). Large numbers of birds can be captured for ring-marking and marking with drive traps. Birds can usually be aged or sexed by plumage except during the 'eclipse' period when males resemble females. Male waterfowl have an intromittent organ in the ventral wall of the cloaca and can be sexed in hand by extrusion of the cloaca (Brennan et al., 2007). Ringing of waterfowl has been widely used to determine movements and survival rates. The precocial young are usually too small for the rings used on adults but can be individually marked with web tags. However, waterfowl are highly aquatic species, and it is often difficult to view the legs or feet. Unique marking techniques for waterfowl include nasal saddles for ducks, and neck collars for geese and swans. Nasal saddles can be prone to icing during winter with adverse impacts on animal welfare. Waterfowl are large-bodied birds are therefore able to carry relatively heavy tracking tags. Attachment techniques are important because waterfowl are often dependent on maintaining the waterproofing of their plumage for thermoregulation while foraging in cold water. Use of harnesses or subcutaneous anchors for radio attachment to the body or tail-mounted devices can cause problems for feather condition and preening. Alternative methods include tag attachment to neck collars or use of abdominal implants.

Diving birds (Podicipediformes, Gaviiformes, 10 spp.)

The worldwide diversity of diving birds includes 23 species of grebes (order Podicipediformes) and five species of divers (order Gaviiformes, (Gill et al., 2023). A total of 10 species of diving birds regularly occurs in Norway, including six species of grebes and four species of loons (BirdLife Norge, 2022). Little Grebe (*Tachybaptus ruficollis*) is red-listed as an Endangered species, whereas Slavonian Grebe (*Podiceps auritus*) and Yellow-billed Diver (*Gavia adamsii*) are listed as Vulnerable species (Artsdatabanken, 2021). Grebes and loons are diving birds that primarily feed on small fish in freshwater lakes in the summer and coastal sites in the winter. Both grebes and loons are leg-propelled divers with a body shape with ventral legs and high wing loading which means that it takes them a long time to get airborne (Abt & André, 2009; Burgess et al., 2005; Clifton et al., 2018; Grear et al., 2009). Grebes are unusual in having feet with lobed toes for locomotion and both species have flattened tarsi that are hydrodynamic. Diving behaviour can put birds at risk of entanglement in fishing gear and a diet of fish can lead to high levels of exposure to methyl mercury as an environmental contaminant in some areas (Burgess et al., 2005). Nest sites are often low mounds of vegetation at the water edge that are susceptible to flooding from heavy rainfall or waves from boat traffic. Disturbance from human activity can lead to nest abandonment. Both grebes and loons are typically long-lived with low fecundity (Abt & André, 2009). Clutch sizes are typically small and only two eggs in loons (Grear et al., 2009). Loons can be aggressive in defence of territories and brood-rearing grounds and have been documented killing competitors. The challenges with capture and marking of diving birds are similar to waterfowl. Loons and grebes can be captured with spotlighting from small boats at night or with bow nets at nest sites. Birds are usually marked with leg bands and tags have been attached with abdominal or subcutaneous implants.

Wading birds (Gruiformes, 6 spp.)

The worldwide diversity of wading birds in order Gruiformes (118 spp.) includes seven diverse families of terrestrial and marsh birds (Gill et al. 2023). A total of 6 wading birds regularly occur in Norway, including 3 species of rails, moorhens and coots, and the Common Crane (BirdLife Norge, 2022). In total, 5 of the 6 species are red-listed as being of conservation concern including Corn Crake (*Crex crex*) as a Critically Endangered species, Spotted Crake (*Porzana porzana*) as an Endangered species, and three other birds as Vulnerable species (Artsdatabanken, 2021). Eurasian Coots (*Fulica atra*) are harvested elsewhere in Europe but are not a quarry bird in Norway where they are listed as a vulnerable species. Common Crane is ranked as a species of Least Concern due to successful population recovery during the past 30-40 years.

Rails are secretive but noisy birds that are often monitored with playbacks, call surveys or automatic sound recorders instead of direct capture and marking (Fraixedas et al., 2020; Guillemain et al., 2014; Ojaste et al., 2019; Richmond et al., 2010). Important habitats include moist meadows, coastal marshes and riparian areas where rails feed on aquatic invertebrates. The species are nocturnal migrants and often prone to collision mortality with powerlines, tower and other anthropogenic structures. Rails can be captured with box traps or spotlighting and have been radio-tracked with harnesses. Coots and moorhens are conspicuous aquatic birds that are associated with wetland habitats, including freshwater lakes and ponds, marshes, and coastal habitats. Similar to grebes, rails and moorhens have lobed toes for locomotion. Large numbers of coots have been captured and ringed in Europe and North America, often as bycatch in baited traps deployed for waterfowl (Guillemain et al., 2014). Common Cranes are a large-bodied bird that breeds in wetlands and mountain bogs and migrates to wintering sites in pastures and agricultural fields. Cranes are efficient predators of eggs and small vertebrates and recovery of crane populations have been suggested as a cause for losses of peatland birds in mountain bogs in Norway (Fraixedas et al., 2020). In Europe, coordination and reporting of color rings for cranes is maintained by the internet-based Crane Observation Ring Archive (iCORA). Cranes have the ability to carry large tracking tags and satellite tags have been widely used to track migratory movements of different species (Ojaste et al., 2019).

Waders (Charadriiformes: Charadridae, Scolopacidae and allies, 34 spp.)

The worldwide diversity of order Charadriiformes includes 390 species of waders, gulls, skuas, and auks (Gill et al., 2023). A total of 34 species of waders (or shorebirds) regularly occur in Norway (BirdLife Norge, 2022). Waders are a diverse group that includes oystercatchers, plovers, curlews and godwits, snipe and woodcock, phalaropes and sandpipers. In total, 10 of 32 species (22%) are red-listed as being of conservation concern including Northern Lapwing (*Vanellus vanellus*) and Black-tailed Godwits (*Limosa limosa*) as Critically Endangered species, Eurasian Curlew (*Numenius arquata*) and European Golden-Plover (*Pluvialis apricaria*, Svalbard only) as Endangered species, and six other birds listed as vulnerable species in either Norway or Svalbard (Artsdatabanken, 2021). Common Snipe *(Gallinago gallinago)* and Eurasian Woodcock *(Scolopax rusticola)* are quarry birds in Norway but Eurasian Golden-Plover was removed from the quarry list in 2022 (Miljødirektoratet, 2022). Population numbers for waders are declining worldwide but appear to be stable in Fennoscandia (Lindström et al., 2015).

Waders are ecologically diverse and inhabit a range of habitats including coastal estuaries, freshwater habitats, and upland alpine areas. Foraging modes are highly variable and include filter feeding, probing and pecking in different substrates. Body mass varies several orders of magnitude from small-bodied sandpipers (ca. 25 g) up to large-bodied curlews (ca. 1.3 kg). Some species are dimorphic and sexes can be distinguished by plumage but others are monomorphic and can only be sexed with genetic methods (Jehl & Murray, 1986). Many species are highly migratory with a remarkable capacity for long distance movements and flight at high elevations, including nonstop flights >8,000 km that can last for 4-9 days (Conklin et al., 2017). The typical life-strategy of migratory waders includes low fecundity with a 4-egg clutch, low juvenile survival, and high adult survival (Méndez et al., 2018). Waders are noteworthy for wide range of mating systems and pattern of parental care that rivals the full range of reproductive systems found in birds. Mating systems include promiscuous lek-mating species of Ruff (*Calidris pugnax*) and Great Snipe (*Gallinago media*), polygyny in Northern Lapwings and Eurasian Woodcocks, polyandry in phalaropes, double-clutching in Temminck's Stint (*C. temminckii*) and social monogamy in a range of species. Parental care during incubation and brood rearing can be biparental or uniparental by either the female or male (Jönsson & Alerstam, 2008).

Waders can be captured with a variety of techniques including cannon nets or noose carpets at high tide roosts, mistnets or spotlighting at stopover sites, and different types of nest traps. Large-bodied species of waders can be susceptible to capture myopathy where handling stress induces muscle damage that requires rehabilitation (Rogers et al., 2004). Waders are often long-legged birds and marking techniques commonly include combinations of metal and colour rings. Alphanumeric flags have also been widely used to mark individuals for field studies of demography and migratory movements. The hatchling young are precocial with well-developed legs and can be marked with the same rings that are used with full grown adults. In sexually dimorphic species, females and males may require use of different ring sizes (Ward, 2000). Migratory movements have been tracked with a variety of methods, including geolocators mounted on leg rings, and different tracking tags attached with glue, leg-loop or body harnesses, or abdominal implants (Mong & Sandercock, 2007; Mulcahy et al., 2011; Warnock & Warnock, 1993). Some species of waders undergo dramatic seasonal fluctuations in body mass to fuel their migratory movements and require nonstandard harness designs (Chan et al., 2015; Hudgins et al., 1985).

Landbirds in terrestrial habitats

Gamebirds (Galliformes, 8 spp.)

The worldwide diversity of order Galliformes includes 302 spp. of grouse, quail, pheasants, guineafowl, and brush turkeys (Gill et al., 2023). A total of eight gamebirds regularly occur in Norway, including three species of forest grouse, two species of ptarmigan, and Common Quail (*Coturnix coturnix*) (BirdLife Norge, 2022). Grey Partridge (*Perdix perdix*) and Common Pheasant (*Phasianus colchicus*) are thought to occur due to import and release of birds produced in captive-breeding facilities. Grey Partridge were thought to occur in Norway before 1950 and are classified as regionally extirpated. Common Quail are red-listed as a Vulnerable species due to low population numbers (Criteria D1). The remaining seven species are quarry birds that are popular for hunting in many areas of Norway (Miljødirektoratet, 2022). Population trends have often been negative and Willow Ptarmigan (*Lagopus lagopus*) was previously included as a Vulnerable species on the Norwegian Red List.

Quail are found in pasture lands, forest grouse are associated with deciduous and coniferous forests, whereas ptarmigan are found in alpine habitats and open bogs in mountainous areas. Partridge and pheasants occur mainly in agricultural lands. Developing young have a protein-rich diet of arthropods and gradually shift to a plant-based diet of grain, seeds, buds, or leaf shoots as adults (Blomberg et al., 2018; Sandercock et al., 2005; Sedinger, 1997; Wiley, 1974). Average body mass ranges from ca. 100 g in Common Quail up to 4 kg in male Western Capercaillie (*Tetrao urogallus*). Most species are dimorphic and can be routinely sexed by plumage and aged by molt of the primary wing feathers. Ptarmigan are adapted to snow conditions and molt from a dark summer coloration to a white plumage in winter. Quail are latitudinal migrants whereas the remaining five species are all resident birds. Mobility is affected by variation in the ratio of white and red fibers in the pectoral muscles. Hazel Grouse (*Tetrastes bonasia*) tend to be sedentary whereas the other forest grouse and ptarmigan often have seasonal migrations among different regions or habitats. Grouse are ground nesters that lay the clutch in a shallow nest scrape. Life-histories of gamebirds vary from high fecundity and low survival among quail to small clutches and relatively high survival in some populations of alpine ptarmigan (Sandercock et al., 2005). Mating systems are quite variable and include promiscuous lek-mating among Black Grouse (*Lyrurus tetrix*) and Western Capercaillie, polygyny in Common Quail and Hazel Grouse, and social monogamy in ptarmigan (Wiley, 1974). Incubation is usually by the female alone, but males contribute to parental care of young in ptarmigan.

Grouse and ptarmigan can be captured at night with spotlights and nets, on territory with mirror traps, nets or noosing poles, and different nets for broods after the young have fledged. Capture and handling can be stressful for large-bodied birds, especially under warm conditions (Blomberg et al., 2018). Ring-marking with metal and colour rings has been widely used to use mark individual adults, and metal wing tags affixed to the wing patagium have been used to mark hatchlings. VHF radios and satellite tags have been widely used to collect data on demography and seasonal movements. Earlier studies often used wing harnesses or ponchos for radio attachment, but the most common method now is a necklace collar where the transmitter sits on the chest above the crop and a whip antenna extends from the neck over the back. Radio-marking studies of chicks and juveniles have often used sutures or implants to attach tracking tags.

Pigeons and doves (Columbiformes, 4 spp.)

Order Columbiformes is a diverse group of birds that are found worldwide on all continents except Antarctica, with a total of 351 species (Gill et al., 2023). Four species of pigeons and doves are found as breeding birds that nest in Norway.

Pigeons have well developed and strong flight muscles, with low wing loading that makes them swift and manoeuvrable flyers. Domesticated lineages of pigeons have been used in competitive races (Irvine et al., 2007), and provide a useful model for investigations of flight performance. The body shape is typically compact with small heads with a short bill, a large body and short legs. The tarsus is relatively short, and the hind toe is well developed as in passerines.

Pigeons are herbivores that are adapted to foraging on seeds on the ground in both forested and open habitats. The nestlings are unable to the digest seeds, so they are fed a soft substance of partly digested seeds ("pigeon milk").

All pigeons build their own nest. The Collared Turtle Dove (*Streptopelia decaocto*) and the Wood Pigeon (*Columba palumbus*) build flimsy open nests in trees whereas the Stock Dove (*C. oenas*) builds a nest that is hidden in a tree cavity. The native species of Rock Dove (*C. livia*) is considered extinct in Norway but feral populations of domestic pigeons (*C.l. domestica*) are a common feature of urban and suburban habitats. Rock Doves build their nest in cliffs with cave-like structures, whereas domestic descendent builds its nest in equivalent human-made structures. Clutch size in most species is two eggs.

Wood Pigeon and the Stock Dove are migratory species that winter in continental Europe, although some individuals may remain in Norway during winter. The Collared Turtle Dove and the Rock Dove are resident species. One of the species in this order breeding in Norway is on the Norwegian Red List; the Collared Turtle Dove is classified as Near Threatened. Wood Pigeon is a quarry bird that is legal to hunt during the fall hunting season.

Pigeons and doves can be trapped for ringing and tagging with use of walk-in traps baited with grains or fruits. Ring-marking has been widely used to investigate migratory movements and the effects of harvest on wild populations. For the Rock Dove, experimental studies with racing pigeons showed that performance did not differ between control birds and birds with tail-mounted radio-tags, whereas tagged birds with leg-loop harness performed worse (Irvine et al., 2007).

Raptorial birds (Accipitriformes, Strigiformes, Falconiformes, 26 spp.)

Accipitriformes (hawks, buzzards, eagles, harriers, honey buzzard, osprey)

Worldwide (all continents except Antarctica) there are 266 species of raptors (Gill et al., 2023) of which eleven species have been found nesting in Norway. Five of the species (45%) are on the Norwegian Red List: the Hen Harrier (*Circus cyaneus*) is listed as Endangered, the Western Marsh Harrier (*Circus aeruginosus*) and the European Honey Buzzard (*Pernis apivorus*) are listed as Near Threatened, and the Northern Goshawk (*Accipiter gentilis*) and Osprey (*Pandion haliaetus*) are listed as Vulnerable.

Most of the species in order Accipitriformes, and all except one in Norway, are adapted for predation on other vertebrates. Notable features of their morphology include a strong tarsus, and toes with long and sharp talons. Prey are captured with the talons, while the beak is used for tearing up the prey. During nesting, there often a strict role division between the mated pair; the female incubates the eggs and divides up the prey to feed the developing young, while the male is the sole provider of prey to the female and young (Slagsvold & Sonerud, 2007; Sonerud et al., 2014). After fledging, both parents hunt for the young with females taking larger types of prey than males. A notable feature for all species is the pattern of reversed sexual size dimorphism, where females are typically larger than males (Newton, 1979; Slagsvold & Sonerud, 2007). Sexual size dimorphism varies with diet (Newton, 1979). Among species in Norway, differences between the sexes are most extreme in the bird-hunting Eurasian Sparrowhawk (*Accipiter nisus*), and smallest in the mostly insect-hunting European Honey Buzzard. The harriers and the Eurasian Sparrowhawk are also clearly sexually dichromatic, while the other species are monochromatic. All members of this order build their own nest, either in a tree, in a cliff, or on the ground.

The Eurasian Sparrowhawk (male body mass c. 150 g) and the Northern Goshawk (male body mass c. 850 g) prey almost exclusively on birds in forested habitats. The Eurasian Buzzard (*Buteo buteo*) and the Rough-legged Buzzard (*B. lagopus*) (male body mass c. 700 g and 800 g, respectively) are adapted to hunt in open habitats, and prey primarily on small rodents when they are abundant, and otherwise switch to birds as alternative prey, the Eurasian Buzzard also preys on snakes and frogs. When searching for prey, the hawks and the buzzards use a "perch-travel" tactic, where they perch in a tree or another elevated structure and use the vantage point to search for prey. If no prey is detected within a certain time span, they fly to another perch and continue there. Thus, they use relatively little energy when searching for prey (Sonerud, 1992). The Golden Eagle (*Aquila chrysaetos*) (male body mass c. 3600 g) is adapted to hunt in open habitats, and prey on a wide range of birds and mammals up to its own body mass. The White-tailed Eagle (*Haliaeetus albicilla*) (male body mass c. 4000 g) is adapted to prey on a wide range of marine prey; fish, birds and mammals. Both species of eagles regularly exploit carrion. The Hen Harrier and the Western Marsh Harrier (male body mass c. 350 g and c. 500 g, respectively) have relatively long wings and tail. Harriers hunt mostly by slow, continuous flight at a low height in open habitats, first locating prey by vision and hearing and then relying on surprise to quickly capture prey items. The main prey of harriers are small rodents when abundant, and otherwise small birds as alternative prey. The Red Kite (*Milvus milvus*) (male body mass c. 1000 g) has long, slender wings and a forked tail, an adaptation to rapid turns in the air, and often obtains food by pirating prey from other raptors. Otherwise, kites prey on small mammals, birds, amphibians and reptiles, and exploit carrion to a large extent. The European Honey Buzzard (male body mass c. 700 g) is a food specialist that prey mostly on the nests of social bees and wasps, with frogs and small mammals as alternative prey. Last, the Osprey (male body mass c. 1400 g) is a food specialist that exclusively prey on fish, mostly in fresh water. The Osprey often hunts overwater by hovering, rapidly flapping the wings while facing the wind while searching for fish. Hovering is an energy-demanding activity, but less so at higher wind speeds.

Migratory behavior and distance vary among the different species of raptors that breed in Norway. The hawks and the eagles are resident species, although young non-territorial individuals may migrate to southern Scandinavia and in the case of the Eurasian Sparrowhawk to continental Europe. The European Honey Buzzard and the Osprey are migrants that winter in Africa, the Red Kite is a migrant that winters in the Mediterranean area, the harriers are migrants that winter in continental Europe, while the buzzards are migrants that winter in continental Europe.

Nesting birds in order Accipitriformes can captured for ringing and tagging with a variety of methods depending on species, sex, and type of nest site. Smaller species can be captured with mist nets put up at a suitable distance from the nest site, entering the net when they arrive at the nest with prey or leave the nest for the next hunt, or when attacking the researcher to defend its young. A stuffed owl can also be used as decoy that the hawks will attack as a target. Raptors can also be captured with the use of Bal-chatri or Dho-gaza traps, which are a wide-used method to capture raptors worldwide (Berger & Mueller, 1959; Zuberogoitia et al., 2008). Outside the breeding season, bird species that feed on carrion can be captured by clap net or cannon nets deployed at sites where carrion is used as bait.

The species in order Accipitriformes which hunt by the energetically cheap "perch-travel" tactic are particularly robust to the extra load added by a VHF/GPS tag. In all species, tags can be backpack mounted with a full body (thoracic) harness, although this attachment method can have a moderate risk of negative effects. The hawks and the harriers have quite firm and long tail feathers, so that tail-mounting the tag is particularly suitable. Tail mounts have a low risk of negative effects. Of less used methods of mounting tags on raptors, mounting of tags on legs may interfere with capturing of prey.

Strigiformes (owls)

Owls occur worldwide on all continents except Antarctica. Order Strigiformes includes a total of 255 species (Gill et al., 2023), of which ten species are found nesting in Norway. Four of the Norwegian owl species (40%) are on the Norwegian Red list: the Snowy Owl (*Bubo scandiacus*) is listed as Critically Endangered, the Eurasian Eagle-Owl (*B. bubo*) and the Ural Owl (*Strix uralensis*) are listed as Endangered, and the Great Grey Owl (*S. nebulosa*) is listed as Vulnerable.

All owl species in Norway are adapted to predation on other vertebrates, in particular small mammals. The tarsus is strong and covered with feathers, and the toes have long and sharp talons. Prey are captured with the talons, while the beak is used for tearing up the prey. All owls have broad wings and a large wing area relative to their body mass. Thus, their wing-loading is of the lowest among birds, which means that they expend relatively little energy when flying. In common with bird species in the orders Accipitriformes and Falconiformes, the owls have a strict role division between the mates during breeding, as well as reversed sexual size dimorphism (see Accipitriformes for explanations). Because small mammals make up a significant part of the diet for all owl species in Norway, the variation in sexual size dimorphism with diet is smaller among the owls than among other raptorial species in Accipitriformes and Falconiformes. Sexual size dimorphism is greatest in the Eurasian Pygmy Owl (*Glaucidium passerinum*), which hunts birds when small rodents are scarce, and smallest in the Great Grey Owl, which prey almost exclusively on small mammals (rodents and shrews). The Snowy Owl is clearly sexually dichromatic with females having more barring than males. The other species of owls are sexually monochromatic but sometimes occur in different colour morphs that vary in frequency among different regions.

The Eurasian Pygmy Owl (male body mass c. 60 g) and the Eurasian Eagle-Owl (male body mass c. 2400 g) have the largest proportion of birds in the diet among the owls in Norway, whereas the Tawny Owl (*Strix aluco*) and the Ural Owl (male body mass c. 400 g and c. 600 g, respectively) have a lower proportion, and the Boreal Owl (*Aegolius funereus*) (male body mass c. 100 g) even lower. In contrast, the Northern Hawk Owl (*Surnia ulula*) (male body mass c. 300 g), Long-eared Owl (*Asio otus*) and the Short-eared Owl (*A. flammeus*) (male body mass c. 250 g and 350 g, respectively), the Great Grey Owl (male body mass c. 800 g) and the Snowy Owl (male body mass c. 1500 g) prey almost exclusively on small mammals. When searching for prey, all owl species in Norway, except two, hunt by a "perch-travel" tactic where they perch in a tree or another elevated structure and look or listen for prey. Thus, owls often spend relatively little energy when searching for prey (Bye et al., 1992; Sonerud, 1992). The two exceptions are the Long-eared Owl and the Short-eared Owl, which have relatively long wings and hunt mostly by continuous slow flight at a low height in open habitats, similar to harriers, locating prey by hearing. Among the owls in Norway, the Boreal Owl, the Long-eared Owl, the Tawny Owl and the Eagle Owl are strictly nocturnal, the

Eurasian Pygmy Owl and the Northern Hawk Owl are strictly diurnal, while the Short-eared Owl, the Ural Owl, the Great Grey Owl and the Snowy Owl can hunt both at night and during daytime.

None of the owls build their own nest. Most use a tree cavity for nesting (Eurasian Pygmy Owl, Boreal Owl, Northern Hawk Owl, Tawny Owl, Ural Owl and Great Grey Owl), some use an old corvid nest or hawk nest (Long-eared Owl, Ural Owl and Great Grey Owl), and some are ground nesters, either on flat land such as arctic tundra (Short-eared Owl and Snowy Owl) or in steeper terrain (Eagle Owl). The Boreal Owl is regularly polygynous and polyandrous, while the other species may be polygynous. Such non-monogamous mating occurs in years with abundant supply of small rodents.

Small rodents are often a staple food for Norwegian owls, and the 3-5 years population fluctuations of small rodents strongly affect their breeding frequency. Among the owls that specialize on rodents (Boreal Owl, Northern Hawk Owl, Long-eared Owl, Short-eared Owl, Great Grey Owl and Snowy Owl), almost all breeding occurs in the 1-2 peak years of the small rodent cycle and breeding birds may move long distances to find local areas where rodents are abundant. The food generalists (Eurasian Pygmy Owl, Tawny Owl, Ural Owl and Eagle Owl) may nest also in years when rodents are scarce, although most nests are found in small rodent peak years also in these species.

Two of the owl species nesting in Norway are migrants that winter in continental Europe (Long-eared Owl and Short-eared Owl), while the other species are either resident, or move as nomads at higher latitudes tracking the regional fluctuations in rodent numbers that can be due to spatial asynchrony in their population cycles.

Nesting owls may be captured for ringing and tagging with various methods depending on species and sex. Incubating or brooding females of cavity-nesting owls can be captured with the use of a specially made sweep or hoop nets when birds are flushed from the nest cavity. In the cases when cavity-nesting owls use a nest box, the box entrance can be blocked, and the female can be captured by hand in the box. The male can be captured with a tunnel trap mounted in front of the nest cavity entrance when he arrives with prey. Snowy and Eagle Owls which nest on the ground can be captured at the nest with a bow net. Owls may also be captured with mist nets put up at a suitable distance from the nest site, entering the net when they arrive at the nest with prey or leave the nest for the next hunt, or attacking the researcher to defend the young. Outside the nesting season, owls of some species may be captured in mist-net by use of playback of the male´s territorial calls. Similarly, some specie may be captured with bow net, sweep net, or hoop net used in combination with a lure of a mouse model being towed on a string.

Most species of owls nesting in Norway hunt by the energetically cheap "perch-travel" tactic (with two exceptions) and are particularly robust to the extra load added by a VHF/GPS tag mounted as backpack. A full body (thoracic) harness has a low risk of negative effects in owls. Necklace tags are rarely used as an attachment method for owls but also have a low risk of negative effects. Owls have soft tail feathers which are less suitable for tail-mounted tag than in other raptors, unless the tag is small compared to the body size of the owl. Small tail-mounted tags should have a low risk of negative effects whereas leg-mounted tags might interfere with capturing of prey. Due to the fluffy plumage of owls, a harness and a tag will largely be hidden from sight. Due to the feather-covered tarsus, reading the numbers or letters on a leg ring is usually not possible without physically capturing the owl.

Falconiformes (falcons)

Falcons occur worldwide on all continents except Antarctica with a total of 65 species (Gill et al., 2023). Five species of falcons are found as breeding birds that nest in Norway. Two of the falcons breeding in Norway (40%) are on the Norwegian Red list; the Hobby (*Falco subbuteo*) is listed as Near Threatened whereas the Gyrfalcon (*F. rusticolus*) is listed as Vulnerable.

All falcon species in Norway are adapted to predation on other vertebrates, in particular birds. Falcons have strong tarsi, and toes with long and sharp talons. Prey are captured with the talons, while the beak is used for tearing up the prey. All falcons in Norway are adapted to hunting in open habitats and have relatively long and pointed wings and a short tail, except for one species, the Eurasian Kestrel (*F. tinnunculus*) which have a relatively long tail, and often use hovering as an "air-perch". In common with the species in Accipitriformes and Strigiformes, the falcons have a strict role division between the mates during breeding, as well as reversed sexual size dimorphism, the extent of which varies with the diet. Dimorphism is most extreme in the Peregrine Falcon (*F. peregrinus*), which preys upon birds, and is smallest in the Eurasian Kestrel which is a generalist species that preys mainly on rodents. In dimorphic species, the female is typically larger than the male. The Eurasian Kestrel and the Merlin (*F. columbarius*) are clearly sexually dichromatic, while the other species of falcons are monochromatic.

The Merlin (male body mass c. 160 g), the Peregrine (male body mass c. 700 g) and the Gyrfalcon (male body mass c. 1100 g) prey almost exclusively on birds whereas the Hobby (male body mass c. 180 g) preys on birds and large insects. The Eurasian Kestrel (male body mass c. 200 g) preys primarily on small rodents when they are abundant, and otherwise switches to birds and lizards, or even large insects, as alternative prey. When searching for prey, the Eurasian Kestrel uses the "perch-travel" tactic, where it perches in a tree or another elevated structure and looks for prey. Thus, the Eurasian Kestrel spends relatively little energy when searching for prey. As a substitute in habitats without perches, kestrel can hunt by hovering by holding their position while rapidly flapping the wings, often facing the wind. Hovering is energy-demanding, but less so with higher wind speed. Other species of falcons hunt birds mostly by swift flight in open habitats.

None of the falcons build their own nest. They either occupy an old corvid nest in a tree (Merlin, Hobby), a ledge at a cliff site (Peregrine and Gyrfalcon) or use a tree cavity (Eurasian Kestrel). The Eurasian Kestrel is flexible in selection of nest sites and may be polygynous in years with peaks in small rodent populations with abundant prey. The Gyrfalcon is a resident species in Norway that breeds in the mountains but often winters on the coast, the Hobby is a migrant that winters in southern Africa, while the other falcons are migrants that winter in central Europe or in the Mediterranean area.

Nesting falcons can be captured for ringing and tagging with various methods depending on species, sex and type of nest site. When cavity-nesting Eurasian Kestrels use a nest box, both parents can be captured when they arrive with prey with a tunnel trap mounted at the nest cavity entrance. Eurasian Kestrels can also be captured with the use of a Bal-chatri trap (Berger & Mueller, 1959). Other species of falcons can be captured with the use of a Dho-gaza trap (Zuberogoita et al., 2008). Eurasian Kestrels hunt by the energetically cheap "perch-travel" tactic, and are robust to the extra load added by a VHF/GPS tag. In falcons, full body (thoracic) harnesses have a moderate risk of negative effects, while use of leg-loop harnesses have a low risk of negative effects, at least in small species. Falcons have quite firm and strong tail feathers, hence tail-mounting the tag is suitable and has a low risk of negative effects.

Landbirds (Caprimulgiformes, Apodiformes, Cuculiformes, Coraciformes, Piciformes, 12 spp.)

Caprimulgiformes (nightjars)

Nightjars occur worldwide on all continents except Antarctica with a total of 121 species (Gill et al., 2023). Only one species of nightjar is found nesting in Norway. The European Nightjar (*Caprimulgus europaeus*) is not listed on the Norwegian Red list and is considered a species of Least Concern.

The European Nightjar (body mass c. 70 g) is adapted to capture insects in the air during night by continuous flight at low height in open habitats, including open forest. Like many nightjars, the species has relatively long wings and a long tail, a short tarsus, and a small beak with an extremely wide gape. While foraging, its flight is relatively slow. The species is sexually monochromatic.

The European Nightjar does not build a nest but lays a 2-egg clutch directly on the ground, where the incubating and brooding bird is difficult to spot due to its cryptic plumage. The life-strategy includes low fecundity and high adult survival.

The European Nightjar is a migrant that winters in tropical Africa. In the breeding season nightjars can be captured in mist-net by use of playback of the male´s contact calls and territorial churring (Sharps et al., 2015). The nightjar's long tail feathers are well suited for the low-risk tail-mounting of the tag (Shewring et al., 2020). Wing and body harnesses have been successfully used to attach tracking tags for investigations of the annual movements of migratory species of nightjars (Ng et al., 2018).

Apodiformes (swifts)

Swifts are found worldwide on all continents except Antarctica with a total of 497 species (Gill et al., 2023). Only one species of swift is found nesting in Norway. The

Common Swift (*Apus apus*) is on the Norwegian Red list and is listed as a Near Threatened species.

The Common Swift (body mass c. 40 g) is adapted to capture insects in the air during daytime by continuous flight at varying height above all kinds of habitats, and has relatively long, narrow and pointed wings and a short tail, a short tarsus, and a small beak (short, flat, wide) with a wide gape. While foraging, its flight may be relatively speedy. The species is sexually monochromatic.

The Common Swift does not build a nest. Females lay its eggs directly on the surface in a sheltered place, such as a narrow cavity in a cliff, or in equivalent human structures. Swifts may also nest in tree cavities. The life-history strategy includes low fecundity and high adult survival.

The Common Swift is a migrant that winters in the southern part of Africa. In the breeding season the Common Swift may be captured in a mist-net deployed in front of the nest, or by hand if the nest is accessible from inside a building. Individuals carrying tags attached with a full body (thoracic) harness performed similarly to control birds (Wellbrock & Witte, 2022).

Coraciiformes (kingfishers and bee-eaters)

Worldwide there are 184 species of kingfishers and allies (Gill et al., 2023), of which only one species is found regularly in Norway. The Common Kingfisher (*Alcedo atthis*) was considered as part of the evaluations for the 2021 Red List but was ranked as not applicable (NA) because it was unclear if kingfishers have a permanent breeding population in Norway. Kingfishers use freshwater habitats and are adapted for diving from a perch to capture small fish. They are dependent on open water and migrate south to western Europe during winter. Low numbers of breeding pairs are found along the coast of southern Norway from Bergen to the border with Sweden and as far north as Elverum. Burrow nests are built in banks of soil or mud and are usually associated with riparian habitats. European Bee-eaters (*Merops apiaster*) are a common vagrant to Norway that sometimes occur in small groups at coastal sites.

Cuculiformes (cuckoos)

Cuckoos occur worldwide on all continents except Antarctica with a total of 150 species (Gill et al., 2023). Only one species of cuckoo is found breeding in Norway. The Common Cuckoo (*Cuculus canorus*) is on the Norwegian Red list and is listed as a Near Threatened (NT) species.

The Common Cuckoo (body mass c. 110 g) is adapted to prey on larger insects in open habitats, and has relatively long wings and a long tail, a short tarsus, and a small beak with wide gape. Its flight is swift, similar to that of a small falcon. The species is sexually dichromatic.

The Common cuckoo is the only bird in Norway that is an obligate brood parasite. Females lay parasitic eggs in nests of a range of small passerines that build open nests in open habitats (Moksnes et al., 2013). Cuckoo eggs are mimetic in coloration and match the eggshells of their host species.

The Common Cuckoo is a migrant that winters in tropical Africa. In the breeding season female cuckoos may be trapped in mist nets by use of playbacks of female and male song or calls (Honza et al., 2002; Nakamura & Miyazawa, 1997). Radio-tags have been glued on the back (Nakamura & Miyazawa, 1997), or been tail-mounted (Honza et al., 2002) with no reported adverse effects. Satellite tags have been widely used to track the migratory movements of Common Cuckoos in aid of conservation actions for declining populations (Vega et al., 2016).

Piciformes (woodpeckers)

Woodpeckers and allies occur worldwide on all continents except Antarctica with a total of 449 species (Gill et al., 2023). Eight species of woodpeckers are found as breeding birds that nest in Norway. Being dependent on standing trees with stems above a certain species-specific size, and thus often of old forest, the woodpeckers are vulnerable to habitat loss and degradation associated with modern forestry practices (Rolstad et al., 1992). However, only one of the species (13%) is on the Norwegian Red list: the Three-toed Woodpecker (*Picoides tridactylus*) is classified as a Near Threatened (NT) species. White-backed Woodpeckers (*Dendrocopos leucotos*) are listed as species of conservation concern in Sweden and Finland but are a species of Least Concern (LC) on the Norwegian Red List because coastal populations are large in southern Norway.

Woodpeckers have a well-developed beak for pecking in bark and wood, and they have stiff tail feathers used as braces in support of the hind legs when climbing vertically on tree trunks and branches. Woodpeckers are adapted to feed on insects hidden under the bark and in the wood tissue, and the tongue is equipped with hooks and a sticky secretion. All species live in forested habitats. The tarsus is relatively strong, and the four toes, two pointing forwards and two backwards, have long claws, making clinging to the vertical tree surface efficient. The wings are relatively short and broad with relatively stiff feathers, making the flight noisy and relatively costly. In one exception to the general pattern, the Wryneck (*Jynx torquilla*) has softer tail feathers and forages mostly on the ground for ants, protected from predation by a cryptic plumage. The Wryneck is sexually monochromatic, whereas the other woodpeckers are sexually dichromatic, although differences in coloration between males and females are modest in most species.

All woodpeckers in Norway excavate their own nest cavity except one species; the Wryneck, which is a secondary cavity nester, utilizing cavities made by other woodpecker species, natural tree cavities, or nest boxes. Usually, woodpeckers excavate a new nest cavity at each nesting attempt. Nest cavities created by woodpeckers are long-lasting and provide a critical resource for other vertebrate species in forest habitats, including birds that are secondary cavity nesters and roosting bats. The life-strategy of woodpeckers includes high fecundity and mortality in the Wryneck, relatively low fecundity in the Lesser Spotted Woodpecker (*Dendrocopos minor*) and in the Three-toed Woodpecker, and a medium fecundity in the other species.

The Black Woodpecker (*Dryocopus martius*) (body mass c. 400 g) mainly feeds on carpenter ants. The species excavate large nest cavities that are later used by large-bodied species of secondary cavity-nesters including Goldeneye (*Bucephala clangula*), Eurasian Kestrel, Boreal Owl, Northern Hawk Owl and Eurasian Jackdaw (*Corvus monedula*). The Green Woodpecker (*Picus viridis*) (body mass c. 200 g), the Grey-headed Woodpecker (*Picus canus*) (body mass c. 120 g), the White-backed Woodpecker (body mass c. 100 g), the Great Spotted Woodpecker (*Dendrocopos major*) (body mass c. 90 g) and the Three-toed Woodpecker (body mass c. 70 g) excavate nest cavities that can be used afterwards by smaller-bodied species of secondary cavity-nesters, such as Eurasian Pygmy Owl and different species of passerines. The Lesser Spotted Woodpecker (body mass c. 25 g) excavates a small nest cavity that is later used by small passerines such as tits. All woodpecker cavities except those made by the Lesser Spotted Woodpecker may be used by the Wryneck (body mass c. 40 g). All woodpeckers in Norway are resident species, except the Wryneck which is a migrant that winters in Africa.

Woodpeckers may be captured for ringing and tagging with mistnets in forest habitats. Breeding birds can be captured with noose carpets or a specially made sweep or hoop net put in front of the cavity entrance to capture target birds when they are incubating the eggs or feeding young in the nest cavity (Rolstad & Rolstad, 1995).

The stiff tail feathers of woodpeckers are well suited for tail-mounting of a tag, which has a low risk of negative impact (Noel et al., 2013). Woodpeckers forage on tree trunks, or on the ground, they spend relatively little time in flight, so fitting a tag with a wing or body harness can be an alternative (Rolstad & Rolstad, 1995; Tomasevic & Marzluff, 2018). A leg-loop harness may interfere with the woodpeckers´ hitching up tree trunks (Noel et al., 2013). A full body (thoracic) backpack-mounted tag may potentially cause a problem when the bird enters/leaves the nest cavity if the woodpecker species makes a cavity with a circular and narrow entrance (Rolstad & Rolstad, 1995; Rolstad et al., 1995). This consideration may apply to all species in Norway except the Black Woodpecker, which makes an oval cavity entrance that is vertically elongated (Rolstad et al., 2000).

Perching birds (Passeriformes, 107 spp.)

The world diversity of perching birds in order Passeriformes includes 6,533 spp. (Gill et al., 2023) which is about two-thirds of the entire diversity of birds. Songbirds and allies are a diverse lineage of birds with 107 species that regularly occur in Norway (BirdLife Norge 2022). The order is divided into three suborders including the suboscine birds (suborder Tyranni) and oscine songbirds (suborder Passeri). The suboscines include shrikes and corvids, whereas oscine birds include the national bird of Norway, the White-throated Dipper (*Cinclus cinclus*), farmland birds such as sparrows and finches, forest birds such as tits, nuthatches, and treecreepers, mountain birds such as wheatears, pipits and buntings, aerial insectivores such as the swallows, and a diverse range of warblers. Two songbirds, Crested Lark (*Galerida cristata*) and Corn Bunting (*Emberiza calandra*), are considered to be Regionally Extirpated from Norway (Artsdatabanken, 2021). Three species are red-listed as Critically Endangered, including Barred Warbler (*Sylvia nistoria*), Ortolan Bunting (*Emberiza hortulana*) and Rustic Bunting (*E. rustica)*. An additional five species are listed as Endangered, including Bearded Reedling (*Panurus biarmicus*), Arctic Warbler (*Phylloscopus borealis*), Black Redstart (*Phoenicurus ochruros*), European Stonechat (*Saxicola rubicola*), and Lapland Longspur (*Calcarius lapponicus*). An additional seven species are listed as Vulnerable. Snow Buntings (*Plectrophenax nivalis*) occurs as the only breeding songbird at Svalbard where the species is listed as being of Least Concern. Five species of songbirds are included on the quarry list for Norway (Miljødirektoratet, 2022). Jays, magpies, crows and ravens are legally shot or trapped because of conflicts with agricultural production and to reduce nest predation on upland gamebirds. Fieldfares (*Turdus pilaris*) remain a quarry species, but Redwings (*T. iliacus*) were removed from the quarry list in 2022. In the 5-year period of 2017-2022, between 3,000-6,740 thrushes were harvested per year in Norway (SSB 2023: table 03886).

Passerines are an ecologically diverse group that inhabit a range of habitats in Norway. Generalist species with wide distributions include Great Tit (*Parus major*), Willow Warbler (*Phylloscopus trochilus*), Eurasian Chaffinch (*Fringilla coelebs*) and White Wagtail (*Motacilla alba*). Specialist species with narrow habitat requires include Bearded Reedling in dense reed marshes, Sand Martin (*Riparia riparia*) that require banks with sandy soils for nesting, White-throated Dipper that is highly adapted to riverine environments, and the Ortolan Bunting that uses raised peat bogs or forest clearcuts for nesting (Bohning-Gaese et al., 2000; Dale & Christiansen, 2010; Iverson et al., 2023; Johnson et al., 1991; Ottosson et al., 2005; Peach et al., 2010; Rappole & Tipton, 1991). Diets of passerines are diverse but most species require energy-rich foods such as seeds, berries and cones, soil invertebrates and insects, or small vertebrates. Passerines include many of the common garden birds that are attracted to bird feeders. With the exception of the corvids, most passerines are small-bodied with a body mass <50 g. Body shape and wing morphology are associated with ecological niche and foraging mode. The demography of songbirds covaries with migratory tendency and nest placement. Resident species are often secondary cavity-nesters with large clutch sizes and low annual survival whereas migratory species are more likely to be open-cup nesters with higher annual survival (Bohning-Gaese et al., 2000). Passerines have altricial young that require extensive parental care until independence. Meadow Pipits (*Anthus pratensis*), Common Redstarts (*Phoenicurus phoenicurus*) and a few other passerines are important as host species for the parasitic young of the Common Cuckoo. The social system of passerines is typically male territoriality so that bird surveys usually identify species and record detections as the numbers of singing males. The mating system is usually social monogamy but can include high rates of extra-pair mating. Cooperative breeding is a rare mating system among north temperate birds but occurs in Long-tailed Tits (*Aegithalos caudatus*).

Capture and marking techniques for passerines have been influenced by the small body size of most species. Mistnets with different mesh sizes are the most common technique for trapping free-living birds, although cavity-nesting species can be trapped with different methods at nest boxes. In Norway, long-term monitoring data are available from coastal ringing stations at Lista and Jomfruland. Elsewhere, standardized sampling with grids of mistnets and a fixed schedule has provided the basis for monitoring passerine populations in the the Constant Effort Sites (CES) program of the UK and the Monitoring Avian Productivity and Survivorship (MAPS) program of the US (Peach et al. 1996). Individual marking of birds has commonly used combinations of metal and color rings. The two main challenges with use of tracking tags include the body size of small species < 30 g and large seasonal fluctuations in body mass where migratory species can have fat loads up to 50-100% of their lean body mass (Ottosson et al., 2005). The most common attachment methods have included glue (Johnson et al., 1991) and leg-loop harnesses (Rappole & Tipton, 1991). Use of new classes of GPS and PTT tags on passerines has been limited by the mass of the smallest tags which are currently down to ca. 1 g. Iverson et al. (2023) reviewed 116 published studies where new classes of tracking tags were deployed on small-bodied birds (<100 g) and reported that no datasets were available for tagged birds based on field studies in Norway.

Birds not evaluated

The scope of this VKM report was focused on birds occurring in Norwegian territory, including mainland Norway, Svalbard and Jan Mayen, and territories in southern polar regions including Queen Maud's Land in Antarctica. The avifauna of Norway and Svalbard includes 19 orders of birds that occur at high latitudes which are a subset of the 44 orders of birds that are found worldwide. Orders of birds without representatives in Norway or Norwegian territories include lineages of birds with a tropical or south temperate distribution and unusual orders with <10-30 species that are unrelated to the community of migratory and resident birds that are found in northern Europe. Examples include the sandgrouse (order Pterocliformes, 16 spp.) and flamingos (order Phoenicopteriformes, 6 spp.) that occur as far north as southern Europe.

Ratites, bustards, and storks

The ratites include four orders of large-bodied flightless birds from the southern Hemisphere plus a large radiation of tinamous in South America. Ostriches (order Struthiformes, 2 spp.) have been farmed for meat and leather, including some private farms in Norway (strutsefarmen.no). Bustards (order Otidiformes, 26 spp.) are another lineage of large-bodied birds with two species breeding in continental Europe. Historical records of Great Bustard (*Otis tarda*) are included in the national bird list for Norway and a reintroduction program has been attempted for the species at Salisbury Plain in the United Kingdom (Manvell & Goriup, 2017). Storks and allies (order Ciconiiformes, 19 spp.) include the White Stork (*Ciconia ciconia*) and Black Stork (*C. nigra*) which breed in continental Europe and have been reported as vagrants to Norway.

Tropical trogons, hornbills, and parrots

Three lineages of tropical birds do not occur in Norwegian territory but nevertheless have a high number of species worldwide. Speciose lineages include the trogons and quetzals (order Trogoniformes, 43 spp.), hornbills (order Bucerotiformes, 74 spp.) and parrots (order Psittaciformes, 403 spp.). Several species from these different orders are regular vagrants to Norway, including the Eurasian Hoopoe (*Upupa epops*) and the Rose-ringed Parakeet (*Psittacula krameri*). Both species are widespread in continental Europe but have not yet established breeding populations in Norway. Information on capture and marking of tropical birds was not a focus in this VKM report but was included opportunistically where new methods or techniques could be applied to improvements in animal welfare for wild birds in Norway.

5 Animal welfare in wild birds

The VKM project group agreed on a definition of animal welfare and animal welfare indicators in free-living wild birds before selecting key words to implement the literature search for capture, handling and marking methods used with wild birds.

The Norwegian Animal Welfare Act does not differentiate between domestic and wild animals and applies to 'conditions which affect welfare of or respect for mammals, birds, reptiles, amphibians, fish, decapods, squid, octopi and honey bees' (www.regjeringen.no/en/dokumenter/animal-welfare-act/id571188/). Wild birds and other animals covered by the animal welfare act are considered to possess an inherent value independent of their utility to humans and they should be treated with care and safeguarded from the potential harm of unnecessary stress and strain (§ 3, Animal Welfare Act) (LOVDATA, 2009a).

Assessing risks to animal welfare from capturing, handling, and marking is complicated by a lack of clarity about indicators of animal welfare for wild birds (Soulsbury et al., 2020). The animal welfare literature is dominated by studies concerning domesticated animals or wild species held in captivity. A widely-used approach in assessments and practical management of welfare and establishing of welfare codes and standards for animals in captivity, is the concept of the Five Freedoms and Provisions:

1. Freedom for hunger and thirst
2. Freedom from discomfort
3. Freedom from pain, injury or disease
4. Freedom to express normal behaviour
5. Freedom from fear and distress

(Farm Animal Welfare Council (FAWC), 1979)

first published by the Farm Animal Welfare Council in 1979 (FAWC, 2012) (but partly based on the previous work of what is known as the Brambell Committee (1965).

Based on this concept, the World Organisation for Animal Health (WOAH, 2023) defines welfare as (quote): "*Animal welfare means the physical and mental state of an animal in relation to the conditions in which it lives and dies. An animal experiences good welfare if the animal is healthy, comfortable, well nourished, safe, is not suffering from unpleasant states such as pain, fear and distress, and is able to express behaviours that are important for its physical and mental state (…). While animal welfare refers to the state of the animal, the treatment that an animal receives is* *covered by other terms such as animal care, animal husbandry, and humane treatment*".

In a guidance on animal welfare assessment, the European Food Safety Authority (EFSA) defines the welfare of an animal as good if (quote) "*as indicated by scientific evidence, it is healthy, comfortable, well-nourished, safe, able to express key aspects of behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress*" (EFSA, 2012). Recognizing that the Five Freedoms approach had some limitations, the EU project Welfare Quality adapted and refined the concept for use in the development of standardized welfare assessments into a list of twelve independent sub criteria grouped in four main criteria: 1) Good feeding, 2) Good housing, 3) Good health and 4) Appropriate behaviour (Botreau et al., 2007)).

However, it remains questionable whether WOAH's and EFSA's definitions of good welfare can be applied to wild animals. Challenges arise because conditions such as temporary inability to express desired behaviour, discomfort, insecurity, and experiencing pain and fear may be considered natural aspects of life for free-ranging animals. Likewise, though the Welfare Quality® approach seems rational and clear, some of the criteria are certainly not relevant for wild birds and some not easily adapted for use on free-roaming individuals in their natural environment.

A definition that may be applicable even to wild animals involves assessing the individual animal's perception of its ability to naturally adjust to its surroundings: "*The welfare of an individual is its state as regards its attempts to cope with its environment*" (quote from Broom, 1986 repeated in (Broom, 2023). Broom also states that "*the subjective feelings of an animal are an essential part of its welfare*" (Broom 1996) and emphasises that welfare is a characteristic of an individual animal during a certain time interval and the state of the individual can be assessed in a scientific manner (Broom, 2023).

The Five Domains Model for assessment of animal welfare (Mellor et al., 2020) is an alternative method developed to facilitate systematic, transparent, and scientific evaluation of the welfare of sentient animals, which considers the negative and positive experiences the animals may have. The model is based on evaluation of four interacting domains, including Nutrition (D1), Physical environment (D2), Health (D3) and Behavioural interactions (D4), resulting in specific negative and positive experiences that contribute to a fifth domain for the mental state of the animal (D5, Figure 2). The welfare status of an individual at a given point of time is consequently assessed by use of animal-based data in the first four domains (D1-D4) and, in the fifth domain (D5), the mental experiences are inferred from the available data on other indicators.

The Five Domains Model has been used in a few published scientific assessments of welfare in wild, free-roaming animals that we found in the initial phases of the work with the current report (in Spring 2023), as for example an assessment of welfare in free-roaming horses (Harvey et al., (2020) and a description of the Sharp and Saunders humaneness assessment model for scientific assessment of the impacts on trapping on the welfare of mammals considered pest animals (Beausoleil et al., 2022)).

In the current assessment, we sought to use the Five Domains Model approach described by Mellor et al. (2020), and previously used by Sharp and Saunders (2011), Harvey et al. (2020) and Beausoleil et al. (2022) for a systematic and transparent assessment of the welfare impacts associated with capturing, handling, and marking of wild birds. By using an approach based on the Five Domains Model, we strive to interpret objective data retrieved from the literature in terms of what the field methods mean for an individual bird, including the mental experience of the bird subjected to the described procedures.

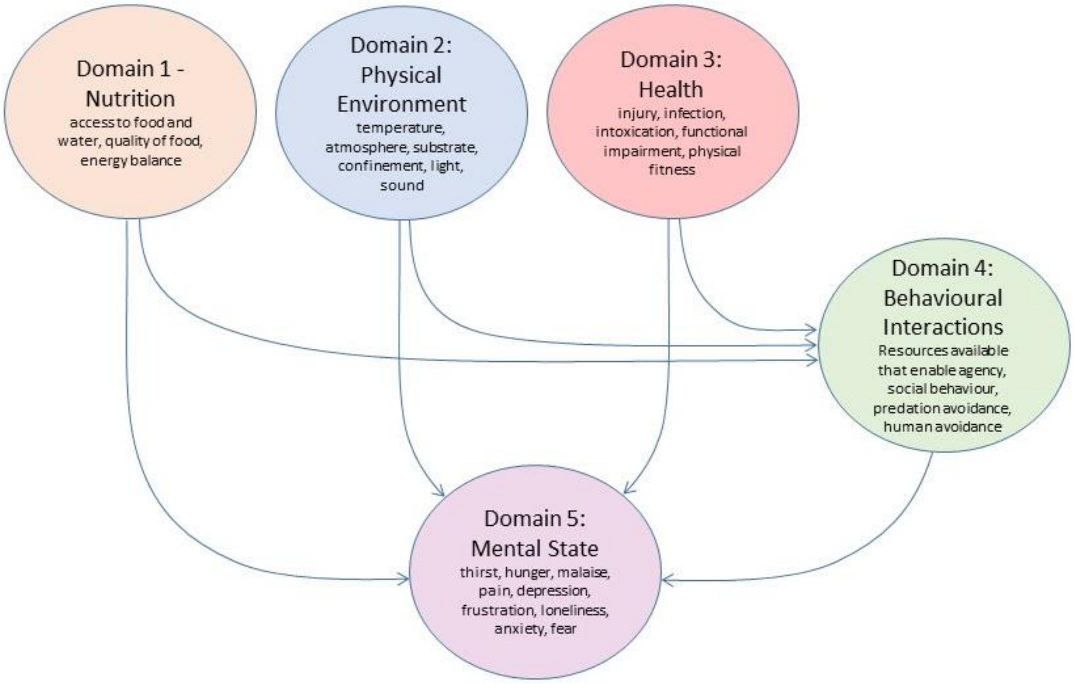

Figure 2. The Five Domains Model describes that the welfare of an individual animal reflects the sum of its various mental (affective) experiences at a particular point in time and systematizes these in five groups (domains) (Mellor et al. 2020, Beausoleil et al. 2022). Three domains are associated with environmental conditions including nutrition (D1), physical environment (D2), and health (D3). D1-3 are physiological responses, while D4 covers behavioural responses, i.e., how the animal interacts behaviourally with its physical environment, other animals, or humans to cope with the conditions and events it experiences. Domain 5 is the mental experiences inferred from the collated evidence of environmental factors (D1-3) and functional factors (D4), i.e. the summarized effects of the four other domains on the overall mental state of an animal. An assessment of the welfare state of an individual should consider all five domains.

Degree of sentience in different species of birds

An assessment of welfare in any species of animals necessarily involve an assessment of the sentience of the study species, such as the cognitive abilities of a species to experience positive and negative affective states (Soulsbury et al., 2020). Field and lab studies have shown that birds are capable of highly complex tasks of cognition, including spatial memory in food-caching species, coordinated behaviours in joint courtship displays, navigational maps in long-distance migrants, song learning in three independent lineages of hummingbirds, parrots, and oscine songbirds, and tool use in multiple species (Araya-Salas & Wright, 2013; DuVal, 2007; Marzluff et al., 2012; Rutz et al., 2010). It is presumed that different categories of birds vary in intelligence, but, in our opinion, we do not currently have knowledge that enable us to scientifically differentiate between bird species in this respect. Accordingly, we treat all species as if they have the same high capacity for both positive and negative affective states.

The terms 'stress' and 'distress'

The term 'stress' is widely used in various contexts, leading to numerous definitions, some of which are, at least in part, incompatible (Beausoleil et al., 2018). Furthermore, individual readers may have different perceptions and associations with the term. Consequently, we have tried to avoid the term stress and instead substitute terms with more precisely defined effects wherever possible and appropriate (Mellor et al., 2020). Where 'stress' is used, we refer to the recently published definition by Broom (2023): "*Stress is an environmental effect on an individual which overtaxes its control systems and results in adverse consequences and eventually reduced fitness*". In line with this definition, responses to stress may be called 'strains'. An individual animal that is not able to cope and accordingly experience reduced fitness, can be said to be 'stressed'. Further, and also in line with Broom (2023), we avoid use of the term 'distress', which have been defined as 'stress that causes harm', in contrast to 'eustress' which is used to describe environmental effects that the animal is able to cope with.

6 Literature search and data gathering

Identification and prioritization of needs to update the previous VKM assessment

All members of the project group reviewed VKM 2013: 'Risk Assessment Concerning the Welfare of Certain Free-Ranging Wild Mammals and Birds Subjected to Marking' (VKM et al., 2013) to determine to what extent the previous risk assessments remained valid or needed updating due to new information being available. The project group concluded that, in comparison to standard methods for capture and handling, the highest priority was to complete an update of the risk assessments for new methods developed for individual marking and tagging of wild birds. Marking refers specifically to the types of tag used for tracking and logging and the alternative modes of attachment of new classes of tracking devices and biologgers. VKM 2013 provided a comprehensive assessment of the effects of capture and handling but had only a limited evaluation of the potential impacts of different marking methods. Moreover, major advances in the past decade have included remarkable technological advancements in the miniaturization of tracking tags and continuing development of improved methods for marking and tagging of wild birds. Consequently, the project team opted to prioritize a systematic literature search to gather scientific evidence regarding the 'animal welfare impacts of marking wild birds', using standardized methods described in the Section 'Systematic literature search'. For capture, handling, and sampling, a less exhaustive literature search and data collection were conducted, as described in the Section 'Compiling data on impacts of capture, handling, and sampling'.

VKM 2013 did not consider the effects of sampling procedures on animal welfare, nor were sampling methods included in the Terms of Reference from the Norwegian Food Safety Authority and the Norwegian Environment Agency. However, permit applications for the capture, handling, and marking of wild birds often include plans to collect biological samples for research questions. Blood and feather samples can be used for multiple purposes and routine sampling can be efficient for reducing the numbers of birds that need to be captured for sampling, thus reducing the potential disturbance from field efforts. Thus, the project group expanded the scope of the current risk assessment to include methods for sampling and collecting tissues from wild birds. However, owing to time and team size limitations, a systematic literature search to gather data on the impacts of sampling was not conducted in the current assessment.

Systematic literature search: marking for individual recognition and tracking/logging

Literature search

In March 2023, the project group contacted the university library at the Norwegian University of Life Sciences (NMBU) for assistance in developing and implementing a literature search. The search aimed to facilitate a systematic synthesis of knowledge regarding the impact on animal welfare during the processes of capture, handling, sampling, and marking of wild birds. When the project group initially contacted the library, we had not yet decided to restrict our systematic literature search solely to marking methods. The project group compiled a list of 92 key publications, known as benchmark papers, covering each of the main topics under capture, handling, sampling, and marking of wild birds. The publications served as the basis for the library's initial mapping and survey as a comprehensiveness check to determine the most relevant scientific databases to utilize.

The project group used a 'PICO' framework to develop a literature search strategy (see Appendix I; Table 8). The PICO framework includes four key elements: P – problem or population, I – Intervention, C – Comparison, control or comparator, and O – Outcomes. We prepared an initial PICO form based on a template from NMBU. The search team from the NMBU library meticulously considered the search terms. Numerous test searches were carried out, during which the NMBU search team explored synonyms and experimented with truncation and proximity operators. The test searches conducted revealed that a fully systematic literature search encompassing both the capture, handling, sampling, and marking of wild birds would be much more extensive than the capacity of the project group to manage within the timeframe available for the project.

Capture, handling, and sampling methods have a long history in ornithological research (Schemnitz et al. 2012, Fair et al. 2023), but there have been remarkable advances in development of new miniature devices for tracking and biologging and the options for attachment techniques for marking and tagging of wild birds (Barron et al., 2010; Bridge et al., 2013; Iverson et al., 2023). Given the constrained resources available for our small project group, we opted not to conduct a systematic literature search to gather data on the impacts of capture, handling, and sampling on animal welfare. Here, we used VKM 2013 as a starting point, consulted guidelines for use of wild birds in research developed for other countries (Fair et al., 2023; Schemnitz et al., 2012), and used literature searches in Google Scholar to identify new work on selected topics.

In subsequent meetings and correspondence with the NMBU search team, the initial request was refined to focus on marking and tracking of wild birds, with the following assignment and purpose:

Period:	March – July 2023
Search assistance for:	Literature search in connection with the design of a rapid review
Platforms:	Web of Science, Biological Abstracts (Ovid), Scopus
Population:	Wild birds in Norway and similar geographical areas
Intervention/exposure:	Marking and tracking of wild birds
Outcome:	Animal welfare in response to marking and tracking
Time limit:	N/A
Language:	English, Norwegian, Danish, Swedish, German and articles where language is specified
Study design:	Peer-reviewed articles, review articles

Known studies:	See list from the scoping search – comprehensiveness check
Requested deliveries:	Search history, log text, RIS files from the databases

When filling out the PICO form, we employed the framework of the five domains detailed in Chapter 5, "Animal Welfare in Wild Birds," namely nutrition (D1), physical environment (D2), health (D3), behavioural responses (D4), and mental state (D5). The structured approach served as both a starting point and a guide, ensuring thorough coverage of animal welfare indicators and outcomes associated with each domain (Appendix I**;** Table 8).

The NMBU library's description of the literature search (translated from Norwegian):

The final version of the PICO form (Appendix I; Table 8) and revised and abbreviated list of 92 key articles (benchmark papers; Appendix I**;** Table 9) were received by the search team on 26 June 2023. Of these, five of the references on the list were books and therefore not included further.

Seventy-nine of 92 benchmark articles were indexed in three scientific platforms: Web of Science, Scopus, and Biological Abstracts (Ovid) (Appendix I**;** Table 9).

Searches were conducted in the Web of Science Core Collection, Biological Abstracts (Ovid) and Scopus platforms. The search was conducted from July 6-12, 2023. The search fields title and abstract were used, and there is no delimitation by year. The search was limited to the languages English, Norwegian, Swedish, Danish, German, and cases where languages were not specified.

Many of the keywords in the search strategy had a very general meaning, even though they are important in a professional context. This makes it impossible to avoid a large proportion of irrelevant findings (noise) in the hit lists. The search team tested various strategies to reduce noise, including:

- Use of Boolean operator NOT on certain selected words and terms in the title. For example, the bird name Rail also gives hits on "rail track".
- Use of proximity operators in the search strings in connection with very general concepts. For example, searching for "pain" may yield a large amount of noise, but "pain" in close proximity to words such as response/reaction/expression etc. will yield more precise and relevant hits.
- Truncation is used where appropriate and occasionally restrictive to avoid large amounts of noise. For example, swallow was not truncated to avoid hits on swallowing, among other things.

To give the client (VKM) a more precise search and a manageable number of references for review, the search team also chose to limit the search fields in each database to just title and abstract. In this way, the searches were also very similar despite different interfaces in each database. All databases support searching with proximity operators. Proximity operators were therefore used across all databases to provide more precise results.

Test searches showed that the use of AND between bird types and tracking/marking led to datasets with a large number of articles. For each database, such searches yielded approximately 60,000 hits, and the total amount of hits could have reached up to (or above) 100,000 titles. It was therefore decided to use a proximity operator between the two parts of the search and then connect welfare with AND. A simplified explanation of the search looks like this: ((BIRDS NEAR/10 Tracking-marking) AND Welfare). A complete search history for each database can be found in Appendix I Table 10, with an accompanying explanation of characters and field codes.

Database compilation – study screening and data extraction

The initial literature search across the three platforms (Web of Science, Biological Abstracts-Ovid, Scopus) resulted in a total of 45,246 hits. We used tools of the CiteSource R package to automatically detect and resolve duplicate records (Riley et al., 2023). A total of 17,995 unique citations remained after removal of duplicate records from the search records.

Record Counts		
	Records Imported[1]	Distinct Records[2]
BioAb	16334	11373
Scopus	16113	16056
WoS	12799	12788
Total	45246	40217
[1] **Number of records imported from each source.**		
[2] **Number of records after internal source deduplication**		

Due to the large amount of heterogeneity in the search results, we decided to use a machine-learning technique to further reduce the search to a manageable level given the logistic constraints. We used Topic Modelling, a type of statistical modelling (for an overview of the method see (Westgate et al., 2015); for use in research synthesis see (Nakagawa et al., 2019)), which can discover hidden semantic patterns in text and identify clusters of similar topics across a body of text. Topic modelling is an unsupervised classification method without human input in terms of training data and is conceptually similar to cluster analysis for numeric data. Instead, natural groups of documents can be found through Latent Dirichlet Allocation (LDA). The method identifies patterns of word co-occurrence to infer underlying themes or topics that characterise the content of the documents. We selected the Title and Abstract (where available) of each article and used the text information to run a topic model using the topicmodels package in R (Grün & Hornik, 2011). Fifteen broad topics were supported by the data (tested using the ldatuning package in R, (Nikita, 2020)). A subset of topics was clearly irrelevant with technical terms often associated with medical research (e.g., swallowing, disease, oesophageal, etc.) whereas other topics included terms that were more relevant to wild birds (e.g., species, predation, tags, etc.).

Each article was assigned to the most likely topic during the modelling and a RIS file created for each topic was created and used in the screening stage. We used the systematic review software Rayyan to screen articles in accordance with the inclusion and exclusion criteria outlined above (Ouzzani et al., 2016). We prioritised topics with clear relevance for wild birds for dual screening. Topics which had high likelihood of being irrelevant such as medical or transport studies were screened by a single reviewer. Articles were screened first by title and abstract based on the pre-defined inclusion/exclusion criteria only considering those published after the year 2000, assessing the marking and tracking of wild birds, and providing some assessment of animal welfare in response to marking and tracking in relation to unmarked controls. Reasons for exclusion were recorded for each article and all inclusion or exclusion decisions are available in Appendix II.

Studies in topics not prioritised for screening were still assessed by one reviewer, of these 1718 were excluded on the basis of date of publication (published before 2000) and 12,945 were excluded on the basis of low relevance (none of these topics included papers that were subsequently included in the review). Of the remaining 5,005 articles (in prioritised topics), 953 were excluded as they were published before the year 2000, 3,736 were excluded for other reasons (e.g. out of scope, no marking, not about wild birds). At least one reviewer assessed 4,844 of these articles for inclusion, and at least two reviewers assessed 161 articles. Agreement between reviewers was high (Kappa 0.86). A total of 289 articles were taken forward to the full text screening stage.

Full text screening and data extraction were carried out in parallel. A data extraction workbook was created in Microsoft Excel. Here, we extracted metadata from each article included at the title/abstract stage. A total of 99 studies were excluded at the full text stage. Therefore, data was extracted from 190 articles which consisted of 732 studies where a single article could contain several studies. We originally planned to summarise the effect of device attachment on birds using quantitative methods in a meta-analysis, but time constraints and a degree of heterogeneity in the reporting and outcome measures used in the primary literature meant that our goals could not be achieved. The dataset is open and available and can be utilised in the future after further cleaning and could be suitable for a potential meta-analysis.

PDF files for each included article were downloaded into a shared Zotero library. Any articles that were missing pdfs were requested via interlibrary loan from institutional libraries at NMBU or NINA/NTNU.

Of the included articles (190), 21 were review papers, where data and insights from other published studies was combined to make inference about the effect of device attachment on various life-history aspects of various bird species. The review articles were critically assessed for internal and external validity using the CEESTAT tool from CEE (https://environmentalevidence.org/ceeder/about-ceesat/) to determine the risk of bias in generic terms for each review (Appendix II). The CEESTAT tool compares aspects of a review to a "gold standard" to get an understanding of which aspects of a review might present a high, medium, or low risk of bias. We downloaded open data and where possible used the information to recreate statistical analyses and to augment existing meta-analyses with new data.

Compiling data on impacts of capture, handling, and sampling

The risk assessments for the impacts of capture, handling, and sampling methods were based on the five sources of evidence: i) information in VKM 2013, ii) the personal experiences of the participating experts with different field methods, iii) the comprehensive libraries of the experts, iv) additional literature searches conducted in Clarivate Web of Science and Google Scholar, and v) an initial compilation of benchmark papers by the VKM project group, before we narrowed down the full systematic literature search to focus solely on bird marking methods. The expert group compiled a list of key references related to capture, handling, and sampling that were designed as benchmark papers to provide a starting point for a systematic literature search (see above).

7 Risk Assessment Method

We used the Five Domains Model described in chapter 5 as a conceptual framework for the assessments of risks of reduced animal welfare associated with capture, handling, sampling, and marking of wild birds. Our method is adapted for this use from Harvey et al. (2020) and Beausoleil et al. (2022).

To ensure systematic, transparent and standardized assessments, we developed a rubric (Table 2) and an associated score sheet (Table 3) comprising both an assessment of animal welfare for individuals within one or several species or species groups when applying a specific method, and a resulting assessment of 'risk of harm to animal welfare' including judgements on probability, impact, risk, and confidence level.

For each of the five subdomains, we developed a list of 'observable indicators' and 'welfare alerting indicators' (Harvey et al., 2020), with a focus on elements that were likely to be relevant for wild birds (Table 2). The list was then adjusted and refined based on findings in the screened literature. 'Observable indicators' are measurable variables that with high level of confidence can be regarded as direct indicators of physical states that affect welfare. In contrast, 'Welfare alerting indicators' are observations and measurements that may indicate that a bird is experiencing a change in welfare caused by the treatment, but which cannot be regarded as a direct reflection of the individual's welfare state. For example, decreased body mass compared to a population mean can be regarded as an "observable indicator" of the experience of hunger in Domain 1. On the other hand, the observation of a bird not eating food normally preferred by the species may be regarded as only a "welfare-alerting indicator" in Domain 1 because the behavior may be associated with an experience of hunger, but can also be attributed to an individual bird's personal taste, habits, or special needs which would not necessarily be associated with a reduction in animal welfare.

Similarly, the framework of the Five Domains Model currently embraces both positive and negative experiences (Mellor et al., 2020). We assumed that few wild birds captured, handled, sampled or marked by humans would have positive feelings about their individual experience, and omitted this part of the assessment.

Based on the literature available and where we could find animal welfare-relevant evidence concerning the use of a certain method within a defined group of birds, we described reported observations judged to represent either observable indicators or welfare alerting indicators under the relevant domain and subdomains in Table 2. When all animal welfare-outcomes in the collected literature were described, we scored the probability (P) of an impact of the method on the species/species group on each subdomain under the first four domains from 0 (no), 1 (very low), 2 (low), 3 (medium), 4 (high) to 5 (very high) and deduced what kind of mental experience this would have in the fifth domain. Having completed these steps for all the relevant literature for the method and species group, we assessed the overall probability of harm to the welfare of a bird within a species or species group subjected to a specific method of treatment on a scale from low to high (low/moderate/high) probability of harm. Likewise, the potential magnitude of impact was evaluated based on the intensity and/or the duration of the impact on a scale from low to high (low/moderate/high) magnitude of impact. Risk of harm to welfare was then expressed as the product of probability and magnitude of impact (Figure 3. For each of the methods for capture, handling, sampling, and marking of wild birds assessed in this report, the conclusion of the risk assessments (low, moderate, or high) is based on the overall probability of short-term and/or long-lasting impact and the magnitude of the potential impact on the welfare of wild birds. The assessment of magnitude is based on both duration and intensity of the impact. The confidence levels for assessments of various bird groups are conveyed through distinct font faces, here illustrated for three orders of birds: Charadriiformes, Piciformes, and Passeriformes.

We carried out a risk assessment for each capture, handling, sampling, and marking method in Table 4, using the Five Domains rubric (Table 2) and score sheets (Table 3). Whether or not a method is applicable for a given bird group was determined from published scientific work and expert knowledge of the members of the project group, who together have extensive experience with a wide range of methods and different groups of wild birds.

In line with previous semi-quantitative risk assessments (VKM, 2023b), and to provide clear justification of why a rating is given in the risk assessment, the project group used ratings and adapted versions of the descriptors from Appendix E in (EFSA Panel on Plant Health (PLH) 2015). A similar approach has been used for example by Beausoleil et al. (2022) in an assessment of welfare of animals trapped for removals. A description of the ratings used for magnitude of potential impact and probability of impact can be found below in Table 5 and Table 6. Last, for each assessment, we report our associated level of confidence in our judgements as described in Table 7 and in accordance with the considerations of Beausoleil et al. (2022).

When assessing impacts on wild birds, it is important to bear in mind that all existing conceptual and theoretical frameworks for assessing animal welfare impacts have been developed for domesticated animals or wild animals held in captivity. There is great variation among bird groups and species in many different aspects of their ecology and life history strategies. For example, some species or individuals within species are adapted to a solitary life. Consequently, assessing whether a method will cause the bird to feel lonely seems far-fetched. Acknowledging the substantial heterogeneity among different bird groups, we used the Table 2 rubric and

Table **3** score sheet in the assessment of each method (see overview Table 4) and bird group, but we also relied on the comprehensive species knowledge of the experts in the VKM project group to ensure that the assessments considered the relevant differences in ecology and life histories.

Table 2. Rubric developed from the Five Domains Model (Mellor et al., 2020, Figure 5-1) by the project group and used in this report to assess short-term and long-lasting impacts on animal welfare from capture, handling, and marking of wild birds. Notably, the form is not developed for detailed evaluation of the immediate animal welfare impact during capture and handling and does consequently not take into account the potential fear and stress the bird experience in this situation. The three Domains: Nutrition (D1), physical environment (D2), and health (D3) are physiological responses, whereas a fourth domain covers behavioural responses (D4). The fifth domain (D5) is the integrated effects of the four other domains on the overall mental state of a research animal. Assessments were done separately for each method (and bird group) in Table 4. Probability (P) of an impact of the method on the species/species group on each subdomain under the first four domains was given a score from 0 (no), 1 (very low), 2 (low), 3 (moderate), 4 (high) to 5 (very high). Animal welfare assessment categories in the rightmost column: Probability of harm, Welfare impact, Risk assessment, correspond to the categories in the risk assessment matrix in Figure 3, and Table 6, and the confidence level corresponds to ratings of confidence in Table 7.

Method of capture/handling/sampling/marking:			**Species/species groups:**		
Physical/functional Domains:	**Observable indicators:**	**Welfare alerting indicators:**	**P** *(0-5)*	**Affective Experience Domain:**	**ANIMAL WELFARE ASSESSMENT:**
Domain 1: Nutrition				Domain 5: Mental State	**Probability of harm:** *(low – moderate – high)*
a) Restricted water intake	Physical examination (sunken eyes, skin fold) blood variables	Bird not drinking while other drinks		*Thirst*	
b) Restricted food intake	Body condition score, fat score, body mass, growth rate	Bird not foraging when this would be normal behavior		*Hunger*	
c) Low food quality/variety	Variable malnutrition syndromes	Bird not foraging on preferred food		*Malaise of malnutrition*	
d) Energy expenditure	Body condition score, fat score, body mass, growth rate	Mass of device relative to bird mass		*Hunger, weakness, exhaustion*	
Domain 2: Physical Environment					**Welfare impact:** *(minimal – moderate – major with regard to intensity and/or duration)*
a) Entrapment/confinement during procedures	Time, character, bird behavior, capture myopathy	Mounting and design of device, bird behavior		*Anxiety, fear, hypervigilance,*	
b) Thermal extremes	Physical examination/ necropsy, respiratory rate	Metal on skin, feather loss/damage, heat generated from glue or device, icing on tag		*Feeling frozen, feeling overheated*	

c) Aerodynamics/balance/drag	Flight, diving, movement pattern, reduced performance	Bird seeming to be uncomfortable with device		*Unease, frustration, helplessness*	
d) Entanglement	Examination/necropsy, mortality	Shape/form of device or harness		*Pain, frustration, helplessness*	
Domain 3: Health					**Risk Assessment:** *(low – moderate – high risk of harm to animal welfare)*
a) Decreased comfort	Trying to remove device, time used for preening, feather picking	Posture, restlessness, stretching		*Discomfort, frustration*	
b) Injury c) Disease susceptibility	Clinical signs/necropsy lesions, mortality	Lameness, lethargy, feather loss, abrasions		*Pain, breathlessness, debility, weakness, sickness, malaise, nausea, dizziness*	
Domain 4: Behavioural Interactions					**Confidence Level:** *(low – moderate – high)*
- with environment					
a) Habitat use, spatial/temporal	Habitat shift	Increased movement		*Frustration, confusion*	
b) Activity, foraging	Aberrant activity pattern, time budget	Changes in activity pattern, time budget		*Unease, confusion, fear*	
c) Migration, movement	Reobservation rate, location use, route, aberrant movement pattern	Delay, route deviation, atypical movement pattern		*Anxiety, fear, frustration*	
- within species					**Central References:**
d) Social behavior	Aggression, social exclusion, isolation	Withdrawal from interaction		*Loneliness, depression, frustration, fear*	
e) Mating	Pairing or mating success	Species-specific behavior		*Frustration, confusion*	
f) Reproduction	Reproductive output, hatching success	Parental behavior, attendance, abandonment of nest/brood		*Frustration, confusion*	
- with other animals					
g) Probability of predation	Predation mortality, escape behavior, increased vigilance	Visibility, loss of camouflage, impairment, decreased shyness		*Fear, anxiety, hypervigilance*	

h) Competition, kleptoparasitism	Body condition score, fat score, body mass, growth rate	Losing competition, increased kleptoparasitism		*Hunger, anger, frustration*	
- with humans					
i) Handling	Avoidance, flight distance, area use, direct response	Handling time, degree of restraint necessary, procedures		*Fear, anxiety, panic, neophobia,*	

Table 3. Score sheet used to assess impacts on animal welfare from capture, handling, and marking of wild birds, for each method, and relevant bird groups for each method. See Table 2 for an overview of possible observable indicators, welfare alerting indicators, and affective experiences. Probability (P) of an impact of the method on the species/species group on each subdomain under the first four domains was given a score from 0 (no), 1 (very low), 2 (low), 3 (moderate), 4 (high) to 5 (very high) .

Method of capture/handling/sampling/marking:			**Species/species groups:**		
Physical/functional Domains:	**Observable indicators:**	**Welfare alerting indicators:**	**P** *(0-5)*	**Affective Experience Domain:**	**ANIMAL WELFARE ASSESSMENT:**
Domain 1: Nutrition				Domain 5: Mental State	**Probability of harm:**
a. Restricted water intake					
b. Restricted food intake					
c. Low food quality/variety					
d. Energy expenditure					
Domain 2: Physical Environment					**Welfare impact:**
a. Entrapment/confinement during procedures					
b. Thermal extremes					
c. Aerodynamics/balance/drag					

d. Entanglement					
Domain 3: Health					**Risk Assessment:**
a. Decreased comfort					
b. Injury					
c. Disease susceptibility					
Domain 4: Behavioural Interactions					**Confidence Level:**
- with environment					
a. Habitat use, spatial/temporal					
b. Activity, foraging					
c. Migration, movement					
- within species					**Central References:**
d. Social behavior					
e. Mating					
f. Reproduction					
- with other animals					
g. Probability of predation					
h. Competition, kleptoparasitism					
- with humans					
i. Handling					

Table 4. Overview of methods described and assessed in this report; the assessed risks (Low, Moderate, or High) for specific methods; and whether the risk assessment was confirmed *[→]*, downgraded *[↓]* or upgraded *[↑]* compared to the risk assessments in VKM 2013. More than one change per method is possible when effects depend on bird group; for example, both confirmed and downgraded *[→ ↓]*. NA: No formal risk assessment in VKM 2013. For the methods marked with an asterix (*), the Five Domains scores sheet(s) (Table **3**) is(are) included in a An electronic Supplementary Information.

Risk:	Low	Mod	High	VKM 2013
Chapter 8: Capture				
Mistnets	■			↓
Corral, funnel, and walk-in traps	■			NA
Drop nets	■			NA
Pull nets, flip nets, and bow nets	■			NA
Nestbox traps	■			NA
Crow traps	■			NA
Noose carpets and noose lines, leg noose traps	■			NA
Raptor traps (dho-gaza, bal-chatri, and box traps)	■			NA
Night captures with spot-lights, thermal imaging and dip nets	■			NA
Noosing poles and hooks, dip nets, cast nets and hoop nets	■			NA
Net guns	■	■		NA
Cannon and rocket nets	■	■		NA
Chapter 9: Handling and sampling				
Handling and capture myopathy		■		NA
Blood sampling	Best practice described			NA
Feather sampling	Best practice described			NA
Cloacal and oral swabs for microbes and sperm	■			NA
Sedatives and anaesthesia	Best practice described			NA
Chapter 10: Marking for individual identification (no tracking or logging)				
Temporary feather dyes	■			→
Metal rings	■	■	■	→↑
Colour rings and leg flags	■	■	■	→↑
Patagial wing and web tags	■	■	■	→↑
Nasal discs and saddles	■		■	→↑
Neck bands*	■	■	■	→↑
Flipper tags on penguins*			■	↑
Chapter 11: Marking for tracking and logging (types of tags) – for risk assessment: see Mode of				
Radio Frequency Identification (RFID)	Method described			
Light loggers	Method described			
VHF radios	Method described			
GPS tags	Method described			
Satellite tags (archiving and non-archiving)	Method described			
Accelerometers	Method described			
Time-depth-recorders (TDR)	Method described			
Other biologgers	Method described			
Video cameras	Method described			
Chapter 12: Mode of attachment (of tags for tracking and logging)				
Glue and tape methods	■	■		→↑
Sutures, subcutaneous anchors and PIT tags*	■	■	■	→ (PIT) NA
Tail mounted tags*	■	■		NA
Leg mounted tags*	■	■	■	NA
Necklace collars	■	■		NA
Leg-loop harness	■	■	■	↓ NA[1]
Backpack (thoracic) harness*	■	■	■	→↓
Surgical implants*	■	■		→↓

[1] VKM 2013 (table 5) evaluated 'body harnesses' as having High risk for negative welfare for wild birds.

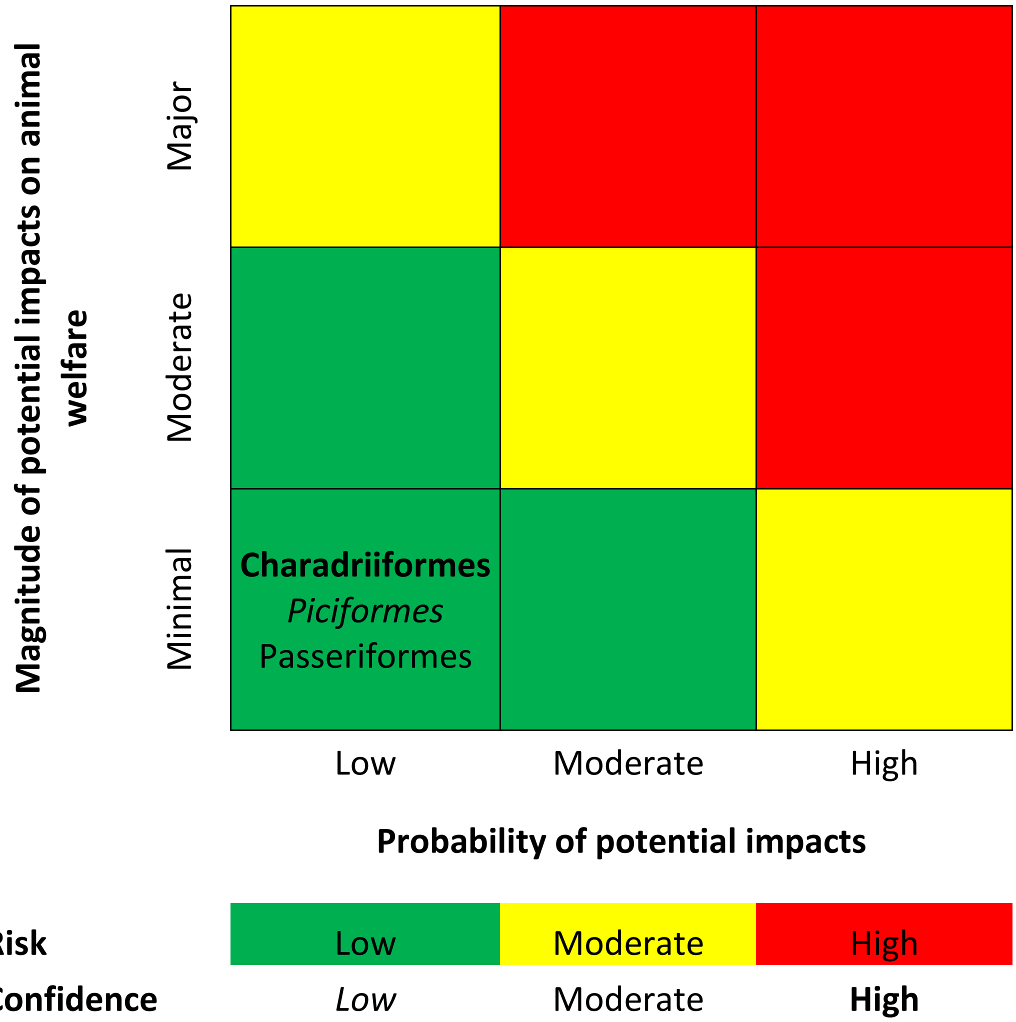

Figure 3. For each of the methods for capture, handling, sampling, and marking of wild birds assessed in this report, the conclusion of the risk assessments (low, moderate, or high) is based on the overall probability of short-term and/or long-lasting impact and the magnitude of the potential impact on the welfare of wild birds. The assessment of magnitude is based on both duration and intensity of the impact. The confidence levels for assessments of various bird groups are conveyed through distinct font faces, here illustrated for three orders of birds: Charadriiformes, Piciformes, and Passeriformes.

Table 5. Ratings utilized for the assessment of the magnitude of the impact, measured as impact on individual birds subjected to the specific method assessed.

Rating	Descriptors
Minimal	Negligible or minimal impact on the welfare of individual birds, either short-term (< a few weeks) with minimal intensity or transient with moderate intensity, resulting in no or minimal changes in welfare-alerting or observable indicators.
Moderate	Impact(s) with long-term (> month) or short-term moderate or transient high intensity, resulting in moderate changes in welfare-alerting or observable indicators
Major	Impact with short- or long-term high intensity, resulting in major changes in welfare-alerting or observable indicators.

Table 6. Ratings utilized to assess the probability of harm to welfare, measured as the probability per individual.

Rating	Descriptors
Low	Negative consequences would be expected to occur with a probability of 0-10%
Moderate	Negative consequences would be expected to occur with a probability of 10-50%
High	Negative consequences would be expected to occur with a probability of 50-100%

Table 7. Ratings utilized for describing the level of confidence in the assessment of risk of harm to animal welfare for a given method used on a given species or group.

Rating	Descriptors
Low	There are no published data, or the available information on the topic is very limited and/or the available information is very divergent regarding impacts on animal welfare, and mostly expert judgements are used. These are based on the accumulated observations of wild birds by the expert panel, combined with inferences from human experience with similar situations.
Moderate	Some published information with some degree of consistency exists on the topic, but there is a need for more specific or detailed data OR the published literature presents discrepant results regarding impacts on animal welfare, and expert judgements are still used.
High	There is sufficient and consistent published information, and expert judgments are in concurrence. The topic is very well investigated in peer-reviewed journals, with consistent results regarding impacts on animal welfare.

Importantly, when carrying out our risk assessments, we assumed that the evaluated method is used by a person who has the necessary knowledge, training, education, and experience to use the method, is updated on new knowledge for improving the method (refinement) and follows best practices. The rationale for this being that if carried out by a person who does have the necessary knowledge and skills, or not following best practice, any method could have adverse impacts on animal welfare.

For the methods that the project team, based on expert knowledge, anticipated to have the largest impact on individual birds, we have attached completed score sheets with references (Table 3). If the score sheet was uploaded in **the electronic Supplementary Information**, specific references were not included in the main text, to keep the text short and easy to read. Detailed references can be found in the score sheets in **the electronic Supplementary Information**, and the reviewed evidence is listed under Key references for each specific risk assessment.

Due to limited resources and time constraints, the completed score sheet was not uploaded in **the electronic Supplementary Information** for all the risk assessments. However, the Five Domains approach and the rubric in Table 2 and the score sheet in Table 3 were utilized for all assessments, using these resources as systematic checklists. If the score sheets were not included in **the electronic Supplementary Information**, the risk assessments are summarized in textual form and the key references are included in the main text.

The style of referencing is somewhat inconsistent among the evaluated methods, but the differences are stylistic rather than substantial, and any the apparent inconsistencies did not affect the outcome of risk assessments *per se*.

Scientific evidence and quality of studies varies, impacting confidence

The scientific literature offers abundant information on the devices used and their potential effects, but field studies often vary substantially in study design and quality (Box 2). Additionally, effects of the same method often vary among species, populations, seasons of the year, and can also depend on environmental conditions. The impact of a given method on birds of the same species and population in the same habitat, may even vary greatly between years, depending on other factors. Variation in avian responses emphasizes a need for testing potential device impacts within the specific study species and population, and under different environmental conditions.

Conducting a pilot study for experimental effect analysis, complete with an appropriate control group, becomes crucial in this context. Ideally, the control group should undergo the same treatment as the experimental group, excluding the actual device upon release—referred to as a sham control. Sham controls would involve identical capture and handling procedures. Employing such a method facilitates that any observed effects are then attributed solely to the presence of marking tag or the tracking device. With a sufficiently large sample size, an approach based on controlled comparisons between control and treatment groups can provides robust statistical evidence and estimates of effect sizes for different devices or attachment methods.

Furthermore, when evaluating the effects of different methods or devices on animal welfare, determining the appropriate reference level is not straightforward. Relevant reference levels may include unmarked birds, ringed birds, or birds subjected to similar treatments in experiments. For instance, a suitable reference group for assessing the impacts of marking birds would include birds that are captured, handled and sampled, but not marked. Alternatively, a reference group might include birds marked with identical types of tracking tags but with a different method of attachment such as a leg-loop harness versus a body harness around the wings and thoracic region.

Box 2. Statistical power

Statistical power is a critical concept in understanding of the strength of evidence in ecological research, representing the probability that a study will correctly detect a true effect if it exists. It serves as a measure of the sensitivity of a statistical test to detect differences or relationships. The probability of correctly detecting an effect is related to two properties, the size of the effect we are interested in (e.g., the effect of marking birds on their survival probability) and the sample size (e.g., the number of birds in the treatment and control groups).

Effect size

The effect size is a standardised measurement of the difference between two groups (e.g. the treatment group and the control group). A simple measure of effect is the standardised mean difference (often expressed as *Cohen's d* or the small-sample bias corrected version *Hedges' g*). Standardised mean difference simply quantifies how much of a difference there is between the control and treatment group. A very large effect of 2 (*Cohen's d*), indicates that for two samples (control and treatment) with a standard deviation of 1 (where there is not much variation in the sample) that the mean of the control group is 2 standard deviations away from the treatment group mean. The concept can be easier to understand with visualisations (Figure 2.1).

How effect size is related to statistical power

Where the effect size is large, then we can have a relatively small sample size and still be confident that we will detect the effect. Where the effect size is small, we need a larger sample size to ensure that we can detect the effect with confidence. We often set the value of 80 % power (shown as a dotted line on the graph below; Figure 2.2) to be the threshold to aim for as this choice balances the risk of making the incorrect decision with the need for more resources (a higher sample size can cost more in terms of time and resources).

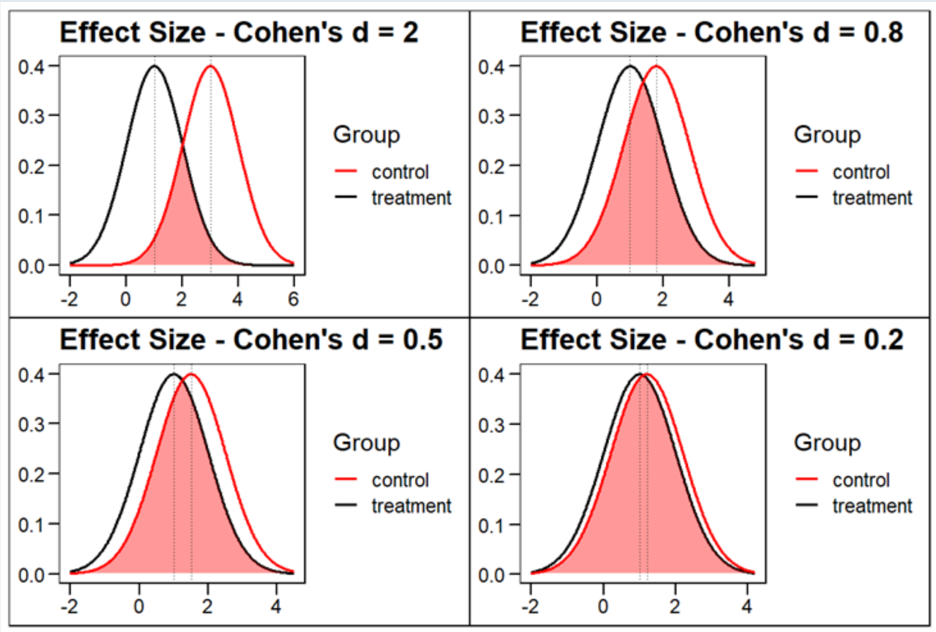

Figure 2.1. Very large (d=2) to small (d=0.2) effect sizes plotted to show the difference between control and treatment groups when standard deviation is 1.

What errors can occur?

Typical statistical power in ecological studies is thought to be low. For example, Jennions and Møller (2003) estimated power in behavioural ecology at 13–16% to detect a small effect and 40–47% to detect a medium effect. These estimates are much lower than the 80% target. We expect effect sizes to be small or medium in ecological studies because of the large natural variability in nature. Therefore, we will need to have larger sample sizes to be more confident of our findings.

There are four types of error that can result from issues with low power and low sample sizes.

A ***Type I Error*** is a false positive that involves incorrectly suggesting an effect when in truth none exists. Conversely, a ***Type II Error*** is a false negative that occurs when a study fails to detect a true effect that exists. Having a small sample size introduces additional challenges. ***Type M Errors***, are cases where the “magnitude” or size of an effect is incorrectly estimated, and ***Type S Errors***, where the direction or significance of an effect is misinterpreted such as the case where a true negative effect of marking on survival could be incorrectly identified as a positive effect.

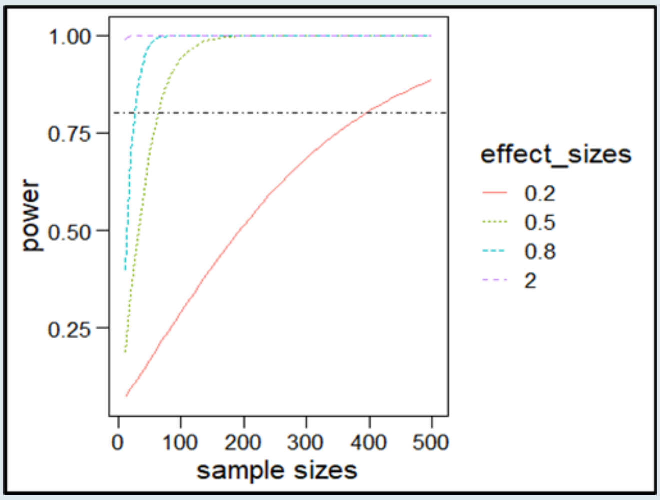

Figure 2.2. The relationship between statistical power, sample size and effect size.

Cleasby et al. (2021) estimated the power to detect effects of bio-logging devices to be between 9% and 65% across a range of assumed effect sizes corresponding to small, moderate, and large effects (*Cohen's d* = 0.2, 0.5, 0.8, respectively). Using effect sizes from a previous meta-analysis (Bodey et al. (2018); d = 0.1), the power was only 6%!

Cleasby et al. (2021) also showed that for the smaller effect sizes there was a high rate of ***Type M*** and ***Type S*** error rates meaning that published statistically significant ($p < 0.05$) studies may exaggerate the size of the effect and it may even be in the incorrect direction.

Well-designed studies that account for sample size effects are vital to understand the true effects of marking birds.

8 Capture of wild birds

Note that in the assessments of methods for capture of wild birds, we have used the observable and welfare alerting indicators belonging to domains 1: nutrition, 2: physical environment, 3: health, and 4: behavioural interactions in Table 2 and Figure 2 as a checklist. Based on these observable and welfare alerting indicators in domains 1 to 4, domain 5: mental state can be inferred.

Any capture (and handling) of a bird that causes the individual to experience loss of control over its environment could be considered to pose a risk of transient harm to animal welfare, in addition to the degree of actual nutritional, physical or health-related challenge the capture implies. Based on own and others' experiences, it should be presumed that a bird that is captured will temporarily lose its ability to escape from threats, seek nutrition and adjust for discomfort, experience stress, fear and anxiety. However, the mental experience during a capture may vary greatly between individuals, age groups, genders, species, time of the day and year, the local circumstances, and the capture devices. In addition, different individuals and species may show different behavioural responses, varying from obvious markers of fear to apparent lack of response, making it inherently difficult to assess and compare the animal welfare impact of different capture methods on mental states of wild birds. Consequently, in the following description of the animal welfare impacts of different capture methods, **we have concentrated on the short-term and long-lasting impacts of the procedure.** This should not be interpreted to mean that we neglect the mental states of birds as an aspect of animal welfare <u>during</u> capture, as we on a general basis think capture constitutes a moderate to high probability of a transient experience of fear, anxiety, and stress for the bird with at least a moderate magnitude of potential impacts. Consequently, and according to our risk assessment matrix visualized in figure 3, most capture methods should be assessed as constituting a moderate, in some cases even high risk of harm to animal welfare. The confidence of the assessment is low for mental states of animal welfare, since the available scientific information is limited.

However, since almost all birds that are marked are captured, we have chosen to not let this general assessment of animal welfare during capture be decisive for the assessment of each of the following capture methods. The rationale for this is to allow a better presentation of the actual differences between the methods when it comes to short-term and long-lasting effects, instead of letting all assessments be concluded as moderate risk due to the immediate effects on mental states described in this section.

A factor that nevertheless should be considered in all assessments and planning of capture methods, is the time an individual has to spend captured. For example, Romero and Romero (2002) describe that the corticosterone-levels in White-crowned Sparrows (*Zonotrichia leucophrys*) and House Sparrows were significantly elevated in birds removed after 15 minutes in mist nets compared to birds removed immediately but did not find the same effect in baited walk-in Potter traps where captured birds were not restrained. An important general mitigation measure may consequently be to minimize the time the bird has to be captured, for example by having continuous monitoring of trap sets and a short response time from capture to handling (Lindsjö & Berg, 2022).

Mistnets

Description of method. Mistnets are a common method for live capture and monitoring of small-bodied birds such as storm-petrels, waders, small owls, woodpeckers and songbirds. A typical mistnet consists of 3-5 parallel lines that support a mesh of net with separate tiers of panels that form loose pockets. Each line ends in a loop which is attached under tension to a vertical pole. Mistnets can vary in configuration with different lengths or more or fewer vertical panels, and different options for mesh size. Low nets can be more efficient in open habitats whereas larger mesh sizes can be used to capture large-bodied species of birds. Multiple mistnets can be deployed end-to-end in a line or in a V-shaped configuration to target a movement corridor. Birds that fly directly into the mistnet will drop into the pockets or become tangled in the mesh. Field workers remove captured birds by untangling them from the tail and pulling the loops of mesh over the legs, wings and head. After removal from the net, birds can be transferred to cloth bags or holding boxes for transport to a ringing station. Mistnets can be used to capture individual birds at nests or feeding sites for a field study or can be deployed in systematic grids for national monitoring programs for bird populations such as the Constant Effort Sites (CES) scheme in the UK and the Monitoring Avian Productivity and Survivorship (MAPS) program in the USA. Mistnets are less effective in open habitats and in windy conditions but capture efficiency can be improved by using them in combination with decoys or playbacks of bird vocalizations. Use of mistnets at night can be efficient for capture of waders in coastal mudflats and small-bodied seabirds that visit nesting colonies after dark to avoid predators. Birds in different habitats can be sampled by raising mistnets up into the forest canopy with a pulley system or by setting up mistnet poles on floats in open water. In a similar manner, gillnets with a coarse mesh size but no weighted bottom line but can be used to capture larger-bodied species of diving birds in aquatic habitats. The sample of birds captured in mistnets may be a biased sample of a population or avian community if juveniles, birds in wing moult, birds associated with understory habitats, or small-bodies species have a higher risk of capture.

Impacts on animal welfare. For small-bodied species of waders, seabirds, and landbirds, the **risk** of negative impacts on animal welfare are assessed as **Low**, with High confidence (**Figure 4**). VKM 2013 (table 4) suggested that the use of mist nets and nets in water had a Medium risk of negative welfare. We have **downgraded** the risk assessment because recent reviews have shown that mistnets are a safe and efficient method for capture of live birds, and injuries or mortalities only occur rarely during the capture process (2a, 2d). Compilation of long-term data from banding organizations suggests that average rates of injury are 0.59% and mortality are 0.11-0.23% per capture event. Risks of stress and injury can be greater for large-bodied species, for juveniles than adults, and can vary among seasons. The general effects of stress of capture can also have adverse effects on animal welfare (3a), particularly if mistnets are deployed under conditions of heavy rain or high temperatures that affect energy expenditure (1d). Most losses are due to two causes. Capture in a net can cause abrasions to body parts such as the leading edge of the wing and can potentially cause strangulation if loops of the net become wrapped around the throat or torso (3b). Woodpeckers and thrushes with long serrated tongues risk entanglement in the net mesh but still can be extracted with extra care. Birds in feather moult may risk damage to the developing feather shafts which are soft with blood-rich pulp cavity (3b). Injuries or exposure to pathogens can potentially reduce survival after capture in a mistnet (3c). Birds can be vulnerable to predators while entangled in a mistnet, particularly if the lower panels of the net are accessible to ground-based predators (4f). Birds can learn from experience with mistnets and ringed individuals may be more likely to avoid nets or the area where they are deployed (4i).

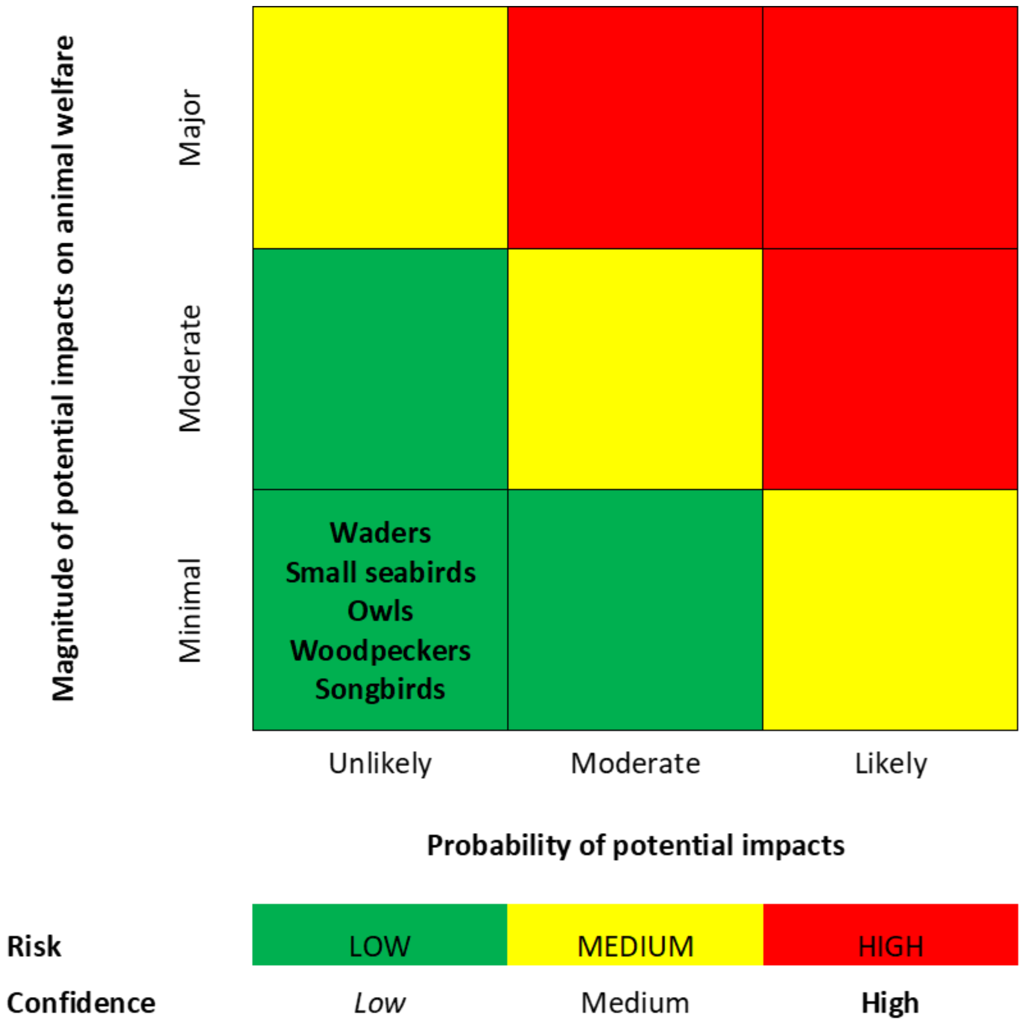

Figure 4. Risk assessment for use of mist nets to capture birds.

Risk-reducing measures. Risk of injury and mortality can be reduced by taking care with good practices for setting and storage of mistnets. The length and mesh size of mistnets should be selected to match the habits and body size of the target study species of birds. The total number of nets deployed should match the number of bird ringers available and their field experience. Excessive entanglement can be reduced by setting the lines far enough apart to avoid capture in multiple pockets, by clearing vegetation around the nest lines, by patching or replacing any nets with holes, and by removing any debris before storage. Birds captured in the lower panels are more easily overlooked and those sections should be checked more carefully. Nets should be set at a height so that birds cannot touch the ground, are not at risk of drowning if the net is over water or set on mudflats with a rising tide, and will not be exposed to predators, biting ants or other hazards. If possible, nets should be set perpendicular to the wind direction so that birds entering from either side will be captured. When nets are furled for storage but left on the poles, care should be taken to wrap any loose sections that could capture unwary birds. Furled nets can be fastened with ties or can be covered with a sleeve to prevent the panels from unwinding. Mistnets are most effective if deployed under low winds and should not be used in heavy rains or extreme temperatures. Mornings and evenings are often effective because birds are more active, winds are still, and temperatures are cool. Nets can be closed quickly if inclement weather arises unexpectedly. Efficient operation of mistnets requires either direct observation of the nets or regular net checks every 20-30 minutes, with more frequent checks if birds are exposed to extreme weather. Safe removal of birds from mistnets requires training of novices under the supervision of experienced bird ringers. The mistnet is approached quietly and species or age-classes that are more vulnerable can be prioritized for first removal from the net and for ringing to reduce handling times. Birds should be removed from the same side of the net that they entered, and in reverse order starting with the tail and legs, wings and then the head. A blunt knitting pin or a small crochet hook can be helpful in removing net mesh from birds that are badly tangled. Carrying a small pair of scissors is a good practice because severely entangled birds can be cut out of the net as a last resort. Ringers should monitor birds during extraction and watch for cues of stress such as blinking and closing of the eyes, lethargy, or excessive panting. Transmission of pathogens may be a risk factor if bird bags, cages or other equipment are used to temporarily house captured birds. Extra measures should be taken to ensure that the equipment is washed and disinfected before beginning work with a new species or at a new location. Bird bags should be large enough that the bird has room to move, a coarse mesh that allows air flow, and no loose threads that could entangle captured birds. The bags with birds awaiting processing should be stored out of direct sun or rain and spaced apart to allow sufficient air flow.

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Corral, funnel, and walk-in traps

Description of method. Corral, funnel and walk-in traps are passive traps that are placed at sites where walking birds are likely to encounter the trapping equipment. The basic design is typically a large holding trap or pen with entrances constructed of tunnels or V-shaped entrances that birds must push through to enter the trap but then have difficulty finding their way back out. Birds are directed or attracted towards the entrances with a combination of drift fences, bait or playbacks of vocalizations, or sets of decoys. Large corrals with long lead fences and handling pens have been used to round up and capture penguins at breeding sites and geese when they are flightless during the brood-rearing periods. Ducks and other waterbirds can be captured in baited clover leaf traps where four lobes of the trap are separated by narrow entrances. Walk-in traps have been widely used to capture waders at coastal and inland sites with stable water levels. Marsh-dwelling rails have been captured with similar designs where birds have been attracted to the walk-in traps with song playbacks. Box traps and fences deployed in a star-shaped configuration or in a zig-zag design are efficient for capturing lekking grouse at courtship display sites. Traps, funnels and lead fences are usually constructed from welded metal panels or fencing to be durable and are pegged down with stakes or metal posts. The lid of a box trap is usually made of a softer material such as plastic or nylon netting to avoid injury to captured birds in the trap. Birds can be safely removed from the trap either by hand or by reaching in to capture them with a small dip net. Small walk-in-traps are also commonly used to catch ground-nesting birds at nest sites. The trap is placed over the nest with a funnel or gate positioned over an entrance pathway. The bird is trapped when it pushed through the funnel or when a gate closes after the bird return to the nest to sit on the eggs. Walk-in traps are commonly used to capture different species of waders, gulls, and terns.

Impacts on animal welfare. For waterfowl, grouse, penguins, gulls, terns and rails, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (Figure 5). VKM 2013 did not include a risk assessment for use of passive walk-in traps to capture of wild birds. Birds that enter and are captured in passive traps are usually held for short periods which does not affect their access to water or food (1a-c) and has short-term effects on activity budgets (4b). Birds can move around in the trap at their own pace and energy expenditure is unaffected unless multiple individuals are captured at the same time and the birds are crowded (1d). Birds are confined within the trap but risk of capture myopathy is low because natural movements are not restricted (2a). Exposure can impact animal welfare if traps are deployed under extreme temperatures (2b). Metal traps with mesh lids can pose a risk of entanglement and injury to captured birds (2d, 3b). Capture of multiple birds at the same time can lead to aggressive interactions among competitors and possible injury (4d, 4h). Eggs can be damaged by the parent when walk-in traps are deployed at nest sites (4f). The greatest risk for birds captured in passive traps is an increased risk of predation if they are unable to escape from the trap (4g). In lekking grouse, passive traps have greater impacts on males than females because the sexes respond differently to confinement but typical injuries to males are usually only scrapes or minor cuts on the wings or soft tissues in the head.

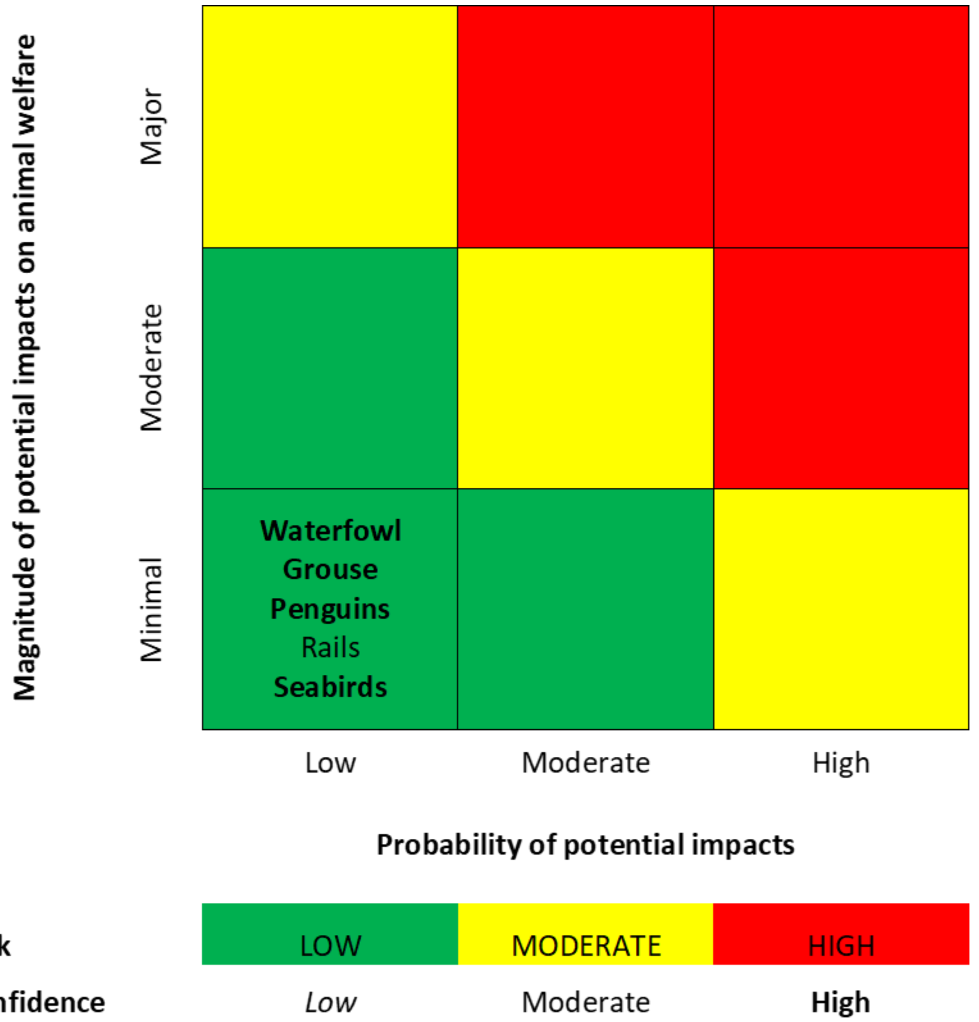

Figure 5. Risk assessment for use of corral, funnel, and walk-in traps to capture birds.

Risk-reducing measures. Risk of injury can be reduced with close attention to trap design and construction. Round or oval shapes can reduce overcrowding and the risk of birds become trapped in the corners of a box trap. The mesh size of the metal panels should be small enough to avoid entanglement. All metal edges of trap materials should be clipped or filed to avoid any sharp objects pointing into the interior of the trap, and netting should be secured to avoid entanglement or escape by captured birds. Use of soft mesh materials as covers on the top of traps reduce injuries if birds flush and try to fly out of the trap upon approach of an observer. If walk-in traps are deployed at a nest, the clutch can be temporarily replaced with dummy eggs to avoid damage to the eggshells during trapping. Holding traps should be large enough to hold multiple birds at the same time and surplus birds can be released to avoid losses to stress or trampling. Traps should be deployed at locations and time periods when captured birds will not be exposed to hazardous weather. Traps can be set in wetland habitats to capture waterfowl and waders but not at sites with risk of flooding. If competitive interactions or risk of predation pose a risk to captured birds, the traps should be monitored continuously so that captured birds can be removed quickly for processing. If birds are held for longer periods, they should have access to food and water inside the holding trap. Flightless geese are often captured as family groups and should be released together after ringing is completed to avoid separation of parents from their broods of young.

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Drop nets

Description of method. Drop nets are a safe and efficient method for capturing flocks of birds at sites where they congregate to display or roost. Common applications of drop nets include capture of lek-mating species of grouse at communal display sites or waders at high tide roost sites. Determining the best site for deployment of a drop net usually requires scouting to find a location where birds are regularly located and then inspecting the area for signs of footprints, droppings or shed feathers. Birds can also be attracted into the capture area by use of baits, decoys, or access to a shaded area. Drop nets are typically large panels of fine mesh that will cover but not entangle the captured birds. Size of the net can be adjusted to match the dimensions of the sampling area, and parallel drop nets can also be set up and monitored simultaneously. Net colour can affect capture efficiency and birds may be less wary of camouflaged nets that match the background environment. The drop net is suspended horizontally over the capture area on a network of poles and connected to a quick release trigger. Different release systems include ropes under tension, pulley systems, or collars or sleeves that slide down the poles after being triggered with electronic systems that are operated remotely. After the net is dropped, one corner or an edge can be rolled back to remove the captured birds. Drop nets need to be continually monitored but then timing of capture is then under the control of the observer. One big advantage of drop nets is that they allow for selective capture and can be used to target a particular study species, individuals that have not yet been ringed, or the subset of age or sex classes needed for a field study. In addition, drop nets can be effective in windy conditions where it is not possible to use mistnets, and are a low impact technique in areas where cannon nets and rocket nets cannot be used. Birds may be more likely to enter the trap area under a suspended net than to go into a box or other types of traps. Drop nets can require less field effort than other trap sets because they can often be set up and monitored by a small team. Drop nets can also be quickly reset for another round of capture as needed.

Impacts on Animal Welfare. For gamebirds and waders, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (**Figure 6**). VKM 2013 did not include a risk assessment for use of drop nets for capture of wild birds. The capture event is usually short and captured birds can be quickly removed from the trap set so impacts on access to water and food (1a-c) and energy expenditure are negligible (1d). Birds are confined briefly during trapping (2a) and can be at risk of overheating if drop nets are used in hot conditions (2b). Risk of entanglement in the net is possible if the wrong mesh size is used (d2). Risks of injury are usually low because the drop net is usually light weight and only falls from a short height (3b). Deployment of drop nets at lek or roost sites can lead to behavioral avoidance or disrupted mating behavior if birds are wary of unfamiliar objects (4a, 4d-e, 4i). Birds are free to move and act naturally while the net is in place, and no effects are expected on activity budgets (4b), competitive interactions with conspecifics (4h), or the risk of predation (4g). Capture of large numbers may require temporary holding of individual birds which can affect handling times (4h).

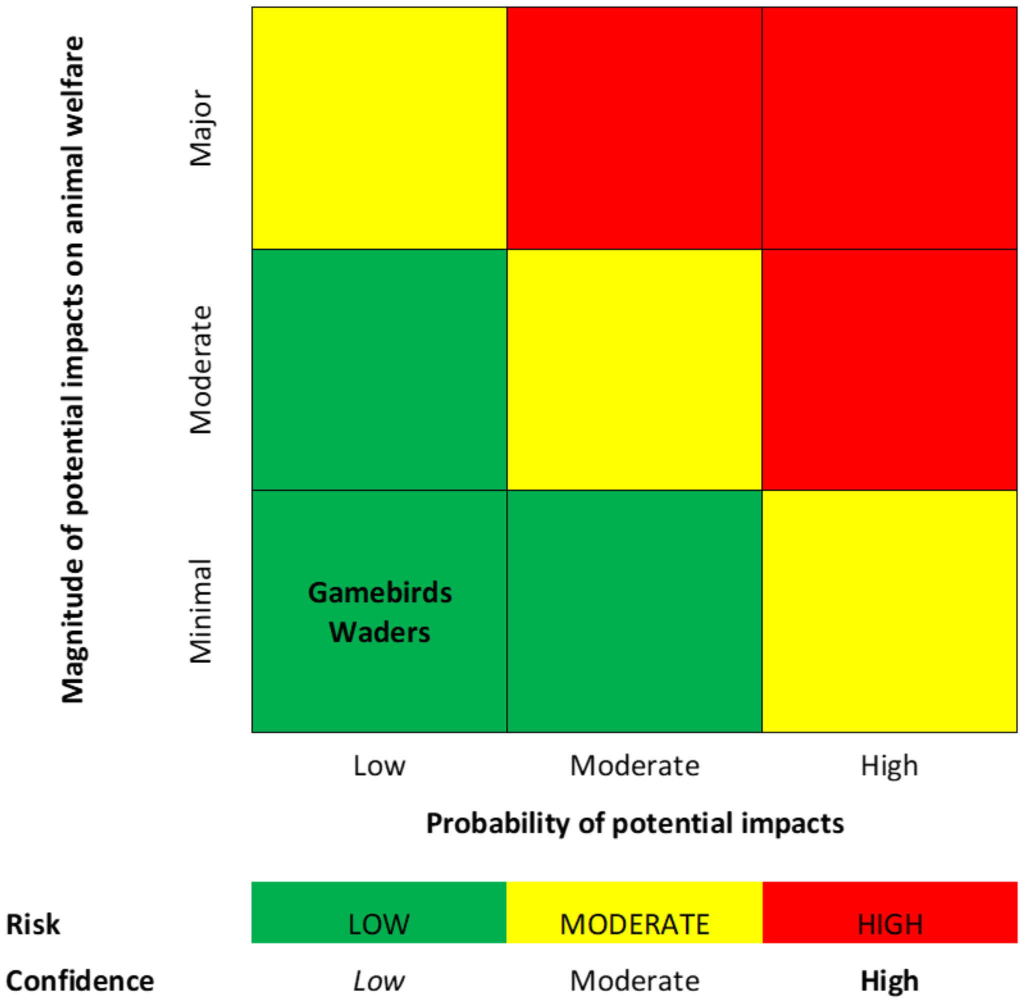

Figure 6. Risk assessment for use of drop nets to capture birds.

Risk-reducing measures. Drop nets can be efficient for simultaneous capture of large flocks of birds and one risk-reducing measure is to ensure that the capture team is large enough to quickly remove birds from the net and that an adequate number of handling boxes are available for temporary holding of birds during processing. If a large flock is captured, spreading a large burlap tarp over the net can reduce stress on the remaining birds awaiting extraction. Captured birds are usually held for only short periods in the drop net because the trap set is monitored continuously. The mesh size of the net should be matched to the body size of the target study species. The mesh size should be fine enough to avoid unnecessary entanglement of the head or wings, but also as coarse as possible to reduce the total weight of the net. The falling net and associated lines pose a low risk of injury once the trap is triggered. If the drop net is set up in advance, it is a good idea to double check the rope tension and have a test drop before setting the net for capture. It is good practice to mark the boundaries of the net area while setting up the drop net, and to trigger the drop net only when birds are clearly under the net area and away from the edges. Similarly, baits and decoys should be deployed in the centre of the trap area to draw birds away from the edges. Flagging can be added to the posts to discourage birds from perching on the lines and prematurely dropping the net. An advantage of selective capture is that drop nets can be triggered when there is a target under the net and otherwise have minimal effects. Birds can enter and leave the trap site without disturbance if the operator decides not to make a catch. During a capture event, individuals that are already ringed or nontarget species can be released immediately with minimal disturbance. If presence of a drop net appears to cause disturbance or behavioural avoidance, the trap set can be moved or removed from the site.

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Pull nets, flip nets and bow nets

Description of method. Mistnets, walk-in traps, and drop nets are all large obvious structures that may have low capture success if they are avoided by wary birds. Pull nets (or clap traps), flip nets (or whoosh nets) and bow nets are three alternative trap designs that have a low profile and are less easy for birds to detect. The footprint of the trap area is typically an area that birds will be attracted to because the site is baited with food or carrion, because decoys are deployed with playbacks, or because the site has been used for roosting or nesting. If birds are roosting outside of the trapping area, 'twinkling' can be used where observers slowly approach a flock of roosting birds on foot while avoiding eye contact to try and direct them to move over into the trapping area but without flushing. The three trap designs have been used to capture a range of different birds, including doves and pigeons, gulls, wading birds, raptors, and songbirds. The trap set consists of a furled net that springs up and over the birds once they are in the trapping area. In the case of pull nets, the net is furled in a line behind angled stakes and an observer pulls the net quickly up and over a roosting flock. In the case of flip nets, the net is attached to a lightweight frame which then is anchored to the ground on a hinged base. When birds land or fly over the trapping area, the panel is flipped up and over the birds. The 'wilsternet' was a traditional method used in the Netherlands to capture Eurasian Golden-Plovers

(*Pluvialis apricaria*) and other harvested species of waders. Last, bow nets have a half circle design and are used to trap a small space such as the area around a decoy or a nest site. In the case of pull nets and flip nets, the observer usually has a pull cord to deploy the net and springs or elastic lines can assist with a rapid motion. If the trap is triggered by an observer, it is possible to avoid unnecessary capture of nontarget individuals or species. Bow nets can be spring loaded with a trigger line that is tripped when the birds enter the trap area, or can be triggered remotely with an electronic release with a solenoid mechanism. Pull nets and flip nets allow capture of multiple birds at a time whereas bow nets are used to capture individuals. The trap designs do not require use of explosives like cannon and rocket nets and are thus safer to deploy in protected areas or suburban gardens. Once birds have been removed, the traps can usually be reset quickly for another round of capture if desired.

Impacts on animal welfare. For the diverse range of birds assessed, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (**Figure 7**). VKM 2013 did not include a risk assessment for use of pull nets, flip nets and bow nets for capture of wild birds. The three types of net traps are continuously monitored, and birds are extracted immediately during a capture event. Effects on nutrition and the physical environment are minimal because birds are held for only a short period (1a-c, 2a-c). Birds can have a risk of entanglement in the mesh of the net during capture (2d). Traps will have little effect on avian health (3a, 3c) except possible injury from fast-moving parts of the trap such as the net frame (3b). Trap-related injuries commonly reported include minor skin abrasions and feather loss caused by nets passing at high speed over the wings as birds flush to escape the trap (Herring et al. 2008, Coxen et al. 2018, Adams et al. 2019). If flocks of birds are captured at one time and held for processing, an individual could have minor effects on their energy expenditure (1d), movements and activity budgets (4a-c), or social behaviors (4d-f). Losses to predation or effects on competition are not expected and only rarely reported (4g-h). The concealed traps are difficult to birds to detect and behavioral avoidance is not expected (4i).

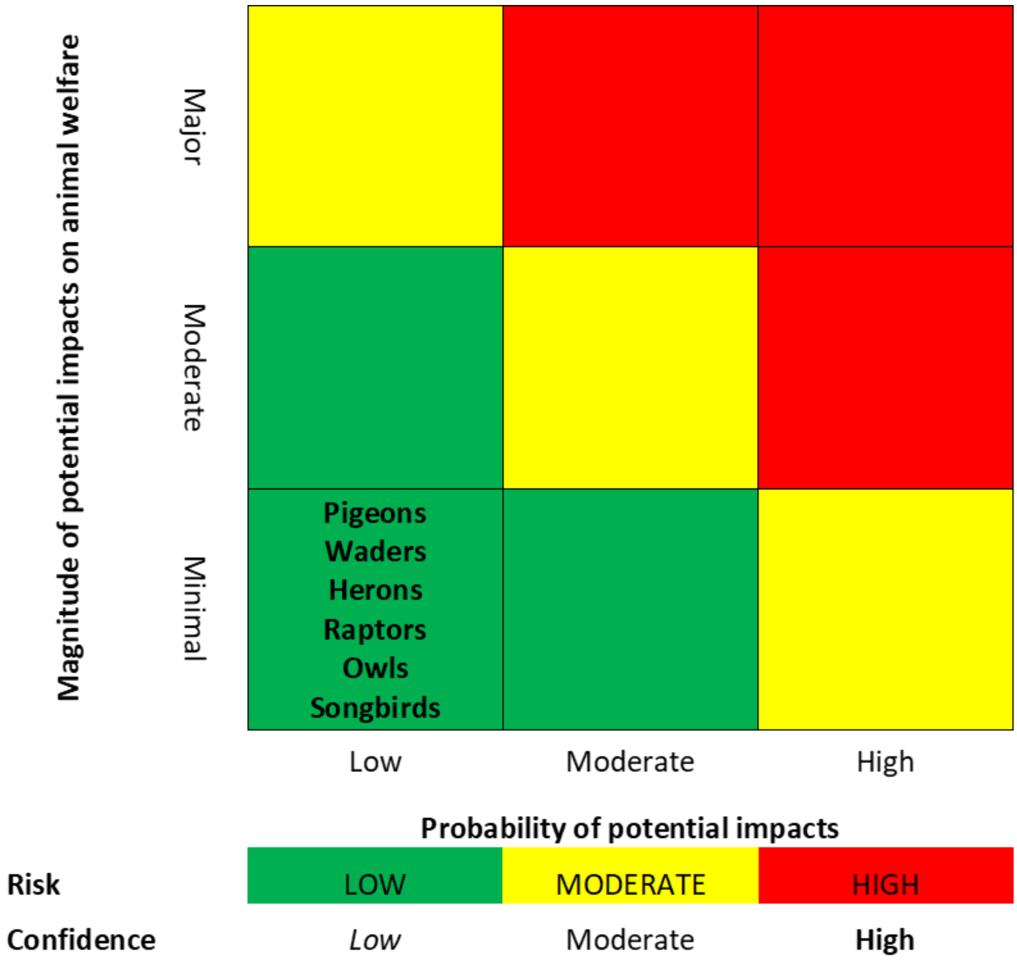

Figure 7. Risk assessment for use of pull nets, flip nets and bow nets to capture wild birds.

Risk-reducing measures. Most negative effects of net trap designs can be minimized by continuous monitoring of the trap set and rapid removal of captured birds. If the trap set is triggered by an observer, the risk of capture for nontarget individuals and species can be minimized. Pull nets and flip nets have the capacity to capture large numbers of birds in one set and it is important to have adequate field personnel and resources to remove, house and process the birds quickly. The trap should not be triggered unless all birds are in the centre of the trap area and none are perching on the edges of the frame or ropes. All net traps have moving parts but use of light weight nets and a flexible frame can reduce risk of injury, and the mesh size can be adjusted to the body size of the target size to avoid risk of entanglement. Traps should not be set in areas where there is standing water or a risk of flooding, and the trap area should be clear of debris that could become entangled in the net. If a bow trap is set at a nest site, the clutch can be temporarily removed and replaced with dummy eggs to avoid damage to the eggshells by a bird bouncing in the trap. Freezing rain or snow can affect the performance of the springs and ropes but a test release can be used to double-check that the net trap will work as planned before it is set for capture.

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Nestbox traps

Description of method. Nest box traps are used to capture cavity-nesting birds that nest in artificial nest boxes, including some species of waterfowl, owls, falcons, and songbirds. Because nest boxes make access to bird nests simple, and scientific manipulations feasible, much of what is known about avian reproductive ecology comes from research using nest boxes as a working tool. In this research, capturing the birds for individual identification is paramount. Therefore, nest box traps take many forms, depending on the species and the researchers need and ingenuity.

Most nest box traps are based on a swing-door/flap shutting the entrance behind the entering bird. In the simplest and most fool-proof case, the bird pushes the door/flap open when it enters the nest box, and the door/flap falls back when the bird has passed by. For small passerines such as Pied Flycatcher (*Ficedula hypoleuca*) and Great Tit, the door/flap may be made of a piece of transparent plastic fastened with pin on the inside of the box above the entrance. For larger cavity-nesters, such as Boreal Owl and Ural Owl, the swing-door may be made of plastic-covered metal-grid, fastened above the entrance on the inside of a tunnel-shaped extension of the nest box, because mounting the swing-door directly on the nest box without a tunnel-extension will often not make a capture of the male successful, because he will perch in the entrance, leaning forward into the box to deliver prey to the female or the nestlings, pushing the trap door open, and then withdraw.

More advanced versions of the swing-door/flap trap have a mechanical arrangement that when triggered by the bird, shuts the door/flap behind the bird. Alternatively, the swing-door/flap can be propped open, and then pulled shut by the researcher when the bird has entered, in the simplest case by using a string, in more advanced cases by using a mechanical device with remote control. For trapping of non-nesting female ducks prospecting for a nest box, an automatic nest box trap is useful.

Impacts on animal welfare. For ducks, owls and passerines, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (**Figure 8**). VKM 2013 (table 4) did not include a risk assessment for use of nest box traps for capture of wild birds. A swing-door/flap nest box trap is very safe, in particular when the bird is pushing the door/flap by itself, because the bird is just being confined to its own nest.

Usually, the researcher is watching the bird´s entering, and will remove the bird from the nest box very soon afterwards. The trapping thus has minimal effect on the bird´s access to food (1b). The risk of injury is very low when the bird pushed the door/flap itself, and still low when the door/flap is pulled shut by the researcher (3b).

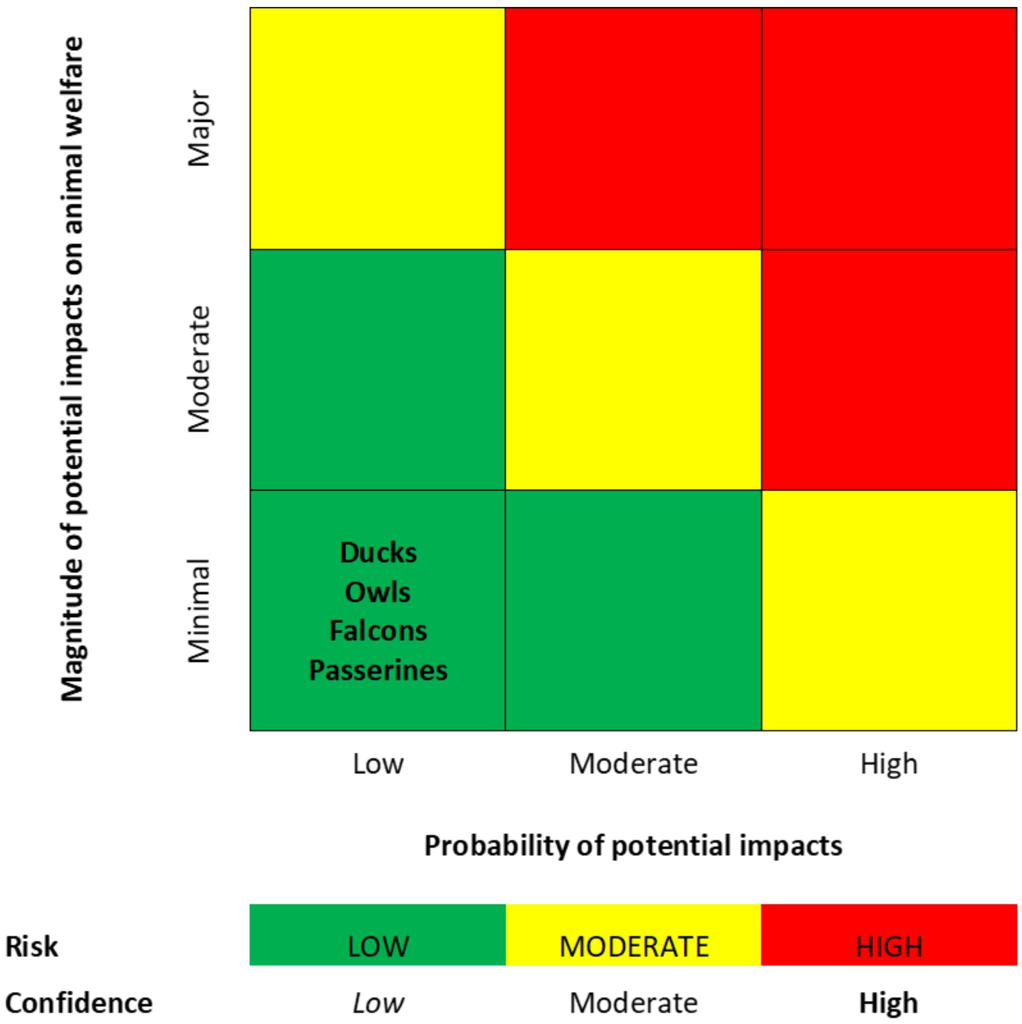

Figure 8. Risk assessment for use of nestbox traps to capture birds.

Risk-reducing measures. The time elapsed from the bird enters the nest box via the trap until the bird is removed from the nest box should be minimized.

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Crow traps

Description of method. The walk-in multi-catch cage trap ("Norwegian crow trap") is aimed at trapping corvids such as Ravens (*Corvus corax*) and Hooded Crows (*Corvus cornix*). It is a cage trap large enough for the operator to walk into. The frame is made of wood and the trap is covered with mesh/netting, which must be made of plastic, and not metal (wire), to avoid injury of the trapped bird. The birds enter by a ladder entry point in a groove in the middle of the trap roof. The trap is baited with carrion such as offal from a slaughterhouse. After being mounted at the trapping site, the trap is left open for several days until the corvids get used to enter it and leave at free will. When the trap is closed the birds which enter the trap will be unable to leave. Similar trap designs have been used to capture starlings and cowbirds for removal programs and take advantage of the sociality among flocking species.

The Larsen trap ("Danish magpie trap") is aimed at trapping Magpie (*Pica pica*) and Hooded Crow. It is a small and portable cage trap with at least two compartments, of which one is a closed compartment for a live decoy bird, which is not legal in Norway (dyrevelferdsloven § 14), where a man-made decoy must be used. The trap is baited with carrion or eggs from domestic hens. It has at least one capture compartment, with spring or gravity activated trap doors, which are either top-mounted or side-mounted. The original Larsen trap design used a top-mounted sprung door to the catching compartment, held open by a 'split perch'. When a bird the size of a magpie or crow lands on the perch the perch gives way and the bird's momentum carries it into the trap and the spring door flips up and closes behind it. The trap is covered in mesh/netting which must be made of plastic, and not metal (wire), to avoid injury of the trapped bird. The efficiency of the trap when baited with a man-made model is unknown, but most probably lower than when baited with a live lure.

Impacts on animal welfare. For corvids, the **risk** of negative impacts on animal welfare is assessed as Low, with <u>High</u> confidence (**Figure 9**). VKM 2013 did not include a risk assessment for use of crow or magpie traps for capture of wild birds in Norway. The "Norwegian crow trap" and the "Danish magpie trap" are very safe, because the bird enters the trap on its own, lured in by the view of supplementary food. In both trap types, the trapped bird has access to the bait until it is removed from the trap, so the trap has minimal effect on the bird's access to food (1b).

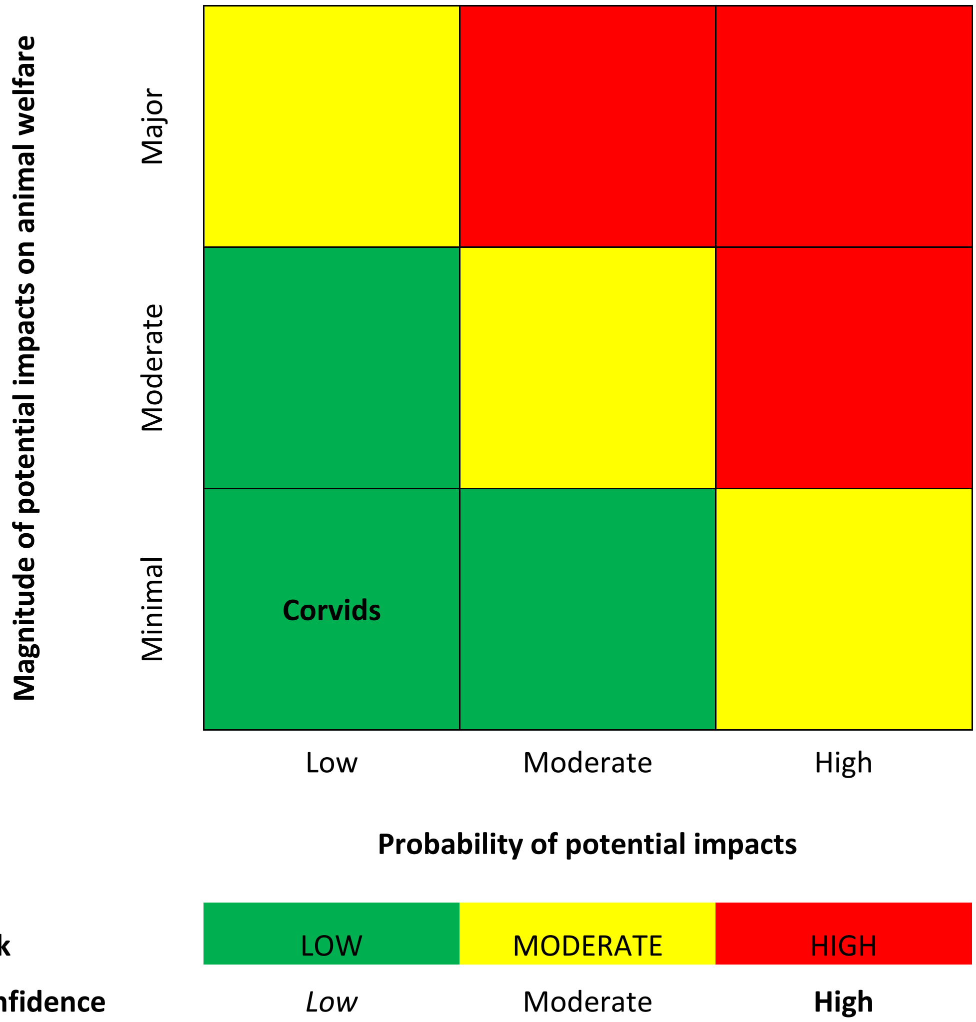

Figure 9. Risk assessment for use of crow traps to capture birds.

Risk-reducing measures. The mesh/netting that covers the traps must be made of plastic, and not metal (wire), to avoid injury of the trapped bird. The traps must be provided with sufficient bait and clean water to keep the trapped birds satiated until the trap is inspected. The trap should be inspected often to minimize the time that birds spend in the trap; at least once a day (night) for the "Norwegian crow trap" and at least twice a day for the "Danish magpie trap".

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Noose carpets and noose lines, leg noose traps

Description of method. Noose carpets and noose lines consist of a series of elliptical monofilament loops with a slipknot that are then attached to a mat of wire mesh or to a heavy line. The design is similar to the bal-chatri traps used to capture raptors but does not have a decoy or bait (see §8.8). Noose carpets and noose lines are constructed by hand by tying loops and attaching them to a base of mesh or an anchor line. Leaving a small tab of monofilament at the slip knot of the noose can be helpful for loosening the knot to untangle a captured bird. The nooses are spaced to cover the entire wire mesh or anchor line but far enough apart that they do not interfere with each other. The loops should stand upright from the base and up to the breast height of the target species. The diameter of each noose is adjusted to the foot size and birds become trapped when they walk across the device and a foot is ensnared in a loop. For large-bodied birds, addition of shock-absorbing elastic bands can reduce leg injuries for birds attempting to escape the nooses. Noose mats should be monitored closely to avoid leg injuries for birds struggling to escape. Noose mats are routinely used at sites where birds are expected to congregate such as roosting or display sites for seabirds on rocky outcrops or at feeding sites for waders. Noose carpets have been used in combination with audio lures to capture marsh-dwelling rails. Noose lines can be deployed around or at the entry of nest sites for waders, woodpeckers and songbirds. Deployment at perch sites may be less successful if birds do not move their feet enough to close a noose and become ensnared. The trap must be anchored securely with a short sturdy tether so there is no possibility that a bird can escape and fly off with the noose carpet attached to a leg. Noose carpets have the advantage that they have a low profile and are less obtrusive than other capture methods, which can be an advantage in open habitats without vegetation or when trying to capture wary individuals. The traps are also light-weight and can be deployed and moved quickly to new sites. The materials to construct noose mats are inexpensive but it can be time-consuming to both construct and maintain the traps.

Leg-noose traps can also be used to capture birds on or off the nest using a single noose instead of a carpet or chain of nooses. In the simplest method, a single noose at the end of a line is pulled when the bird stands inside the noose. The method is widely used to catch gulls and ducks in parks where birds can be attracted with bread or other bait to enter the noose. The same approach can be used to catch a bird on the nest, but without bait, by placing the noose around the nest and waiting until the bird returns to the nest. If birds are wary, the trap set can require a longer pulling line with the observer hiding at distance until the bird returns. Leg-noose traps are commonly used to catch gulls, skuas and other ground-nesting birds during incubation. The noose can also be triggered with a remote control instead of a manual pull cord. The noose can be connected to a remote-controlled line puller which is placed 5-15 m away from the nest. The leg-noose trap including the noose and the line puller device must be anchored to the ground. Nooses are hand made with monofilament fishing line or wader shelf string. Large-bodied birds require thicker noose materials to avoid risk of injury to the legs because thin lines can cut the skin. Leg-noose traps are generally used on larger species of birds compared to noose carpets and noose lines. Leg-noose traps are not used inside burrows. For example, Little Auks (*Alle alle*) and different species of puffins can be captured with noose carpets and noose lines set outside their nest entrances.

Impacts on animal welfare. For waders, seabirds, and songbirds, the risk of negative impacts on animal welfare is assessed as **Low**, with **High** confidence (Figure 10). VKM 2013 did not include a risk assessment for use of noose carpet and noose lines for capture of wild birds. Noose carpets can be closely monitored at close distances and birds can be removed quickly with no effects on nutrition or energy expenditure (1a-d). The physical environment of the trap is identical to the surrounding location and cannot affect animal welfare (2a-d). The main risk to animal welfare is a short transitory period of decreased comfort (3a) and a low risk of leg injury while the bird is ensnared (3b). Mehl et al. (2003) reported an injury rate of 0.12% (3 of 2410 capture events) for plovers captured with noose carpets. The bird cannot engage in natural behavior for the short period while it is trapped (4a-f) with a short-term disruption to normal activity patterns (4b). Captured birds are vulnerable to predator attacks while they are immobilized (4g) and are also unable to defend against competitors (4h).

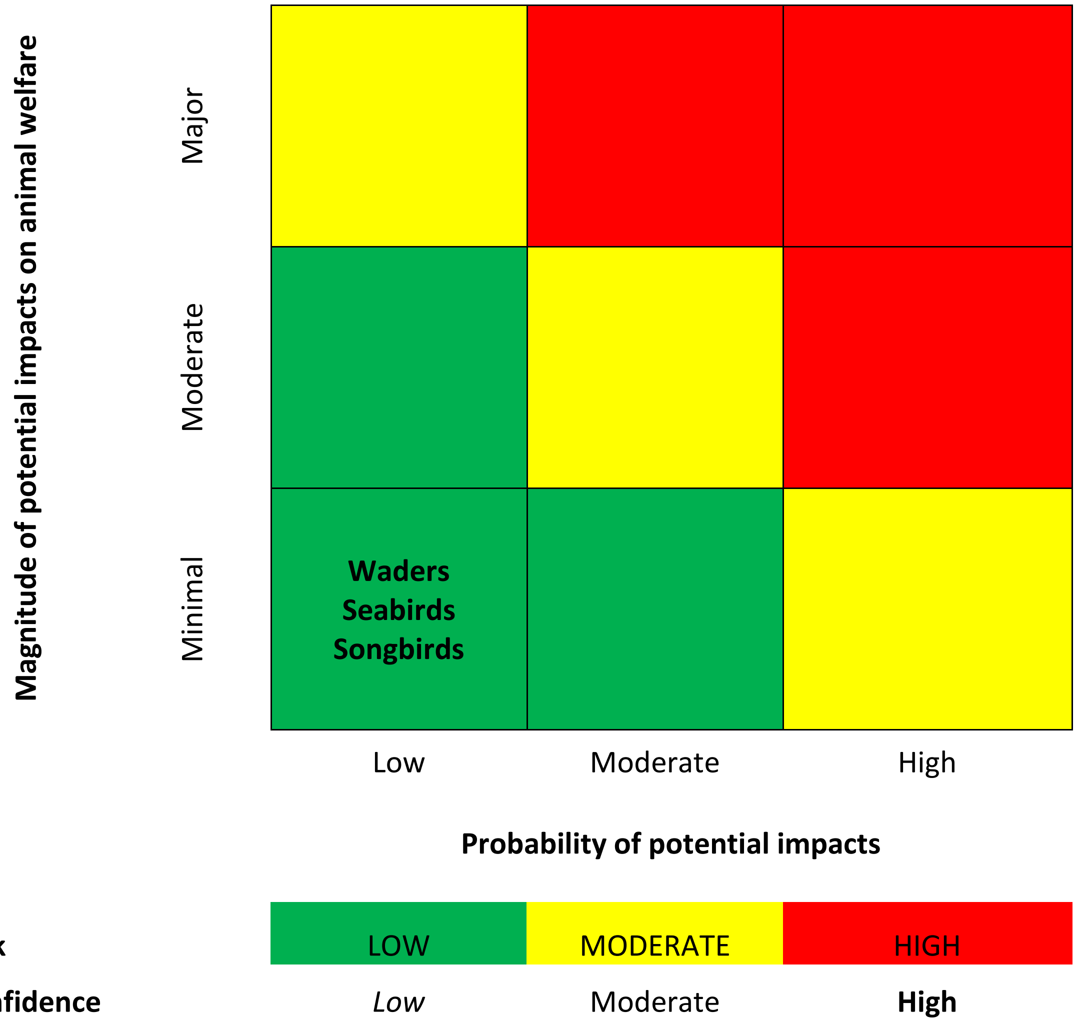

Figure 10. Risk assessment for use of noose carpets and leg-noose traps to capture wild birds.

Risk-reducing measures. Most of the risks to animal welfare can be managed by continuous monitoring of noose traps and leg-noose traps and by prompt removal of birds immediately after capture. Trap efficiency and risk of injury can be further reduced by maintaining noose carpets in good condition by replacing damaged loops and removing any debris. Adjusting the size of noose loops to match the study species and adding elastics as needed for large-bodied species can help to reduce the incidence of leg injuries. Taking care to attach the noose carpet or the leg-noose-trap to a solid anchor ensures that a captured bird cannot escape with the device. If birds are wary about unfamiliar equipment, the wire base can be deployed without noose loops to habituate birds to the trap set before attempting captures. Improved trap efficiency with habituated birds can reduce potential disturbance from capture activities. Similar to other capture methods, use of noose carpets and leg-noose traps during cooler parts of the day and under good weather conditions will help to reduce capture and handling stress.

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Raptor traps (dho-gaza, bal-chatri, and box traps)

Description of method. The bal-chatri trap consists of a double-walled small cage made of metal wire, with the inner cage traditionally baited with a lure, either a bird (e.g., a pigeon) or a mammal (e.g., a mouse). Numerous small hangman knot loops (slip nooses) of nylon thread are attached to the outer cage, to ensnare the talons of the raptor as it attempts to capture the caged mouse model. Due to the double wall, the lure is out of reach from the raptor (Berger & Mueller, 1959). The trap is placed in view of the target raptor. Use of a live animal lure is not legal in Norway (dyrevelferdsloven § 14). Alternatively, a mechanical moving model of an animal, such as a toy mouse, can be used, and in this case the trap can be single walled. A great advantage is that the trap is small and portable and has no moving parts. The trap must be anchored with a heavy object such as a stone or a piece of metal, so that the captured raptor is prevented from flying away with the trap but can still drag the trap a short distance along the ground so that the tension on the nooses remains snug and cannot snap.

The bal-chatri trap is an extremely effective trap for capturing raptors when baited with a live lure, but use of live lures is illegal in Norway (dyrevelferdsloven § 14). The trap probably works best for raptors with long tarsi, such as kestrels, and least well for raptors with short tarsi, such as owls, but even the latter have been captured. The efficiency of the trap when baited with a mechanical model is unknown, but most probably lower than when baited with a live lure.

The dho-gaza trap is simply a mist nest suspended between two poles, where the net detaches from the poles when a raptor hits the net. This trap is very versatile for trapping raptors. To trap breeding raptors with dho-gaza, the trap is placed near the raptor nest with a model of an Eagle Owl or a Northern Goshawk placed on a perch near the net. The breeding raptors perceive the model of the stuffed raptor as a threat to their offspring and would try to chase the threat away by stooping at it. As the raptor passes close over the threat, it will fly into the net, which then collapses over the bird. Using a live raptor tethered on a perch is more efficient than using a stuffed raptor, but this is not legal in Norway (dyrevelferdsloven § 14).

In Norway, the raptor box trap ("Swedish Goshawk trap") would be aimed at trapping Northern Goshawk and Eurasian Buzzard. The trap can be built in a variety of configurations but usually consists of a box-like frame covered with mesh/netting and with a collapsing top or falling ends. The material of the frame can be made of various materials, but wood is most often used. The mesh/netting must be made of plastic and not chicken wire, because the latter may cause injury to the feet and head of a captured raptor. Inside the box is a cage where lure animals are placed, which is not legal in Norway (dyrevelferdsloven § 14), but instead a man-made decoy or a carrion can be used. The trap is placed at a site the actual raptors are likely to visit. When the raptor enters the trap from above, the top closes.

Impacts on animal welfare. For raptors, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (**Figure 11**). VKM 2013 did not include a risk assessment for use of Bal-Chatri or Dho-Gaza traps for capture of wild raptorial birds.

The bal-chatri trap is safe for the trapped raptor. The trap can be closely monitored, for instance from a car, and birds can be removed quickly with no effects on nutrition or energy expenditure (1a-d). The physical environment of the trap is identical to the surrounding location and cannot affect animal welfare (2a-d). The main risk to animal welfare is a short transitory period of decreased comfort (3a) and a low risk of leg injury while the bird is ensnared (3b). Berger & Mueller (1959) trapped more than 400 individuals of seven species of raptors without any losses to mortality. The bird cannot engage in natural behavior for the short period while it is trapped (4a-f) with a short-term disruption to normal activity patterns (4b).

The dho-gaza trap is also safe for the trapped raptor. Zuberogoitia et al. (2008) captured 133 raptors of 10 species with no cases of mortality or obvious effects on the trapped birds, or on their nesting success.

The raptor box trap is safe for the trapped raptor. The trapped bird has access to the bait until it is removed from the trap, so the trap has minimal effect on the bird´s access to food (1b).

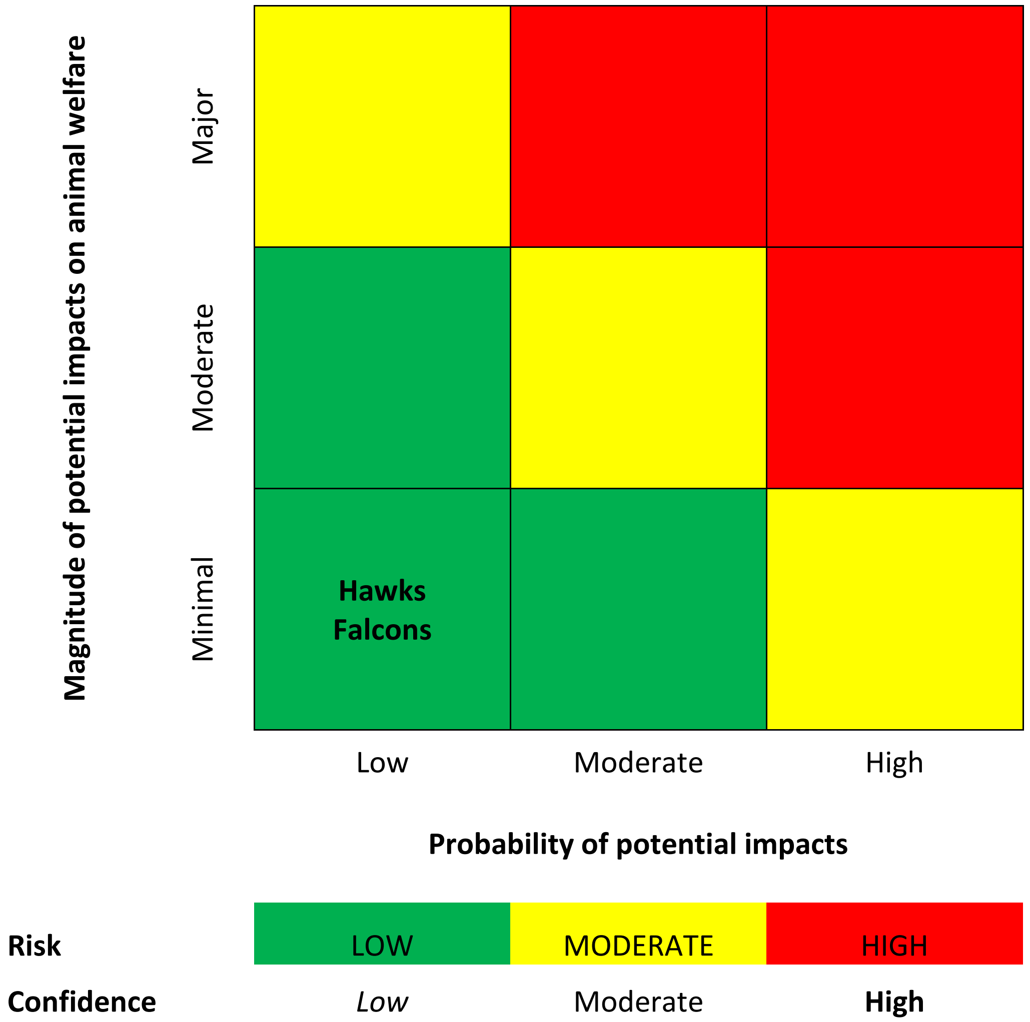

Figure 11. Risk assessment for use of raptor traps (dho-gaza, bal-chatri, and box traps) to capture birds.

Risk-reducing measures. The bal-chatri trap must be kept in view by the researcher at all times, so the trapped bird can be liberated from the entanglement in the nooses as soon as possible, minimizing the effect on the bird´s nutrition and energy expenditure (1a-d).

The dho-gaza trap must be kept in view by the researcher at all times, so the trapped bird will be liberated from the collapsed mist net as soon as possible. minimizing the effect on the bird´s nutrition and energy expenditure (1a-d). Birds trapped with dho-gaza nets can sometimes fly a good distance after hitting the net. Thus, to prevent harm to the trapped bird, the trap should not be placed close to cliffs, rivers or lakes.

If the raptor box trap is placed at a site which is shaded, the trap may be left unattended for 3-4 hours between inspections. The trap must be provided with sufficient bait to keep the trapped birds satiated until the trap is inspected.

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Night captures with spot-lights, thermal imaging and dip nets

Description of method. Nighttime conditions can be advantageous for field captures because it is difficult for wild birds to see and react to an observer approaching under the cover of darkness. Roosting and foraging birds can be located by searching at night with spot-lights on foot, or from an ATV, snowmobile or boat. Thermal imaging can be efficient for finding birds at night, particularly if they are highly camouflaged or concealed in cover, or for species that occur at low densities. Once located, birds can then be 'dazzled' with bright spotlights while approaching them for capture with a long-handled dip net or a cast net. Birds can be alerted by movements or shadows so it is helpful to use bright lights with a narrow beam and keep the net out of the light during an approach. Roosting birds are often reluctant to flush, especially if they have recently completed a long migratory movement. A combination of spot-lighting and dip nets have been routinely used for capturing grouse in upland habitats, cranes, rails and waders in marshes, and seabirds and cormorants at sea. Spot-lighting is also an effective method for locating and capturing nocturnal birds such as nightjars, rails and woodcocks. Capture success can be affected by ambient conditions with better success during nights with a new moon, cloud cover or light precipitation, and winds that mask sounds from an approaching observer. Observers will be less visible if they wear black clothing for field work. If conditions are still, observer noise can be obscured by broadcasting white noise from a portable speaker or by beating a cymbal with a mallet while approaching the birds (the 'gong' method of Potts and Sordahl 1979). On the other hand, captures of seabirds at sea can be more efficient by switching over from a noisy outboard engine to an electric motor for a quiet approach. Use of spot-lights and dip nets has several advantages. It is one of the most effective techniques for large-bodied species of birds, including grouse and cranes. If birds are spaced out, they can be captured and processed individually which reduces holding times. The footprint of the capture crew and lights is often relatively small, which can reduce disturbance to the study site or to a nesting colony.

Impacts on animal welfare. For the diverse range of birds assessed, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (**Figure 12**). VKM 2013 did not include a risk assessment for use of spotlights or thermal imaging for capture of wild birds. Capture of birds with spotlighting and dip nets has negligible effects on nutrition (1a-c) or the physical environment (2a-c) because birds can be removed from the net and processed immediately after capture. Captured birds may have elevated energy expenditure and decrease comfort during the handling period (1d, 3a) and can risk entanglement in the dip net during capture (2d). The main possible effect on animal welfare is a risk of injury from capture if a bird is hit by the edge of the frame of the dip net during capture (3b). As with other capture methods, the short handling period will restrict natural behavioral interactions with the environment (4a-c) and with conspecifics (4d-f). One large advantage of capturing birds at night is the probability of predation and competitive interactions are often reduced (4g-h), which improves animal welfare because individual birds have a longer period to acclimate to the effects of handling and marking before they return to natural behaviors. Birds can learn from their trapping experiences and previously marked birds can become wary and more difficult to catch with spot-lighting methods (4i).

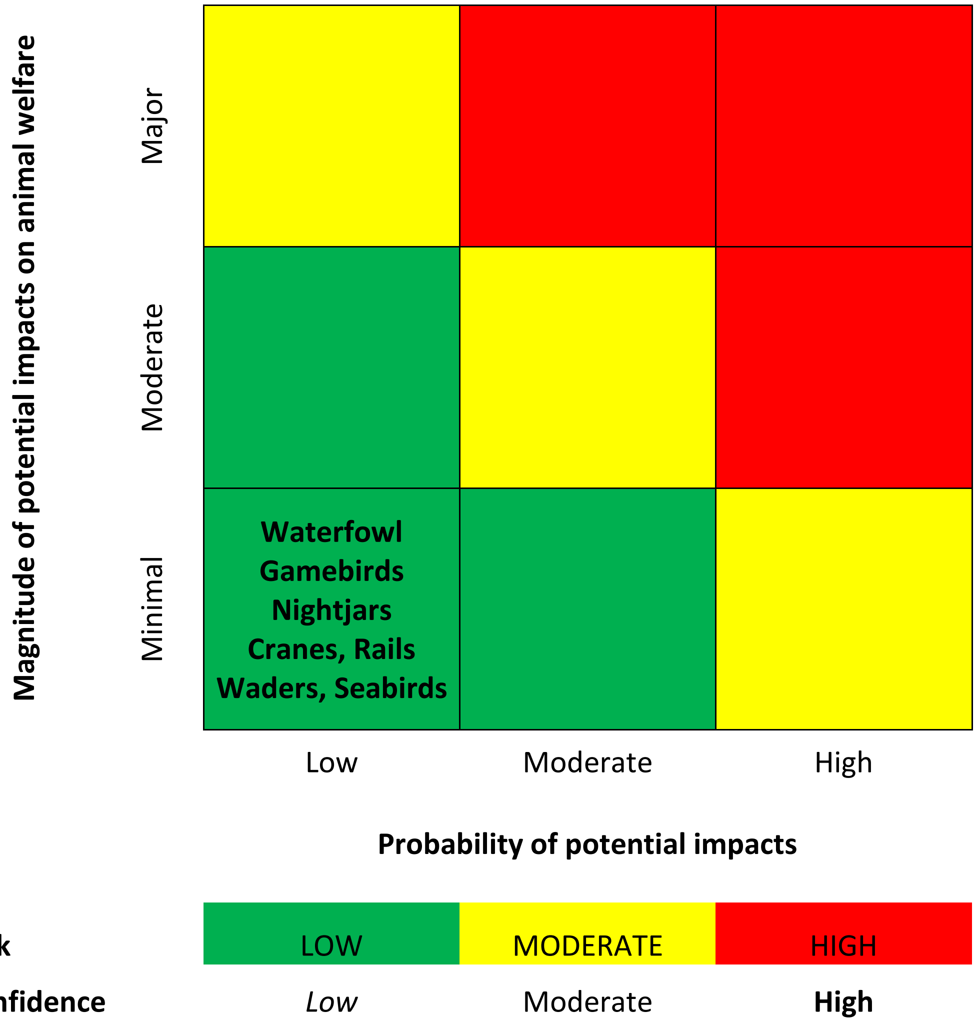

Figure 12. Risk assessment for use of night-lighting or thermal imaging to capture birds.

Risk-reducing measures. Roosting birds and gamebirds attending broods of flightless young can be difficult to see at night with a risk of trampling by observers. Use of thermal imaging can be useful to locate birds at a safe distance before capture and to avoid stepping on a hidden bird. Use of spot-lights to 'dazzle' roosting birds for capture has the advantage that is a short-term effect that wears off immediately. Spot-lighting is often most efficient with a two-person capture team with a lead person holding the spotlight and a trailing person following with the dip net. Coordination between the two members of the capture team can be used to reduce risk of injury and to increase capture success. If the person with the spot-light walks past a roosting bird, the person with the net can approach within capture range before the bird flushes. A lightweight net with a large diameter requires less care in placement and risk of injury can be reduced if the net is swung quickly over top of the bird but then lowered gently once the bird is covered by the mesh. If the person with the spot-light puts a hand on the bird to immobilize it, the risk of injury from thrashing is reduced, and the net person can drop the handle without risk of the net pivoting or shifting and then they can move around to extract the bird. A dip net with fine mesh will prevent entanglement and can help to speed up extraction. Working quickly and quietly will also minimize stress for the captured bird. Captures at night reduce risk because conditions are cooler and birds are less likely to overheat, and reduced risks of predation and competition give birds a longer acclimation period to adjust to new marking or tracking devices before returning to normal behaviours.

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Noosing poles and hooks, dip nets, cast nets and hoop nets

Description of method. Noosing poles are commonly used to catch gamebirds, waterfowl and seabirds, and may also be used to catch owls. In the case of gamebirds, waterfowl and owls, noosing poles work best for populations where birds are relatively tame and can be approached at a close distance, such as the Svalbard Rock Ptarmigan. Noosing poles are also useful in seabird cliffs, and also on ground breeding seabirds or terrestrial birds that stay on the nest when approaching them at approximately 4-6 m, e.g. like common eider and barnacle goose. Noosing poles consist of a ca. 4-6 m rod, usually a telescopic fishing pole, with a noose in the end. The noose is put around the neck and the bird is lifted gently off the nest, or off a branch in case of owls. The flexibility of the rod ensures that the tension on the neck is buffered. Hooks are less flexible and mainly used on ground breeding birds. The hook is placed around the leg or the neck and then the bird is pulled gently in by the researcher. Length and size vary. Thin metal sticks (1 m) with a bend at the end (greek eta letter shape) have been used to hook the leg of Snow Petrels at the nest, while 5-7 m composite poles with a metal hook at the end can be used to catch the neck of Northern Gannets from their nest. Dip nests and cast nets can be used as alternatives to the above-mentioned methods, especially if it is difficult to approach the bird and precisely place a noose or hook before the bird initiate flight or escape. Dip nets can also be used to catch owls as they fly out of nesting holes or nest boxes. Dip nets can also be used to catch birds swimming close to the side of a boat. Cast nets and hoop nets are commonly used to catch birds on water, slightly further away from the boat. Hoop net and cast nets are the same, apart from hoop nets having a ring frame. Hoop nets are for example used to catch procellariform seabirds on the sea surface, sometimes attracted with fish oil or other smelly bait. Hoop nets have also been successfully used to catch Northern gannets on the sea surface.

Impacts on animal welfare. For seabirds, eiders and geese, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (**Figure 13**). VKM 2013 did not include a risk assessment for use of noosing poles for capture of wild birds. Capture of birds with noosing poles and hooks, dip nets, and cast nets has negligible effects on nutrition (1a-c) or the physical environment (2a-c) because birds can be removed from the net and processed immediately after capture. Captured birds will have elevated stress and decreased comfort during the handling period (1d, 3a). Any entangling in the cast net should be resolved immediately (2d). There is some risk of strangulation with noosing poles and being hit by the edge of the frame of the dip net during capture (3b). Estimates of mortality rates are as low as 1.9% (23 of 1,200+ captures) in Sooty Grouse (Zwickel and Bendell 1967). The risk of predation is minimal (4g), since the researcher is often close and removes the bird immediately. Catching some species on nest or in the colony may result in nest desertion (4f), especially if birds are captured during early incubation. For example, Atlantic Puffins and Northern Fulmars can be sensitive to disturbance early in the nesting cycle. Catching at the nest can damage eggs, especially in Common Guillemots and other birds that incubate eggs on their webbed feet (4f). The risk of predation on the bird is low (4g), since the researcher is close and removes the bird immediately. However, the nest may be depredated if the partner is not present, and the caught bird does not immediately return back to the nest.

The main risk of the noose pool is that the outer, thin part of the pole can break, or that the researcher can lose their grip on the pole, so that the bird escapes with the outer sections or the entire pole. If a bird escaped with a cast net or hook, it would equally be detrimental. Birds can learn from their trapping experiences and previously marked birds can become wary and more difficult to catch with the same methods (4i).

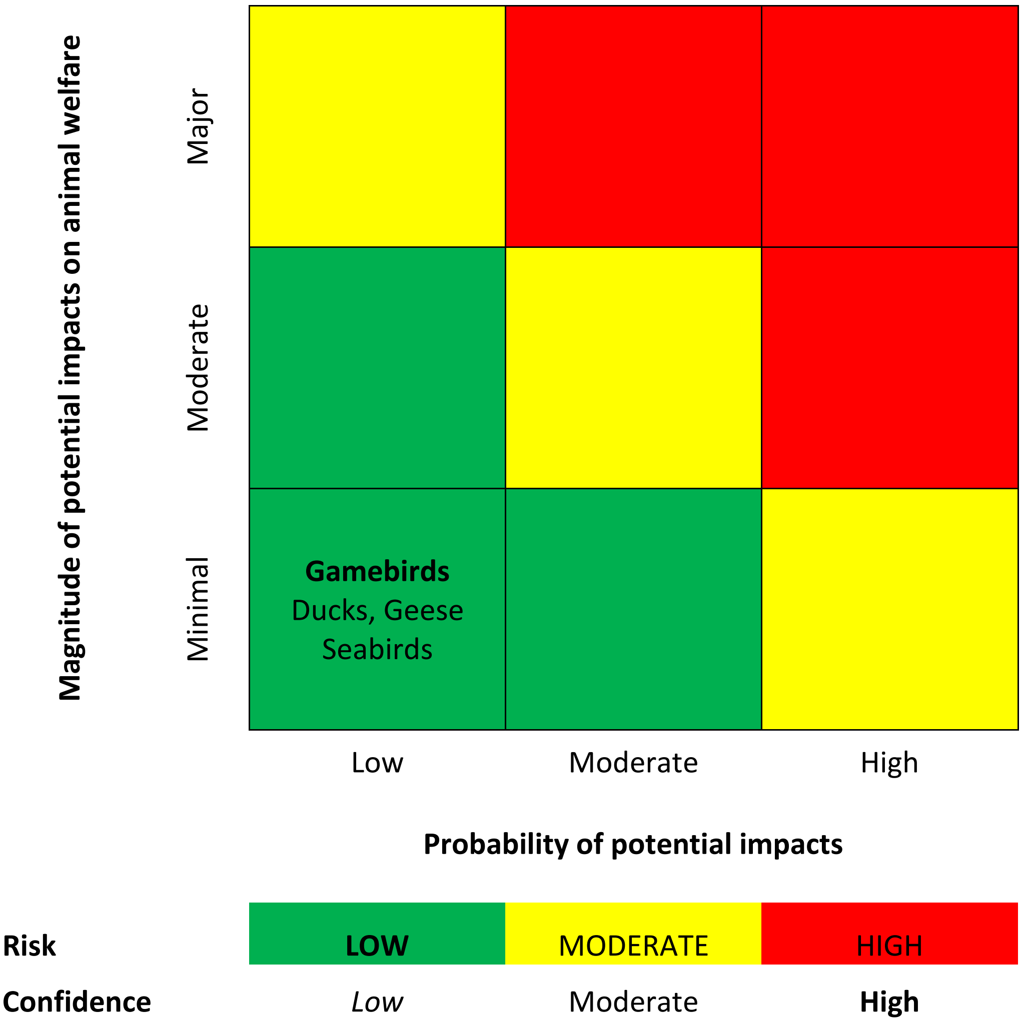

Figure 13. Risk assessment for use of noosing poles and hooks, dip nets, and cast nets to capture birds.

Risk-reducing measures. Most of the risks to animal welfare can be managed by training with and learning from experienced researchers. Especially, it is important to decide the thickness and strength of the outer part of the noose pole to balance flexibility and strength and avoid breaking the pole. This is further aided by regulating the force on the pole by the hands. Hand skills is required by all these methods. Use of relatively short nooses with heavy line and thick stopknots helps to minimize the risk of strangulation. Noosing should be avoided near sites with branches, wires or other features that risk entanglement. Careful consideration must be done to avoid damage to eggs and nest desertion, and in some species, it may be necessary to consider avoiding catching on nest during incubation. For example, Common and Brünnich's Guillemots breed on narrow cliff ledges and incubate the egg on the web. Experienced researchers capture these species during the nesting period but choose nest sites where the probability is low for the egg to fall off the ledge and carefully noose the bird. Otherwise, they target the non-incubating partner. Risk to predation on eggs or chicks in the nest while catching on nest can be reduced by assessing the predation risk imposed by other species and conspecifics. Risk-reducing safety measures can be implemented as necessary such as guarding the nest, replacing the eggs with dummy eggs, or avoiding capture at nest sites where risk is high and measures are not possible.

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Net guns

Description of method. Net guns are hand-held devices that fire a net which catch the target. They are designed to catch several types of animals. The net guns commonly used for birds use C02 cartridges to fire the net from reloadable net cones. The net is pulled out by rubber-padded weights that are shot as projectiles from the net gun. Nets are available in different mesh sizes suitable for small (>100 g, e.g., terns) to large birds (> 1 kg, e.g., large gulls). Typical horizontal range is 10 m, and effective firing distance is 3-7 m. However, sizes and ranges differ among models of net guns. The most powerful net guns use gunpowder cartridges but are generally designed for captures of larger animals and not birds.

A successful shot is characterized by the net spreading fully out and the bird hitting the middle of the net at a safe distance from the weights. Net guns are useful for catching birds that are difficult to trap with other methods and have been used on a wide range of birds (e.g., ptarmigan, skuas, gulls, albatrosses, shearwaters, ducks, eagles, shorebirds, egrets, ibises). Net guns can be used to catch birds on the ground, on water and flying in the air. However, the method comes with some risk of injury or mortality if any of the projectile weights strike the bird. It is easier to have a successful shot when the bird is not moving and is sitting on the ground or on water. Accordingly, the method has highest risk of impact when applied to flying birds.

Net launchers are similar to net guns but are larger, more powerful and fixed on ground or platform instead of being hand-held. The traps are fired from long distance remotely or via direct wiring, to catch small flocks. Net launchers are powered by blank cartridges and shoot substantial steel weights and have higher risk for negative effects when fired at flying birds or over large flocks. Deployment of net launchers is also sensitive to wind conditions.

Impacts on animal welfare. When applied to non-moving birds on the ground or water, the **risk** of negative impacts on animal welfare is assessed as **Low**, with HIGH confidence (**Figure 14**). When applied on fast flying birds the **risk** of negative impacts on animal welfare is assessed as **Moderate**, with HIGH confidence (**Figure 14**). VKM 2013 did not include a risk assessment for use of net guns for capture of wild birds. Capture of birds with net guns has negligible effects on nutrition (1a-c) or the physical environment (2a-c) because birds can be removed from the net and processed immediately after capture. Captured birds will have elevated stress and decreased comfort during the handling period (1d, 3a). Any entanglement in the net will be resolved immediately (2d). There is moderate risk of injury and mortality when using a net gun on fast flying birds (3b). The assessment is due to risk from being hit by the weights, and risk for the net to fully collapse/compress both wings so that the bird will crash to the ground (3b). The risk for injury is low when applied to non-moving birds (3b). The risk of predation is minimal (4g), since the researcher is usually close and can remove the bird immediately.

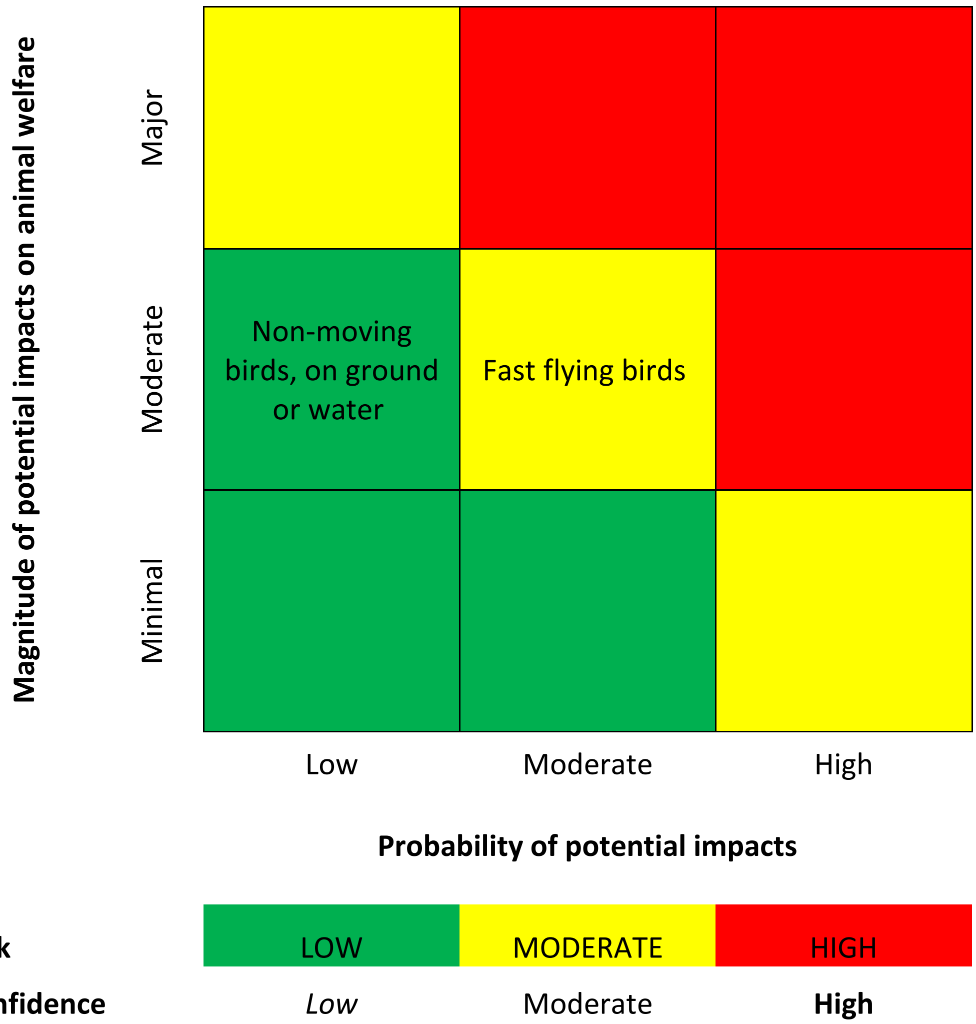

Figure 14. Risk assessment for use of net guns to capture birds.

Risk-reducing measures. Using net guns require extensive training and experience to acquire appropriate skills to reduce risk. The researcher needs to be well acquainted with the spread, speed and range of the net, as well as the movements of the bird, to select the appropriate firing distance and timing. The projectile weights usually have high energy at a close distance. They rapidly lose energy with distance as they pull the net, but it is more difficult to catch the bird in the middle of the net and at a safe distance from the weights, at longer distances. Successful shots highly depend on careful packing of previously used nets, so that they fully spread out when fired. Packing of nets must be practised. Used nets must also be carefully inspected, and the cords attaching the weights to the net should be replaced regularly to reduce risk. If such a cord breaks, the weight will not be anchored to the net, and it will be fired 'almost like a bullet'. Successful shots also depend on assessing wind conditions. The nets are affected by wind, and using the net gun in conditions with no or low wind will reduce the risk. Furthermore, wind affects the speed and the movements of flying birds. It is best to avoid using the net gun on flying birds in moderate or strong wind. For example, swooping birds can rapidly gain height in a head wind. If the bird is shot at high altitude and both wings collapse, the impact will be strong when hitting the ground, especially if the surface is rocky. Choosing appropriate topography and surface of the landing zone will also reduce risk. A net gun should not be fired on top of a cliff where the bird has a risk to fall outside a safe retrieval area. Water provides a soft-landing surface, but the net gun should not be fired where the bird is at risk of landing on water, unless the team has a boat ready to quickly retrieve an entangled bird.

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Cannon and rocket nets

Description of method. Cannon and rocket nets use explosives to fire projectiles that are attached to the leading edge of a large net and pull it over a predetermined trapping area. Cannon nets use black powder charges to fire a projectile from a smooth bore cannon whereas rocket projectiles require specialized propellants which are less widely available. Both methods can be highly effective for capturing large flocks of birds such as waterfowl in agricultural field, lekking grouse at a courtship arena, waders at a high tide roost, and songbirds attracted to baits. In Norway, cannon nets have been used to capture Red Knots (*Calidris canutus*, Wilson et al. 2007) and Taiga Bean Geese (*Anser fabalis*, Kroglund and Østnes 2015). Elsewhere, cannon nets are routinely used by ringing groups such as the Wash Wader Research Group in the UK and the Australasian Wader Studies Group. Cannon nets can facilitate large captures with such as average of 57-138 birds per firing for dabbling ducks, turnstones and ravens (Thompson and Delong 1967, Cox et al. 1997, Camp et al. 2013). On the other hand, use of explosives requires additional licensing and stringent procedures for safe storage, transport and deployment of black powder or propellants. Safety procedures are also needed for field personnel such as not standing in front of loaded cannons, clearing the area during circuit testing, and procedures for handling possible misfires. In a typical set, cannon nets are deployed by anchoring the back of the net with jump ropes, stretching out and then furling the net so it will sail out smoothly, installing cannons so that the bases are secured against recoil and the projectiles will carry the net out at a low angle, loading the projectiles and connecting them to the net with ropes, and then laying out and connecting a firing cable to multiple parallel cannons. A loose 'jiggler' line can be used to bump birds out of the danger zone in front of the leading edge of the net. The net can be covered with light-weight materials for additional camouflage, and the trapping area can have decoys to attract birds into a roost. The set is monitored by observers in a nearby blind and the nets are fired from an electronic firing box when conditions are judged to be safe. Firing the net over a large flock requires a coordinated field team with adequate training to ensure rapid extraction of captured birds. If the net is fired over water, the net requires rapid furling to move it back to dry land with care taken not to step on any captured birds. If fired over land, the net can be quickly covered with a burlap tarp to calm birds and reduce heat stress until they are extracted. Successful capture of large numbers of birds requires holding cages with separate compartments to temporarily house birds until they can be ringed and processed. Cannon and rocket nets require a large amount of equipment that takes considerable time to set up and retrieve. The nets cannot be reset until the equipment is cleaned and the explosive charges have been replaced.

Impacts on animal welfare. For waterfowl, grouse, and waders, the **risk** of negative impacts on animal welfare is assessed as **Low** for experienced cannon netters, with High confidence (Figure 15). However, the probability of potential impacts is likely to be **Major** if cannon or rocket nets are used improperly. VKM 2013 did not include a risk assessment for use of cannon net and rocket nets for capture of wild birds. Simultaneous capture of large numbers of birds has greater associated risks for restricted nutrition and increased energy expenditure (1a-d), and risks from confinement, thermal extremes and entanglement (2a-d). If the angle of the projectiles and the leading edge of the net are set too low, flushing birds risk exposure to fatal wing injuries or decapitation (3b). Thompson and DeLong (1967) reported mortality rates of 0.2-2.1% per year during 17,517 captures of turnstones, with most of the mortality caused by two bad firings when the angle of firing was misjudged which caused the leading edge of the net to hit the birds. Cox and Afton (1994) had a mortality rate of 0.09% (12 of 1116) due to occasional drownings when multiple nets were fired to capture waterfowl in shallow water. On the other hand, risk of injury can be low if cannon nets are set correctly. No injuries or fatalities were reported from use of cannon nets in 831 captures of waterfowl (O'Brien et al. 2016) and captures of 283 ravens (Camp et al. 2013). Temporary holding of large numbers of birds can affect their behavioral interactions with the environment (4a-c) and within the species (4d-f). Trap sets with projectiles must be monitored closely so that predation risk and competition should be low (4g-h), and handling effects can be minimized with standardized procedures for rapid processing (4i).

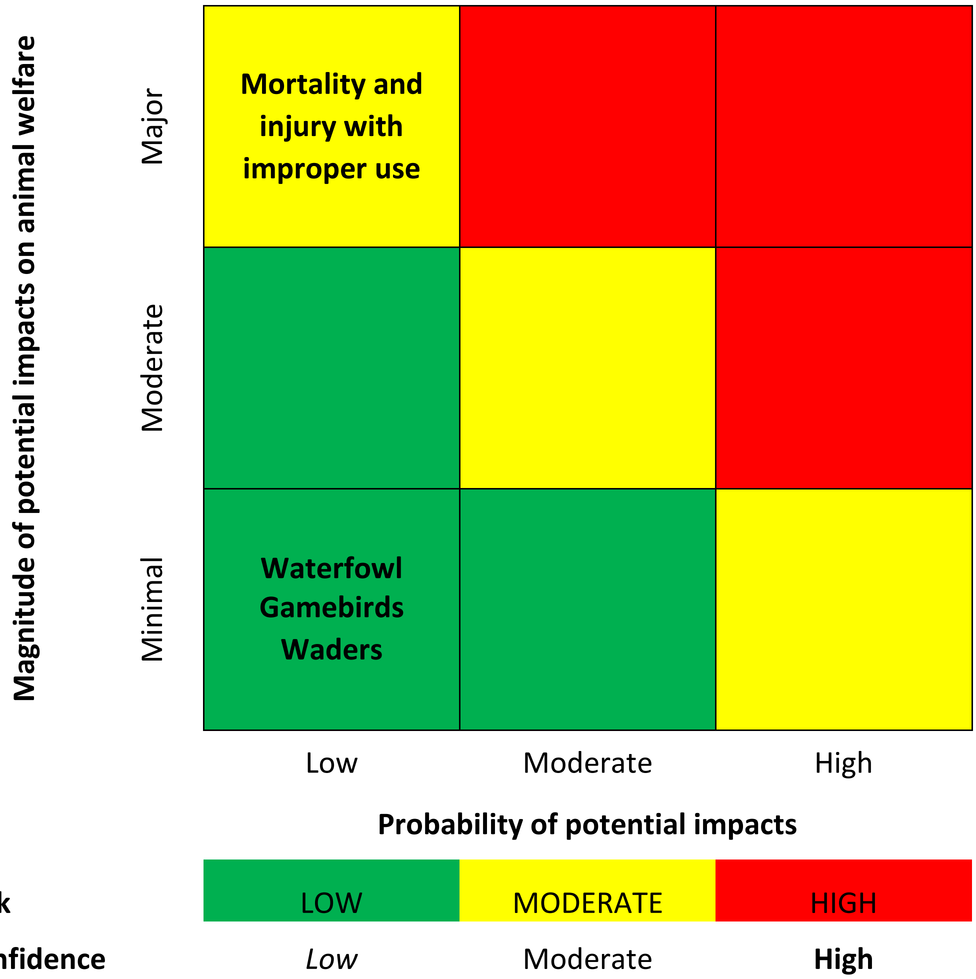

Figure 15. Risk assessment for use of cannon and rocket nets to capture birds.

Risk-reducing measures. The main risk-reducing measure for safe use and deployment of cannon and rocket nets is extensive training, practical experience with sets under a range of different conditions under supervision of experienced trappers, and periodic recertification as needed for licensing. Use of set procedures and checklists to follow can reduce the risk of injury to both birds and field personnel. Effective leadership, experienced team members with clear responsibilities, and orientation and debriefing sessions are vital to ensure field safety. Errors with use of explosive materials can be severe because the projectiles will travel a long distance if they are not properly anchored to the net, if the net is fired prematurely, if the wiring or charges are faulty and the cannons are not fired simultaneously, or if the cannons are loaded with an incorrect amount or the wrong type of powder. Field procedures to ensure that the trap set will be safe for capture of birds include carefully securing the net and projectiles, furling the net so it sails out cleanly, mounting the cannons or rockets so they will carry the net over the bird flock at a safe angle, using markers to flag the danger zone in front of the net and the full extent of the net after it will be fired, deploying decoys that will attract birds to a safe capture zone, double-checking that all danger zone are clear before firing the net, and avoiding firing the net over unusually large flocks or over water unless adequate personnel are present to clear the net.

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9 Handling and sampling

In the assessments of methods for handling and sampling, we have used the observable and welfare alerting indicators belonging to domains 1:nutrition, 2:physical environment, 3:health, and 4:behavioral interactions in Table 2 and Figure 2 as a checklist. Based on these observable and welfare alerting indicators in domains 1 to 4, domain 5: mental state can be inferred.

The short and long-term effects of handling remain an area of ongoing research for animal welfare but it is especially difficult to deduce the mental state of wild birds during capture and handling events. If handling is perceived as a predation event, proximity to humans can be an intense experience for an individual bird with an immediate but transient exposure. Some species of birds appear stressed during handling whereas others remain calm and docile and immediately return to normal activities after release. Behavioural responses to interactions with humans can lead to increased wariness among crows and ravens that learn to recognize individual humans and seek to avoid recapture after a handling event (Blum et al., 2020; Cornell et al., 2011), but also habituation among jays and other seed-eating birds that learn to accept food from the hand. Long-lived species of birds can be more sensitive to disturbance from research activities because they have life strategies that prioritize adult survival and future reproduction over the reproductive value of any current nesting attempt. Abandonment of eggs or young have been reported as a negative consequence of capture and handling of seabirds during early stages of the nesting cycle. Physical responses to capture and handling are better known and can include capture myopathy or trauma in extreme cases. Physiological stress responses have also been widely studied, and a suite of standardized assays have been developed to investigate stress induced by capture and handling (Gormally & Romero, 2020). For example, the capture-restraint protocol has been used to estimate acute stress responses from baseline to maximum levels of corticosterone, a key stress hormone in birds (Angelier et al., 2007; Pakkala et al., 2013). Different groups of birds are known to have heterogeneous responses to research activities, but the experience of physical handling could be negative for wild birds. See additional comments on the immediate impacts of capture in Chapter 8.

Handling and capture myopathy

Description of method, and best practice to minimize negative impacts. In this context, handling is not only defined as the manual handling done by humans during capture, marking and release of the birds, but also the procedures where the bird experiences unusual physical proximity to humans without being touched. In addition, and for practical purposes, *capture myopathy* is described in this section though this condition is not strictly associated with handling but can occur in any situation where birds are physically exerted and/or stressed (in the sense that a fight or flight response is activated). Being in close proximity to humans and being touched and lifted by humans must be a threatening and fear-inducing experience for any bird. This acute strain should in itself be regarded as a harm to animal welfare, although transient, and does most probably evoke emotions like fear, anxiety and/or panic (see general comments on animal welfare during capture and handling in Chapter 8). Nevertheless, handling effects vary widely among species, and some birds appear calm during handling and return quickly to natural behaviours immediately after release. To minimize these experiences, anybody handling birds should be well trained to perform the marking and tagging procedures as quick and gentle as possibly, avoiding making sounds and visual impressions that can scare the bird more than unavoidable and use as little physical force and violent movements as possible. Care must be taken to have a calm body language, work quietly and efficiently, lifting arms above your head or moving your hands rapidly towards the bird. Training and knowledge exchange with people experienced with handling of the same or similar species is crucial, as they have experiences with which methods that function for holding the birds (bander's grip, reverse grip, photographer's grip etc.) and which devices that can be used to restrain or calm the bird (bird bags, holding boxes, falconry hood etc.). Field workers that handle birds should be aware of abnormal behaviour that can indicate fear, anxiety and high level of stress, for example struggling, biting, panting, gaping/open mouth breathing, blinking with eyes, eye pinning (pupil rapidly dilated and contracted), head-shaking, vocalization or freezing (i.e. lying still). Small-bodied birds have high heart rates to meet the demands of power flight, and a fast pulse is not necessarily a sign of stress for a bird in the hand. It may be valuable to have included species-specific humane endpoints where a sum of behavioural signs of fear and stress should result in release of particularly affected birds. Release of birds must be done away from the trap site by placing on the ground or a runway that allow escape in a safe direction.

The animal welfare of handling may be difficult to measure in an objective way, as there are so many qualitative aspects to consider and the response of a given individual may vary so greatly. Within a given context, however, *time* may be valuable and objective indicator and *level of invasiveness* a welfare-alerting indicator. Handling time should be minimized but without compromising bird safety, and it is important to avoid doing redundant measurements, photographing and sampling. Animal welfare is likely to be improved if birds spend less time in capture devices and transport, and if the sampling procedures are rapid but efficient. Having access to enough experienced and well-trained personnel is imperative to reach that goal.

Capture myopathy (also called exertional myopathy and rhabdomyolysis) is a condition that is well known in reptiles, birds and mammals and has been reported in both wild and domestic animals. Myopathy is characterized by necrosis (cell death) of striated muscle with subsequent leaking of myoglobin into the circulation, resulting in toxic effects on the kidneys. Typical clinical signs are decreased consciousness (lethargy), incoordination, stiffness/lameness, loss of flying ability, bent neck (torticollis) recumbence, increased body temperature, metabolic acidosis and myoglobinuria. Necropsy typically reveals muscle necrosis, dark kidneys and dark urine. The condition has been classified into four syndromes based on time frame and clinical signs: 1) Capture shock syndrome presenting as acute disease and multiorgan failure resulting in sudden death 1 to 6 hours after capture. 2) Acute or ataxic myoglobinuric syndrome occurring from hours to a few days after the capture and characterized by ataxia, torticollis and myoglobinuria. 3) Sub-acute or ruptured muscle syndrome occurring 1 to 2 days after capture and characterized by muscle ruptures and inability to move properly, resulting in death within a few weeks. 4) Chronic or delayed capture myopathy that occur in animals that previously have been through a capture or a similar experience as a sudden death due to fatal heart arrhythmia. Capture myopathy is thought to result from stress overload, most often a combination of psychological stress and exertion. Factors that may predispose birds to development include prolonged pursuit/exertion before capture, struggling, long handling time, vitamin E/selenium deficiency, high fat body content, other diseases and hyperthermia.

Capture myopathy has been observed in several large-bodied species of birds, among them Red-legged Partridge (*Alectoris rufa*), Wild Turkeys (*Meleagris gallopavo*), flamingos, several crane species (*Grus* spp.), bustards, Greater Rheas (*Rhea americana*), Bar-tailed Godwits (*Limosa lapponica*) and other long-legged waders. Waders have traditionally been regarded as particularly sensitive. However, with reference to the above-mentioned wide range of symptoms of capture myopathy, the condition should be considered among the potential causes of increased mortality, weight loss and/or decreased breeding success among captured and released birds - also in species that have not been previously reported to show the acute forms of the syndrome.

Impacts on animal welfare. For handling, the **risk** of negative impacts on animal welfare is assessed as **Moderate**, with Low confidence. It should, however, be emphasised that the impact of handling to a high degree is a result of the quality of the handling rather than an inevitable and consistent consequence of handling *per se*. VKM 2013 provided risk assessments for capture and marking methods but did not evaluate alternative methods for safe handling and sampling of wild birds.

Risk-reducing measures should be focussed on avoiding unnecessary stress (see above) and exertion. For example, in waders, increased incidence of capture myopathy was observed more frequently with wide-meshed cannon nets that allowed entanglement, than with light, fine-mesh nets. Careful monitoring of the captured birds, ideally with a pre-made humane endpoint scale, and interruption of the procedure if the animals show signs of exaggerated stress response, is advised. If possible, habituation is thought to desensitize birds against an exaggerated stress response, for example if the birds are allowed to walk in and out of a trap for a period of time before they actually are captured, or get used to the sight of humans. Avoiding capturing during the hottest periods of the day can possibly decrease the incidence. Active cooling with ice packing, cold baths, mist sprayers have been suggested as preventive measures, and even possible treatment of mild cases, but the effect has been disputed.

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Blood sampling

Description of method: Blood samples from wild birds are useful for various analyses in immunology, endocrinology, toxicology, genetics and for diagnostic purposes. Unlike mammals, the red blood cells of birds are nucleated so only small volumes of blood are needed to collect adequate DNA samples for population genetics. There are different techniques for collecting blood samples, for example venous access from the brachial, jugular or metatarsal veins. The brachial wing vein is routinely used to collect blood from small-bodied species of waders, owls, woodpeckers, and songbirds. On the other hand, the medial metatarsal vein is generally the preferred vein for waterbirds as it is more readily accessible in these species. The venipuncture site will vary depending on species, size and condition of the bird. Another important aspect to factor in the decision for a venipuncture site is how the bird will be restrained. Clipping a toenail will provide capillary blood and is considered to be more painful than venipuncture. Collecting blood by clipping a toenail can be safer for large-bodied birds where the wings are difficult to restrain and is the best option for newly hatched precocial young of gamebirds and waders where the wing has not yet developed. Studies involving blood samples need approval from the the Norwegian Food Safety Authority and the blood sampling procedure must be described in detail in the application. Note that cardiac puncture is only allowed under general anaesthesia and in a terminal procedure where the bird will be euthanized unless special exemptions are made by the Norwegian Food Safety Authority approving experiments (cf. the Norwegian Regulation concerning the use of animals for scientific purposes (forskrift om bruk av dyr i forsøk). Observers should ensure that bleeding has stopped before birds are released. Gentle and the correct amount of pressure with a cotton ball at the bleeding site may be necessary. Blood coagulants based on iron sulfate can be effective at stopping bleeding quickly if needed.

The amount of blood (and/or frequency of sampling) that is needed to answer the research question must be determined. There may be situations where prioritization of analyses must be done in relation to the amount of blood that can be withdrawn from smaller bird species. As a general principle, sample volumes and frequencies of blood samples should be kept to a minimum. Relevant information on the bird species in question from both the literature and from experienced personnel need to be gathered when planning to take blood samples. Knowing the species is key to success. A general rule of thumb is that one may take no more than 10% of the total amount of blood from a bird at any time. It is estimated that blood volume comprises 10% of body mass, but a new conservative method calculates blood volume based on lean body mass. A common rule to remember for field use is that a sample equal to 1% of the body mass can be removed at any one time, and no more than 2% of the body mass of the bird in a 14-day period. Note that these rules of thumb are based on the assumptions that sampling will take place on healthy birds in homeostasis. Blood loss may for example aggravate conditions like capture myopathy (see above). Competence in handling and restraint of the relevant species is fundamental for swift and successful blood sampling in relation to animal welfare.

Possible adverse effects of blood-sampling are hematomas, hypovolemic state, distress, disturbance of normal behaviour, pain, and any injury inflicted on the birds by sampling blood. Adverse effects may be minimized by using a technique appropriate for the purpose and species, practical skills in handling and blood sampling, and knowledge of species both on physiological parameters like blood volume but also on behaviour to facilitate planning of sampling procedures to minimize disturbance.

Best practice to minimize negative impacts: Important considerations when deciding blood-sampling technique are bird species, competence in specific technique, purpose of blood sampling, volume to be taken, health status of the animal, and the potential of stress-induced effects on the parameters in question. There is always the possibility of using chemical immobilization (sedatives or anaesthesia) when taking blood samples but they are rarely used under field conditions because of the necessary recovery time. One must evaluate whether the use of chemical immobilization in combination with the blood sampling is more traumatic to the birds than the blood sampling alone (Sedatives and anaesthetics may also influence circulation), and also the potential impact of drugs on the results of some analyses. Voss et al. also emphasize the need for considerations of environmental factors like temperature and humidity which may make it more difficult for birds to compensate the physiological effects of sampling. Physiological factors like metabolic rate, breeding status, nutrition status, moulting and so forth are also important factors that will influence the volume and timing of blood sampling.

Risk-reducing measures. Developing skills in any given blood sampling technique require a step-by-step approach involving literature search, videos and simulation tools for the technique (mock-up or cadaver if available) to become familiar with anatomy, restraining- and sampling technique, and then team up with experienced personnel to be properly trained. Training should be done by competent trainers so that the most refined and updated techniques are passed on. Focus should include an aseptic technique, and also details down to the size of the needle relative to size of the bird. Smaller diameter needles are often better for the bird, but need to consider the risk of hemolysis with smaller syringes. All supplies and equipment needed for the procedure should be easily accessible when out in the field, and only sterile needles should be used to collecte blood samples. Using a needle to quickly puncture the vein but then a microcapillary tube to collect to the pooling blood can reduce the risk of injury if a bird suddenly moves the wings or feet during handling. Blood flow is often better if the bird is held in a relaxed position by an experienced handler which can reduce handling times. Use of an approved sharps container to dispose of used needles and capillary tubes reduces risk of injury to both the birds and field workers. Blood samples should be stored in sealed tubes without risk of spillage or cross-contamination. For new sampling methods, pilot- and effect studies are warranted and recommended. Publishing both positive and negative results on methods can ensure reducing the total number of birds used in development of new methods and when implementing a known method on new species.

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Feather sampling

Description of method. Plucking feathers on live birds or collecting shed feathers are a valuable source for DNA. As feathers grow, they are supplied with blood containing nucleated red blood cells. Skin cells on the outer side the feather shaft can also supply DNA. Feathers are also a valuable sample for measuring stable isotopes which provide information about diet/trophic level of the bird during feather formation, and for measuring contaminants or physiological parameters (e.g. stress hormones) during the same period. Plucking feathers is assumed to have limited impact on birds, but little research has been done on this topic. The innervation around the area surrounding calamus of feathers implies an immediate impact. Long-term effects on flying performance, metabolic rate, ability to regulate temperature, season and individual status are also among factors to consider when plucking feathers.

Plucking a few feathers is by many regarded as an innocuous procedure, but the wall of feather follicles is innervated by an abundant supply of sensory nerve fibers. In addition, the papillae, pulp, and feather muscles are well innervated. The physiology indicates that feather plucking may be painful for birds, though little is known of the level of pain. Veterinarians working in avian medicine often anesthetize the skin area before they pluck feathers on their patients for analyses.

Best practice to minimize negative impacts. Plucking of feathers on live birds should be done in a firm and swift procedure. Plucking of feathers should be kept to a minimum, and when it is done; collection of contour feathers from the back or breast may have less impact than removal of flight or tail feathers that are well anchored. It is also best to avoid collection of growing feathers because they are well innervated and connected to the vascular system. One advantage with plucking feathers is that it is an easy method if there is competence in practical skills like handling and restraint. Little equipment is needed for the technique, and feathers can be stored in paper envelopes until further analysis.

Risk-reducing measures. As a general principle, number and size of feathers plucked should be kept to a minimum, because regenerating replacement feathers come with a metabolic cost. The metabolic costs should be considered to avoid periods with limited food resources. Also plucking of feathers and therefore number, site on the body and season of the year must be considered. It is important to avoid plucking the outer flight feathers because the shape of the wing tips can influence flight performance. Do not collect feathers from badges or ornaments associated with sexual selection.

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Cloacal and oral swabs for microbes and sperm

Description of method. The cloaca of birds is an exit cavity that captures waste products from the digestive and excretory systems and also the gametes produced by the reproductive systems. Waterfowl and gamebirds have intromittent organs and extrusion of the cloaca can be used for sexing of males and females. Similarly, male songbirds can have an enlarged cloacal protuberance which can used for sexing or assessments of breeding condition. Cloacal swabs or lavage are two simple procedures for nonlethal collection of biological samples from wild birds. During handling, the bird is held on its back with the feet and tail restrained so that the vent area under the tail is exposed. The cloaca can be exposed and viewed by gently blowing on the vent area to separate the feathers. For cloacal swabbing, a small narrow cotton swab is inserted gently into the cloaca and rotated slowly to collect materials and then transferred to storage media such as an Eppendorf tube with ethyl alcohol. Similarly, swabs from the oropharyngeal tract target products secreted from the respiratory system. A combination of cloacal and oral swabs are a standard method used in screening wild birds for possible shedding of avian viruses. Cloacal swabs are also used to collect samples of the gut microbial community in the lower sections of the digestive tract. In the case of cloacal lavage, a small plastic pipet tube is filled with 0.5-3.0 mL of distilled water, inserted gently into the cloaca, and then used to flush and collect the contents of the cloaca. The water suspension of cloacal contents is then transferred from the pipet to storage media such as a specimen tube or a clean microscope slide. Cloacal lavages have been useful for collecting sperm samples to determine reproductive state of birds at different stages of the annual cycle and to examine variation in sperm morphology among different species of birds. Cloacal lavages can also be used to collect samples of endoparasites when they are shed by the host, such as gulls infected with *Cryptosporidium*, a parasitic group of protists.

Impacts on animal welfare. For waterfowl, waders and songbirds, the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence (**Figure 16**). VKM 2013 provided risk assessments for capture and marking methods but did not evaluate alternative methods for safe handling and sampling of wild birds. Cloacal sampling and oropharyngeal swabs are noninvasive procedures that can be used to collect biological samples from wild birds. Collection of waste products from the cloaca has no negative impacts on water or food intake (1a-b). Sampling of live birds requires capture and handling which can increase energy expenditure (1d) and induce stress (2a). Collection of samples may cause momentary discomfort (3a) but a negligible risk of injury or exposure to disease (3b-c). Munster et al. (2007) sampled over 36,000 birds in a global surveillance project with no reports of injury. Cloacal sampling does not affect the behavior of wild birds (4a-i) and individual birds can be sampled repeatedly without adverse effects.

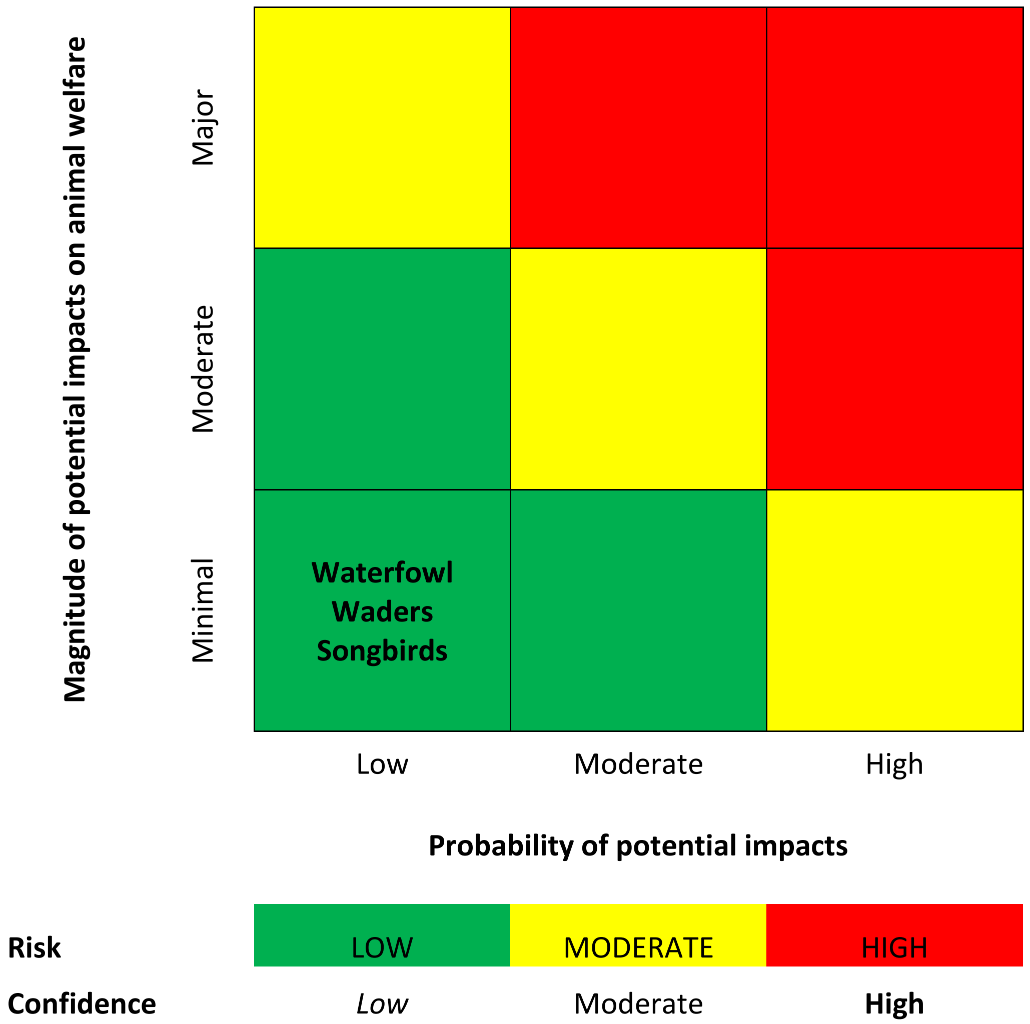

Figure 16. Risk assessment for cloacal samples and oropharyngeal swabs for microbes and sperm from wild birds.

Risk-reducing measures. Collection of samples should follow sterile procedures to avoid cross-contamination. Bird handlers should wear protective gloves, use sterile swabs or disposable pipets with distilled water, and transfer the samples into sterile containers. Samples from the cloaca can usually be collected quickly to minimize handling time. However, care should be taken when inserting probes into the cloaca to avoid any risk of injury to the bird. Field workers should receive training from personnel experienced with the two techniques, which can help reduce handling times and minimize the risk of adverse impacts.

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Sedatives and anaesthesia

Description of methods. Special considerations apply to use of anaesthesia when working with wild birds in the field that are to be released immediately upon recovery. The most important one being that any anesthesia and procedure must put the recovered bird in a position where it is fully recovered to survive in its normal environment. The potential benefit of using of anesthesia or sedatives in minor procedures on wild birds in research is usually outweighed by the high costs of stress during induction and recovery, and the prolongation of the procedure. A general anesthetic is an agent that produces immobilization and loss of consciousness so that the individual is unresponsive to stimulation. Most procedures used in studies of ecology are minor procedures where distress, discomfort and pain are expected to be of short duration, and therefore focus is more on competence in handling- and sampling-procedures to ensure birds are released quickly. If major procedures like surgical procedures are planned, then anesthesia together with postoperative analgesia must be addressed. There are different forms of anaesthesia that may be relevant; local or regional anesthesia and general anesthesia administered as a gas or an injection. Local or regional anesthesia may for example be in a cream to lubricate skin or injected to anesthetize the area in question. The drawback is that one must wait for the effect, and extreme care must be taken when calculating the dose. When it comes to general anesthesia, inhalation anesthesia is preferable because of the quick induction and recovery associated with the unique respiratory systems of birds. If isoflurane or sevoflurane is used, anesthesia can be induced in the majority of birds (but not in some diving birds) with minimum stress using a face mask applied directly over the beak and nares. Care must be taken to avoid panic reactions during the induction phase, so physical restraint or even injection of a sedative might be needed for a smooth induction phase. If chemical sedation is needed, one must consider the duration of the sedative effect, and whether there is an available antidot to reverse the sedative. The challenge is that gas anesthesia is more demanding when it comes to equipment. If injectable agents are used, one must have an accurate bodyweight to calculate a precise dose to avoid overdosing, and recovery from anesthesia is slower. During general anesthesia, endotracheal intubation is recommended to be in control of the situation.

Sedatives and/or anaesthesia will be considered for animal welfare reasons in projects involving capture, handling and marking of wild birds. The main goal of using sedatives and/or anaesthesia is then to chemical immobilize the birds for procedures to be done without inflicting pain or fear. Historically sedative drugs have mostly been administered by intramuscular injections, but in avian medicine intranasal administration has become an attractive alternative. It is an attractive method also in the field by its ease of administration and rapid onset of action. The challenge is to find the sedative for the specific bird species and an antidote that can be given by intranasal administration for rapid onset of dose-dependent sedation that is completely reversed. There is always some handling or restraint involved in the administration of drugs, even with the attractive intranasal route. Therefore a cost-benefit analysis of using sedatives or anaesthesia in procedures on wild birds should be done in each project. When deciding on the appropriateness of using sedatives or anaesthesia consider whether the use is more traumatic to birds than the procedure itself.

A form of anesthesia is used when surgical procedures are done, whereas sedatives are given to calm/tranquilize the bird for easier handling/restraint and/or to reduce fright.

Adverse effects of sedatives and anesthesia; The drugs may impact the body's ability to regulate the body temperature, to regulate respiration and circulation, and inhibit reflexes like for example the reflex to blink when cornea is dry. Transient effects may be managed with proper monitoring and support. Short-term effects can include an unpleasant recovery, muscle pain (due to compression during anesthesia), and confusion. Animal welfare considerations for general anesthesia/sedation alone: may have transient negative impacts on water or food intake and the ability to find the best quality food(1a-b-c). Decreased comfort and disease susceptibility are possible short-term effects (3a, 3c). Directly after anesthesia behavioral interactions may be affected, but waiting for the bird to fully recover will minimize this risk.

Best practices to minimize negative impacts. When using sedatives and/or anesthesia contact experienced and trained personnel, especially a veterinarian trained in avian medicine to write a protocol for the specific bird species. You might need drugs that are not easily accessible, and in volumes that you might need to dilute for the smaller species. New protocols must be tested in a pilot study before being used in a research project. When new practical skills (like injecting drugs subcutaneously/intramuscularly) are to be trained, start with mock-ups or cadavers before training on live birds.

Risk-reducing measures. Only healthy birds should be subjected to sedatives and/or anaesthesia. Out in the field this is done by visual inspection and rely on experience and knowledge of normal behaviour of the target species. In this aspect clinical considerations go hand in hand with most research projects involving capture, handling, and marking of birds that focus on birds with normal behaviour and no obvious sign of illness. Smooth and quick induction is key to successful sedation or anaesthesia, and this require both knowledge of physiologic and pharmacologic sensitivities of the avian species and pharmacologic characteristics of the drug(s). When sedatives and/or anaesthesia is used, monitoring is key to a successful outcome; basic vital signs, such as reflexes and respiration and temperature (hypothermia is one of the most common complications).

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10 Marking for individual identification

In the assessments of different methods for marking for individual identification, we have used the observable and welfare alerting indicators belonging to domains 1: nutrition, 2: physical environment, 3: health, and 4: behavioral interactions in **Table 2** as a checklist. Based on these observable and welfare alerting indicators in domains 1 to 4, domain 5: mental state can be inferred, using **Table 2**. We have filled in domain 5: mental state for the methods marked with (*) and uploaded the

Table 3 score sheet to demonstrate how the Five Domains Model can be used to make assumptions about the birds' affective experiences (mental state).

Temporary feather dyes

Description of method. Dyes applied to the plumage have been commonly used with wild birds, especially colonial waterbirds and waders. Reading information from leg bands on these birds can be challenging since their legs are frequently submerged underwater. Feather dyes serve as temporary markers, and marked feathers will be replaced by unmarked feathers during the first body molt. Waterproof, felt-tipped markers on feathers and nail varnish on nestling toenails are commonly employed for brief marking. Dyes that have been frequently utilized include picric acid, Rhodamine B, and malachite green, but the use of picric acid is now strongly discouraged, not only because it is toxic, but also because it is associated with an explosion hazard.

Impacts on animal welfare. For temporary – *non-toxic* – feather dyes, the **risk** of negative impacts on animal welfare is assessed as **Low**, with <u>Moderate</u> confidence (**Figure 17**). Our risk assessment is consistent with VKM 2013 (**Table 5**) which suggested that use of feather dyes with wild birds has a Low risk of negative impacts on animal welfare.

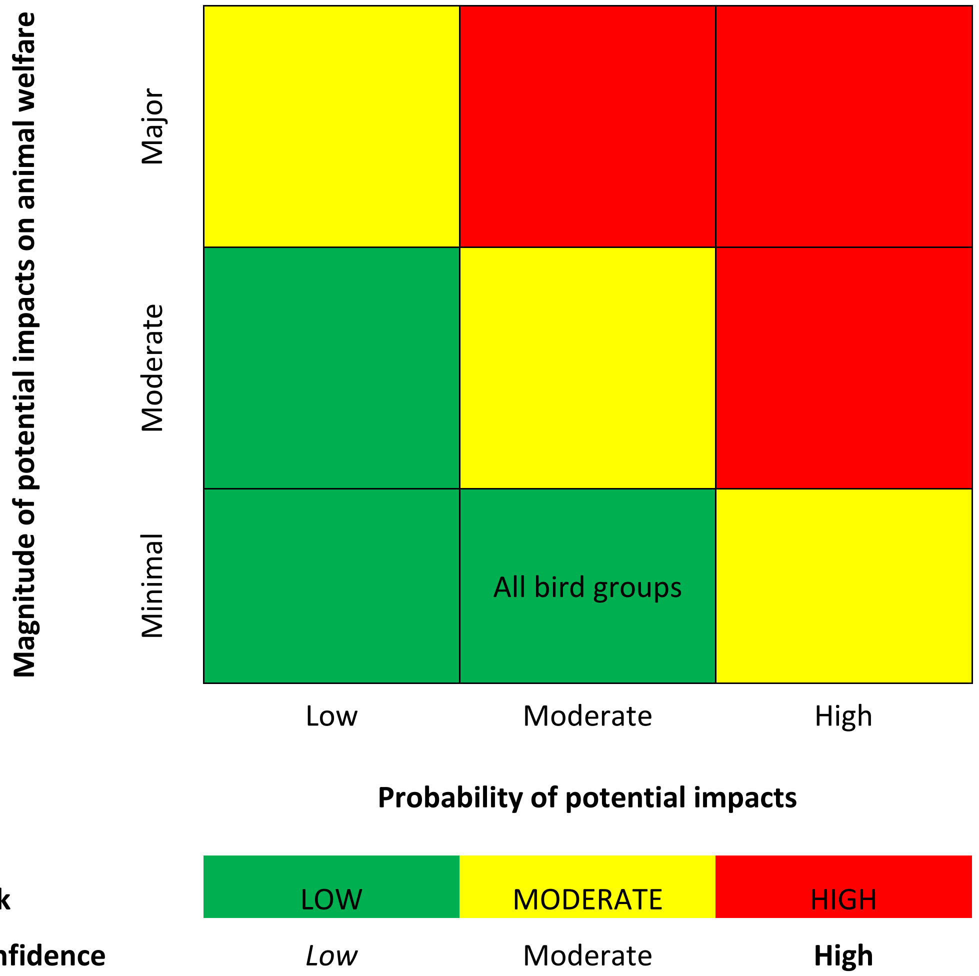

Figure 17. Risk assessment for use of temporary non-toxic feather dyes to mark birds.

The evidence base for the effect of marking birds with temporary feather dyes is relatively old with no reviews since 2000 and is not well synthesised. Calvo & Furness (1992) reviewed the effects of different types of marking techniques in 786 papers on birds in the journals Auk (between 1979 – 1989), Ibis (between 1975 – 1990), the Journal of Applied Ecology (between 1975 – 1989), the Journal of Wildlife Management (between 1975 – 1989) and Ornis Scandinavica (between 1977 – 1989). Of the 786 papers reviewed, 64 papers addressed the use of dyes in marking birds, and only 6 papers made a comment about the effect on the birds. There was no experimental tests of harmful effects of dyes on birds. Dyes may cause discomfort (D3a) (birds spend longer time preening dyed feathers, Dickson et al., 1982), can be toxic (D3b,c) and alter social behaviours (D4d) (e.g., Western Sandpipers *Calidris mauri*; Handel & Gill, 1983). Marked birds can face rejection or increased aggression from conspecifics (D4d) (e.g., Black-headed Gulls *Chroicocephalus ridibundus*; Neumann, 1982,1985), impacting reproductive success and nest abandonment rates (D4e,f). However, some studies show no significant effects on social interactions or nest desertion (e.g., Canada Geese *Branta canadensis*; Raveling, 1969), blackbirds and starlings (White et al., 1980) and Cliff Swallows (*Petrochelidon pyrrhonota*, Brown & Brown, 1988). The review of Calvo & Furness (1992) has a high risk of bias, due to a limited (only 5 journals) and biased search. The lack of experimental assessments of the effect of feather dyes in the 64 papers highlights a potential research gap as we cannot be sure that the effects observed by researchers are causal.

Risk-reducing measures. The most important risk-reducing measure is to avoid using irritating and toxic dyes, such as picric acid, which is irritating to the skin and eyes and toxic if swallowed, inhaled, or absorbed through the skin. Further risk-reducing measures: (i) Exercise caution when applying dye, especially if contour feathers are extensively colored. (ii) The alcohol or detergent base in the dye may remove oil from the bird's feathers, potentially causing heat loss when wet. (iii) Ensure dyed birds are completely dry before release. (iv) Use paint sparingly on feathers due to the potential impact on feather structure and function.

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Metal rings

Description of method. Marking individual birds with numbered metal rings is one of the most valuable field methods used for scientific investigations and conservation of wild birds. Metal rings provide fundamental information on bird movements, demographic rates, causes of mortality including harvest, social behaviour, and mating systems. In many of the evaluations of the tracking tags and attachment methods elsewhere in this VKM report, birds marked with rings only have been the control group for comparisons. In Norway, marking of birds with metal rings alone does not require an animal permit from the Norwegian Food Safety Authority and is a standard procedure used by both amateur ornithologists and research scientists. Ringing permits are issued by the Norwegian Environment Agency whereas rings and reporting are coordinated by the Bird Ringing Centre at the Stavanger Museum. Standard metal rings can be used with most birds with a few exceptions such as penguins which have a peculiar leg joint, and vultures and storks that defecate on their legs for cooling.

Metal rings are available in a range of diameters and recommended ring sizes are available for all bird species in Norway from the Bird Ringing Centre. Recommended ring sizes differ between the sexes in dimorphic species of grouse, raptors, waders and gulls. Customized rings are required for bird species with short or flattened tarsi, including some loons, gulls, alcids and owls. Aluminium rings are soft and easy to apply but can become worn from abrasion or saltwater corrosion. Steel rings are stiffer and can be difficult to close but are more durable and last longer, which is important for studies of long-lived birds. Rings can be easier to read or resight if placed below the leg joint on the tarsus but may have less wear if applied above the leg joint on the tibiotarsus. Rings are attached to bird legs with specialized ringing pliers to ensure the butt edges meet when the ring is closed and to reduce the risk of accidental overlap. Rings should be closed snugly and should be free to rotate and slide on the leg. Marking of juvenile birds is determined by their stage of growth and rings should not be applied until the leg bones have developed sufficiently. Rings can be used immediately at hatch for the precocial young of waders, a few days before fledging in nightjars, pigeons and songbirds, but at later stages of development in large-bodied species of waterfowl, gamebirds, divers and cranes. Metal rings are widely viewed as a safe and nonintrusive method for individual marking of wild birds. Leg injuries have been reported occasionally but a relatively rare event for most species of birds. The main disadvantage with the method is that bird must be physically recaptured alive or recovered dead to retrieve the unique number from the metal ring.

Impacts on animal welfare. For most species of birds, the **risk** of negative impacts on animal welfare is assessed as **Low** with <u>High</u> confidence (**Figure**). For a handful of bird groups such as penguins, storks and vultures that have unusual morphology, the risk of negative impacts on animal welfare is assessed as **High**, also with <u>High</u> confidence. Our risk assessment **confirms and upgrades** VKM 2013 (table 5) which suggested that use of 'leg rings' with wild birds has a Low risk of negative effect on animal welfare. Metal rings on the leg have no effect on nutrition of wild birds (1a-c) and are small enough to have no effect on energy expenditure (1d) or aerodynamics (2c). Problems with icing (2b) are rare but have been reported for at least two songbirds (Calvo and Furness 1992). The main risks of metal rings are a risk of entanglement with vegetation or debris in the environment (2d), decreased comfort due to abrasion (3a), and occasional injuries that can lead to loss of the foot or leg (3b). Use of metal rings is not known to affect behavior or trophic interactions (4a-h). Capture and marking with metal rings can lead to behavioral avoidance such that ringed birds have a lower probability of capture compared to unmarked individuals (4i).

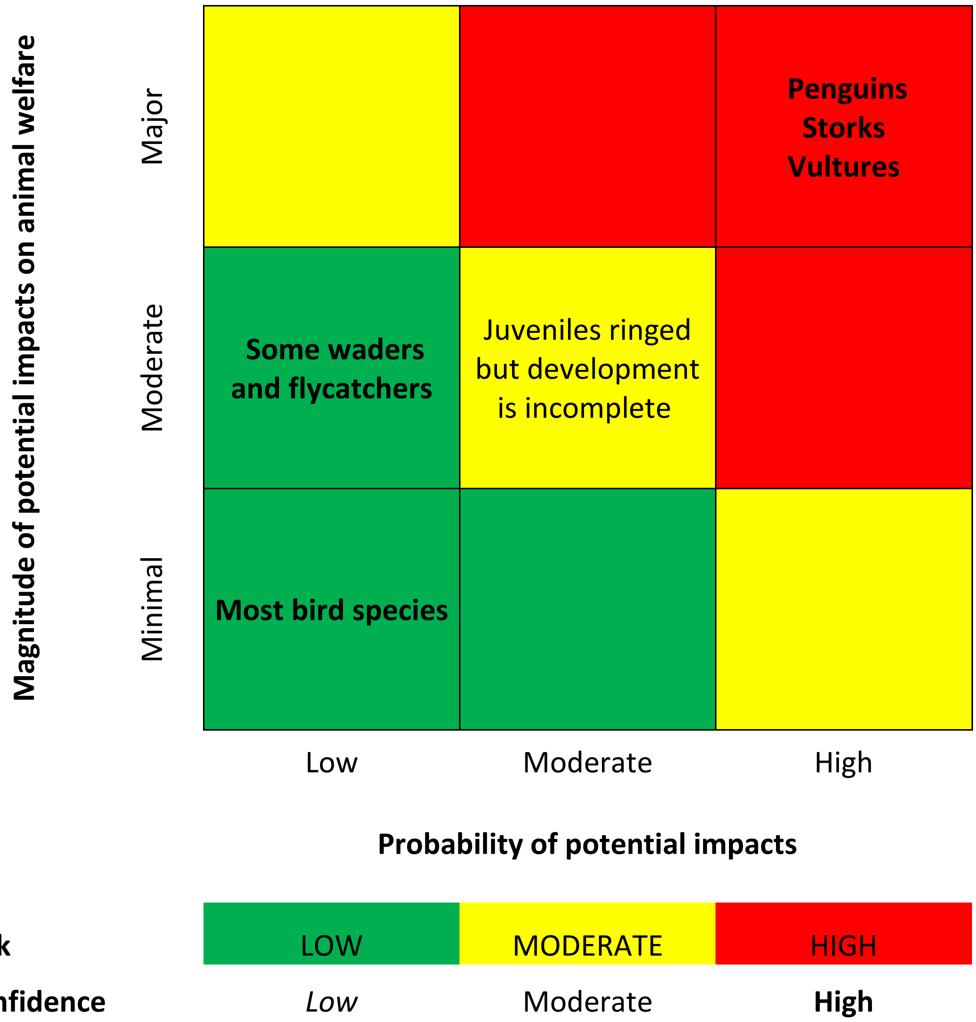

Figure 18. Risk assessment for use of metal rings to mark birds.

Risk-reducing measures. Marking of wild birds is a specialized field method but many negative effects are reduced by the requirements for licensing with obligatory coursework and practical training under the supervision of experienced bird ringers. Good resources for bird ringing include handbooks describing best practices and potential pitfalls (Runde 1991, NABC 2001). The main measure to reduce negative impacts is to ensure that the correct ring size is used on each bird species because loose rings can slide down over the leg joint or ankle leading to immobilization of the leg or foot. A list of ring sizes recommended for different species and demographic classes of birds in Norway is available from the Bird Ringing Centre. The ring size can also be confirmed by measuring the diameter of the leg with callipers or with use of a leg gauge with premeasured slots for different ring sizes. When attaching the ring, care should be taken to close the edges completely because leaving a slight gap can trap mud, vegetation and other foreign materials between the edges or behind the ring. If the edges of the ring overlap the rings should be removed and replaced before the bird is released. Specialized 'circlip' pliers with fine angled tips can be used to open and remove an aluminium ring but steel rings can be more difficult with risk of damage to the leg. Rates of injury are typically low but are occasionally high in some sensitive species, including Willow Flycatchers *Empidonax traillii* (0.6%, Sedgwick and Klus 1997), Ovenbirds *Seiurus aurocapilla* (1.2%, Haché et al. 2016), Snowy Plovers *Charadrius nivosus* (1.9%, Amat 1999) and Spotted Sandpipers *Actitis macularius* (2.6%, Reed and Oring 1993). Risk of injury can be reduced by placing the ring on a different section of the leg or by avoiding use of metal rings in combination with colour rings. Birds can survive and reproduce after loss of a foot but unnecessary injury from ringing remains an undesirable outcome for animal welfare. Similarly, ringing of juveniles should be delayed until birds are large enough to receive the same rings as adults. Plasticine-filled leg rings have been used to mark ducklings at the nest where the soft lining gradually wears away during growth of the young. A last possible concern for marking nestlings is that parent birds can be sensitive to changes in the nest environment and may remove ring-marked young if they are perceived as foreign objects. New metal rings can be prepared by boiling them with chicken eggshells to tarnish and discolour the metal to make the rings less conspicuous before use on wild birds.

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Colour rings and leg flags

Description of method. Marking birds with metal rings alone has the drawback that birds usually must be either recaptured alive or recovered dead to register the unique number on the ring. A key advantage of attaching colour markers to the legs is that resightings can be collected at a distance without physical capture or handling of the marked bird. Colour rings and leg flags are supplemental markers to the metal ring and allow birds to be marked in batches or with unique ring combinations to distinguish individuals. Challenges with colour markers under field conditions are that colours can fade with exposure to sunlight, be difficult to distinguish under poor light conditions and unique ring combinations can be disrupted by tag loss. Both leg rings and flags can be laser-engraved with large alphanumeric codes that are often easier to read and with fewer errors. If colour markers are used on migratory birds, the marking scheme often needs to be coordinated with other ringing groups working in the same flyway. Colour markers have been widely used on birds where the legs are visible, including waterfowl, gamebirds, cranes, waders and gulls, cormorants, herons, raptors and songbirds. Colour markers are rarely used with birds with short or feathered legs such as swifts, doves, or owls. Parrots and other birds with heavy beaks can remove plastic rings but retention rates can be better with anodized aluminium rings. Colour markers should have the same dimensions as the metal rings and are usually made of UV-stable plastics or anodized aluminium. Colour rings can be split rings like the metal rings or wrap-around rings that are coiled around the leg. Flags are usually split with a flange that protrudes from the leg, which can be easier for observers to notice at a distance. Split rings and flags are applied with a thin metal applicator spoon whereas wrap-around rings are coiled back on themselves. Plastic rings and flags can be sealed if needed with a drop of acetone or glue, or by melting the edges with a portable soldering iron. Anodized colour rings can be applied with standard ringing pliers. Like the metal ring, all colour rings or flags should have a loose fit and be able to rotate and slide on the bird's leg. Markers can be used on the same or a different leg than the metal ring but should not slip over each other if stacked.

Impacts on animal welfare. Use of colour rings and leg flags permits better quality information to be collected from a smaller sample of individuals without the need for physical capture, which leads to *reductions* in bird numbers and a *refinement* of less disturbance to wild populations (two 3R alternatives). For most birds, the **risk** of negative impacts of colour markers on animal welfare are assessed as **Low**, with <u>High</u> confidence (**Figure 19**). Our risk assessment for use of color rings is consistent with VKM 2013 (table 5) which also suggested that use of 'leg rings' has a Low risk for negative impacts on animal welfare. Negative impacts have been reported in a few case studies which we review below. Colour markers are small and light weight and are not expected to affect nutrition or energy expenditure (1a-d). Rings and flags can be applied rapidly and do not greatly extend handling time for wild birds (2a). Glues and soldering irons used to seal the markers can release heat but proper safety procedures can protect the bird during handling (2b). Colour markers can affect balance, entanglement, and lead to injury (2c-d, 3b) if they are loose enough to overlap with the metal ring (Sedgwick and Klus 1997) or lead to snagging (Broughton 2015). In rare cases, plastic rings lead to decreased comfort (3a) by causing inflammation to the leg surface or joints (Pierce et al. 2007, Griesser et al. 2012), possibly because the plastics have an abrasive surface (Splittberger and Clarke 2006). Colour markers can affect susceptibility to disease by creating abrasions on the legs or feet (3c). Use of wrap-around colour rings on Siberian Jays *Perisoreus infaustus* created problems when rings became entangled around the foot, possibly when birds attempted to remove the markers (Griesser et al. 2012), Tests of the effects of colour bands on behavior in the environment (4a-c) have found little evidence of changes in activity budgets or movements (Burton 2001, Weiss and Cristol 1999). Colour markers were found to affect mate choice of Zebra Finches in captivity but have limited effects on social or mating behavior (4d-e, Holder and Montgomerie 1993) and competitive interactions among wild birds (4g, Metz and Weatherhead 1991). Effects of color markers on reproduction (4f) include no effects on nest survival but possible reductions in egg viability if leg flags damage eggshells (Weiser et al. 2018) and a lower fledging success for male woodpeckers marked with red bands (Hagan and Reed 1988). In Pinyon Jays (*Gymnorhinus cyanocephalus*), parents pecked at nestlings marked with red or white colour bands, possibly because the materials resemble blood or fecal sacs (J. Marzluff, pers. comm.). Color-marking does not lead to a higher predation risk (4g) for either nestling or adult waders (Bart et al. 2001, Cresswell et al. 2007).

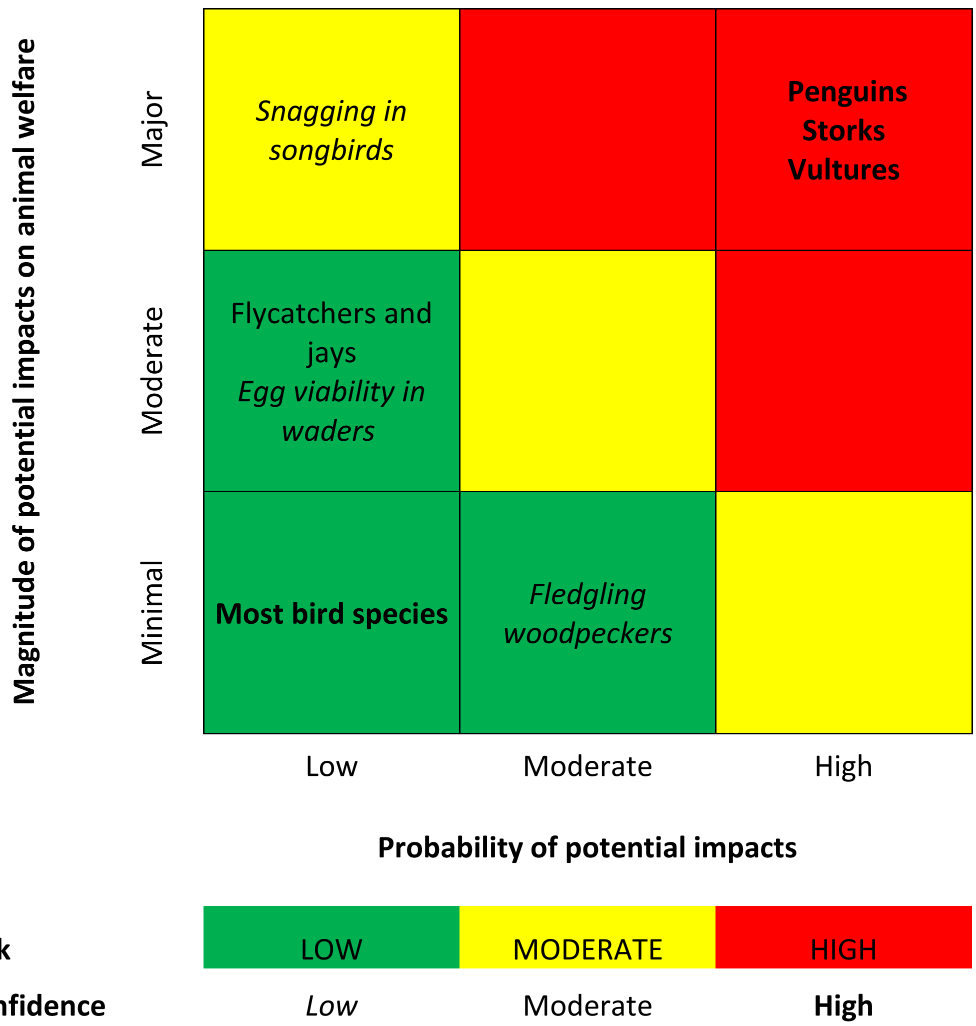

Figure 19. Risk assessment for use of colour rings and leg flags to mark birds.

Risk-reducing measures. Many of the risk-reducing measures identified for metal rings also apply to colour markers: selecting colour rings that are the right diameter for the study species, attaching and sealing the tags so that they cannot become loose, and recapturing birds to remove markers that cause leg injuries. The number and position of the colour markers should be reduced to the minimum number needed for batch or individual marking. Use of engraved tags means that only a single colour tag is needed in addition to the metal ring, and alphanumeric codes can reduce resighting errors (Roche et al. 2014). It may be possible to check recommendations from previous work for selected bird species (Griesser et al. 2012). Thus, bird ringers might avoid placing colour markers on the tibia if damage has been reported to the tarsus, or vice versa. If plastic rings are known to cause inflammation, use of anodized aluminium rings can be a good substitute. Flycatchers appear to be a group of birds with a higher rate of injuries from colour markers and new projects might test marking protocols with a small sample of birds before launching a large-scale ringing effort. Marking nestlings with colour rings might pose a risk of abandonment if parental birds are sensitive to foreign objects in the nest environment, but problems could be mitigated by use of neutral colours or by postponing ring-marking until after fledging.

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Patagial wing and web tags

Description of method. Metal and colour leg rings cannot be used in several situations. Leg rings cannot be used with hatchlings before development has been completed and should not be used with vultures and storks that defecate on their legs for cooling or penguins and other diving birds that use wing-propulsion to swim underwater. Leg rings can also be difficult to read for waterbirds that are often sitting on the water or raptors where the legs may be feathered or otherwise difficult to observe while birds are roosting. Patagial wing and web tags provide an alternative method of marking hatchlings and adults with individual markers. Hatchling waterfowl and grouse can be marked with small, numbered metal tags that are ordinarily used for marking fish or small mammals. Monel tags are a nickel alloy that is resistant to corrosion. Hatchlings are captured by hand and tagged as a brood before they leave the nests. The metal tag is clipped to the foot web in ducks and geese, or to the leading edge of the wing in grouse. Precocial young can shed tags without lasting damage and double-tagging can be used to estimate rates of tag loss. Hatchlings marked with metal tags must be recaptured as adults to retrieve the tag number. Patagial wing tags are also used as individual markers for adult birds. Wing tags are typically a coloured plastic flap with unique alphanumeric codes for individual identification. Ear tags for marking livestock have been used with large-bodied birds such as swans, vultures, and storks. The tags are mounted with metal clips or rivets in the patagium, a triangular membrane bounded by the propatagial tendon in the leading edge of the wing and the angle formed by the humerus and radius bones of the wing. The tags then sit on the leading edge of the wing and usually remain visible even if a bird is sitting on the water or perched at a roost site.

Impacts on animal welfare. For hatchlings of waterfowl and gamebirds, the **risk** of negative impacts on animal welfare is assessed as **Low**, with <u>High</u> confidence (**Figure 21**). For most groups of birds, the **risk** of negative impacts on animal welfare is assessed as **Moderate to High**, with <u>Moderate to High</u> confidence (**Figure 21**). VKM 2013 (table 5) suggested that use of 'wing feather tags' had a Low risk for negative impacts on animal welfare. We have **upgraded the risk assessment** because emerging evidence has shown that patagial wing tags can have negative effects in selected species of wild birds. VKM 2013 did not evaluate use of Monel tags for marking the precocial young of gamebirds or waterfowl. Calvo and Furness (1992) reviewed the effects of markers on wild birds and reported that patagial wing tags did not appear to affect food acquisition or energy expenditures in a range of bird species (1a-d). Wing tags can usually be applied quickly without extending handling time (2a) and do not appear to increase risk of icing or exposure to different thermal regimes (2b). Patagial tags can affect aerodynamics (2c) and have a dramatic effect on the flight performance of vultures (Curk et al. 2021). Patagial tags have also caused mortalities due to entanglement (2d). Patagial tags can cause decreased comfort (3a) and ducks with wing tags have been reported to spend more time preening (Brua 1998). Minor injuries (3b) can include wing callouses, increased feather wear, or failure to molt feathers around the site of tag attachment (Green et al. 2004). Wing tags are not known to affect risk of disease (3c). Patagial tags are not recommended for waders because at least two field studies have reported lower survival among tagged birds (Gratto-Trevor 2004), which could be due to multiple causes but most likely due to reduced performance during migratory movements (4a). Some birds can tolerate wing tags and tagging had no effects on breeding success of kestrels (Smallwood and Natale 1998). Wing tags can also affect social behavior, pairing success or reproductive success (4c-f) with all three effects reported in some gull populations (Kinkel 1989). Waterfowl with patagial wing tags can have difficulty gathering resources for egg formation sometimes failing to nest (Bustnes and Erikstad 1990, Brua 1998). Plastic tags are conspicuous objects that reduce flight efficiency which may increase predation risk or competitive interactions (4h-i). Higher predation rates on birds with wing tags have been reported for parrots and raptors (Saunders 1988, Zuberogoitia et al. 2012). Territorial eagles were more likely to be displaced from breeding territories after being marked with wing tags. Marking corvids and raptors with wing tags may make the birds more conspicuous and vulnerable to persecution in areas with human-wildlife conflicts. Patagial tags are unlikely to affect behavioral responses to handling (4i). Last, several studies that reported negative impacts also found that birds returned to normal behavior after they were recaptured and the wing tags were removed (Kinkel 1989, Curk et al. 2012).

Meta-analysis of effects on animal welfare. Our literature review recovered one meta-analysis which assessed the effects of patagial wing tags on wild birds. Trefry et al. (2013) summarized 51 measures from their own work and an unpublished study of frigatebirds plus data from 19 published studies reviewed by Calvo and Furness (1992). All measures compared experimental and control groups of birds. A total of 17 measures were counts of success and failure for territory establishment, hatching success, nest success or survival, and success in establishing a breeding territory. An additional 34 measures were reported as means ± SD (*n*) for body condition, number of chicks or fledglings, hatch date, and behaviour or migratory variables. Counts were assessed with log-odds ratios (LOR) whereas continuous variables were assessed with standardised mean differences (SMD). Trefry et al. (2013) used random-effect models and reported that patagial wing markers had a significant and negative effect on wild birds where the response variables were counts (LOR = -1.28, 95%CI = -1.76 to -0.79) but not continuous variables (SMD = 0.07, 95%CI = -0.19 to +0.34). Funnel plots showed that the estimates were heterogenous but without any evidence of publication bias.

Trefry et al. (2013) did not account for lack of independence among different measures reported for birds from the same article. The measures could easily be related since they were often derived from the same set of individual birds for each population and location. We extracted the data from Trefry et al. (2013) and re-ran the analysis with a random-effects meta-analysis that included a random factor for the source article that each measure was taken from. Our reanalysis showed that patagial wing markers had an even stronger negative effect on wild birds where the response variables were counts (LOR = -1.44, 95%CI = -2.00 to -0.89). Birds tagged with a wing marker were 24% more likely to fail compared to an unmarked bird in the control group. We found considerable heterogeneity among the measures (Q_{16} = 50.9, $P <$ 0.0001) with the large prediction intervals (**Figure 20**). On the other hand, our reanalysis also found no significant effect on continuous variables (SMD = 0.08, 95%CI = -0.39 to +0.23), confirming the previous findings of Trefry et al. (2013). The second evidence base was also characterized by a great deal of heterogeneity (Q_{33} = 246.9, P < 0.0001) and wide prediction intervals. The estimates should be interpreted with caution because the studies have a risk of selection bias. Trefry et al. (2013) evaluated references cited by Calvo and Furness (1992) and searched one database (WoS), and we have not extended their dataset with a systematic search.

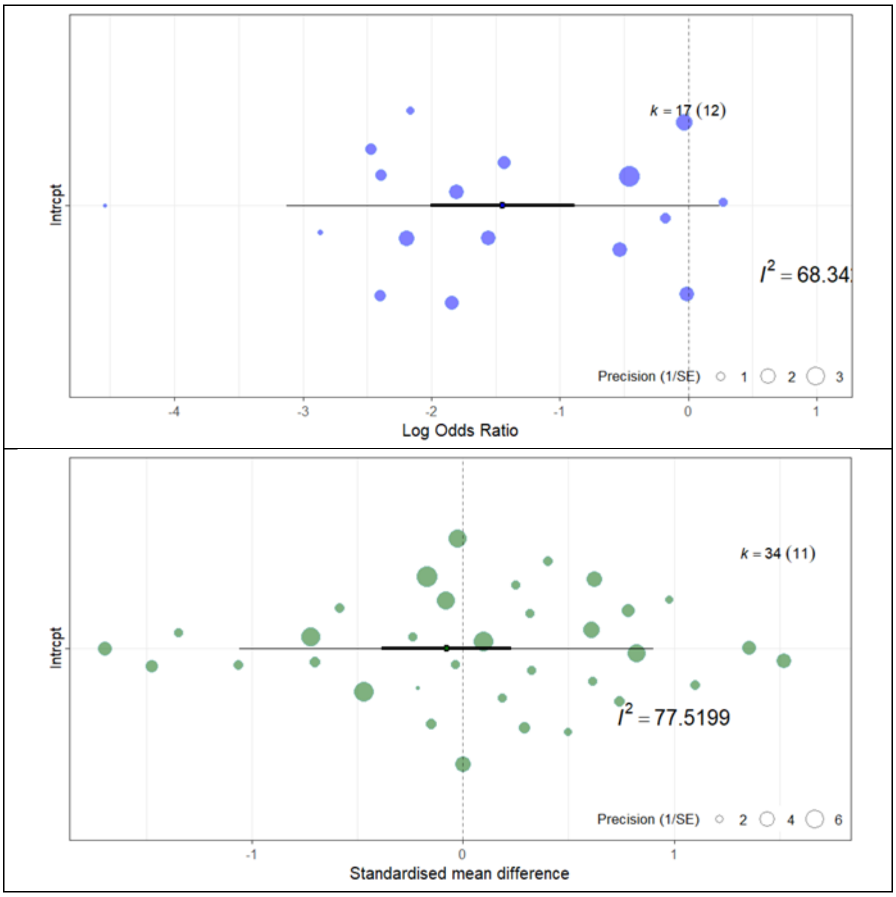

Figure 20. Orchard plots of effect sizes from field studies reviewed by Trefry et al. (2013) evaluating the effects of wing markers on experimental versus control groups of wild birds. Measures included log odds ratios (LOR, top panel) for counts of success/failure (outcomes = survival, hatching success, nest success, and success in establishing a breeding territory) and standardized mean differences (SMD, bottom panel) if mean ± SD and sample size were available (outcomes = condition, reproduction, behaviour and migration). Plots show the pooled mean effects (black point with 95% CI; thick black line), prediction intervals (thin grey line), and estimates from individual studies weighted by precision calculated as the inverse of the square root of the sampling variance. The dotted vertical line indicates the line of no effect at zero. The I^2 statistic is the proportion of variance in the effect due to heterogeneity among the different source studies where high values indicate that the variation may not be sufficient to test for differences among outcome measures.

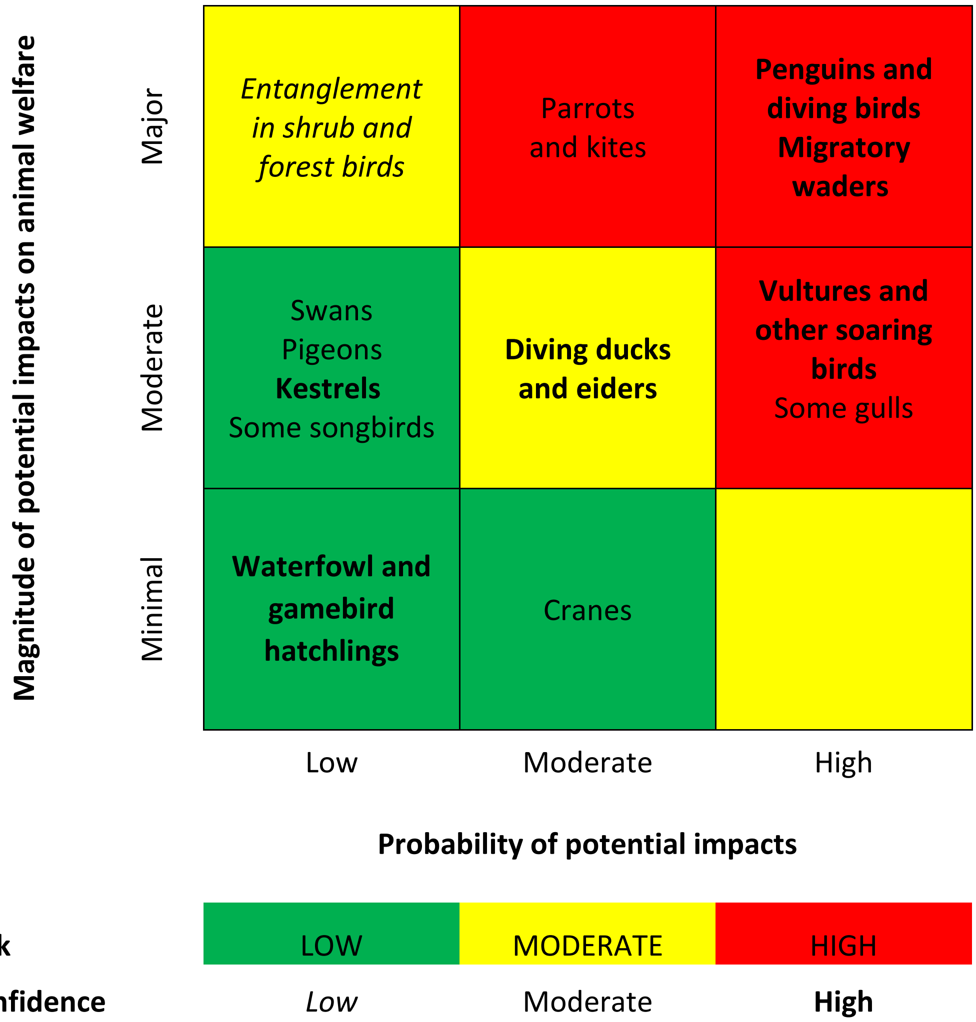

Figure 21. Risk assessment for use of web tags and patagial wing tags to mark juvenile and adult birds.

Risk-reducing measures. Marking the precocial young of waterfowl and gamebirds with Monel tags at hatching requires selection of small tags that match the foot or wing size of newly hatched young. Holding the wing or foot in a relaxed posture allows the tag to be set correctly into the membrane. Tags should not protrude from either the foot or wing or they will have a higher probability of being ripped out. Wing tags should be placed behind the tendon in the leading edge of the wing but not too deep because the wing will not develop properly if tags are set into the wing muscles by mistake. Patagial wing tags should be used with caution on adult birds because a variety of effects have been described for multiple species of birds. The negative effects were successfully quantified with meta-analyses even though the small sample of studies was quite heterogeneous. Nevertheless, patagial wing tags have been successfully deployed in a range of bird species. Thus, a first step to reduce risk would be to review studies of similar species where effects have been reported. Use of wing tags might be avoided if colour rings or other options for individual marking are an option. If wing tags must be used, use of small aerodynamic tags that are attached with safe procedures may help to avoid negative impacts. Pilot studies in an aviary or with small samples of birds in the field might reveal whether problems are likely to arise before starting a full-scale marking program for wild birds.

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Nasal discs and saddles

Description of method. Nasal markers can be efficient methods to identify birds at a distance without having to recapture them. Such numbered and/or colored nasal saddles or discs have been applied primarily in waterfowl, most often in ducks. Nasal discs and saddles are hard nylon markers attached to a bird’s bill using wire through the nares. Nasal discs consist of two pieces, each secured to one side of the duck's bill, while a nasal saddle is a single nylon piece that covers the upper beak.

Impacts on animal welfare. For nasal discs and saddles, the **risk** of negative impacts on animal welfare is assessed as **Low to High**, with <u>Moderate</u> to <u>High</u> confidence, depending on species-specific behavior and environmental conditions (**Figure 22**). Our risk assessment for use of nasal disks and saddles in waterfowl is **consistent** with VKM 2013 (table 5) which suggested there was a Medium risk for negative impacts on animal welfare. Some studies have found no effect on body mass, time budgets, or reproductive behavior. Other have found indications of short-lived discomfort following attachment which have been, while others have found more long-lasting signs of discomfort with birds often removing vegetation from nasal markers after diving and marked birds shaking their head more frequently than unmarked birds (3a). Several studies have documented negative outcomes, such as injury to the nares (3b), increased mortality from getting tangled in underwater vegetation or fishing nets (2d), deaths caused by ice buildup (2b), which can block the nostrils, and lower pairing success rates (4e). There is comprehensive evidence of reduced survival of Lesser Scaup (*Aythya affinis*) from comparison of survival rates of ducks released with nasal discs and those released metal leg bands (4c). The mechanism is unknown but apparently not linked to body condition in summer.

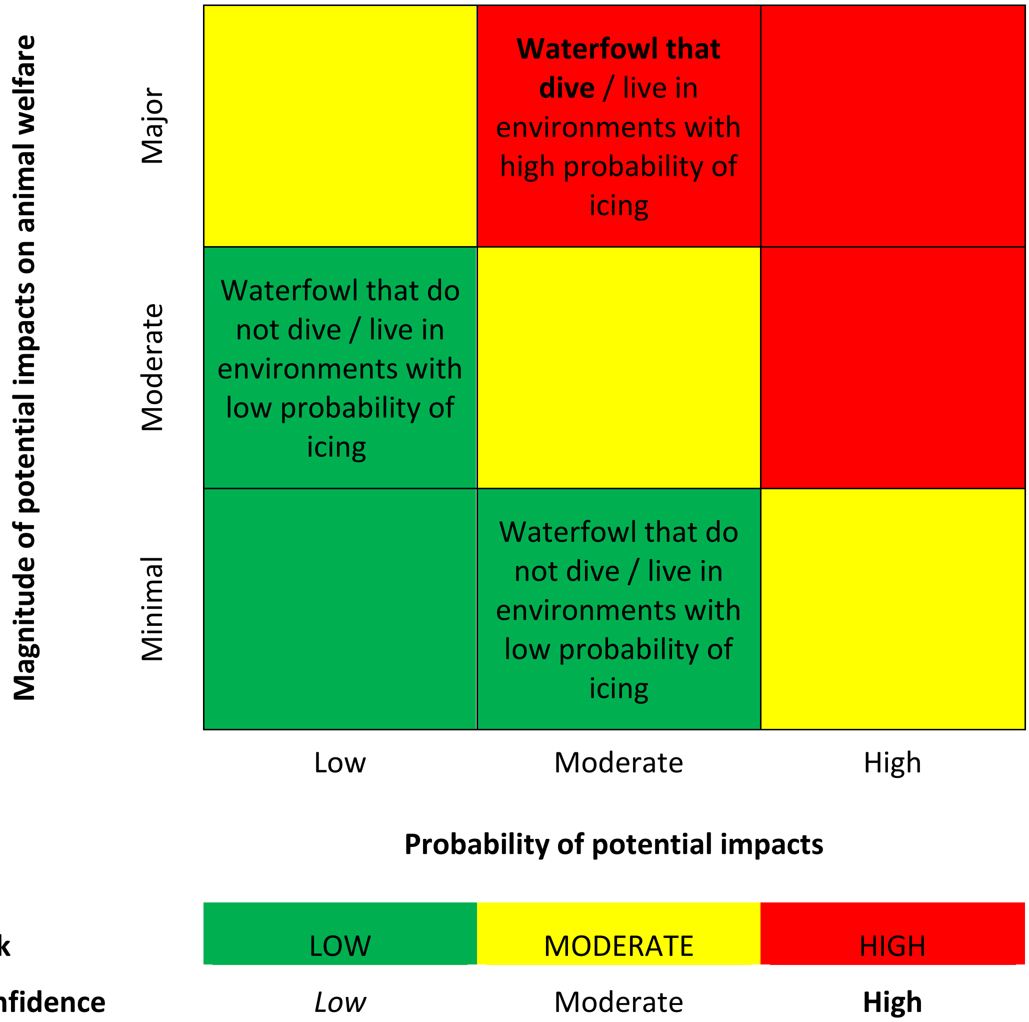

Figure 22. Risk assessment for use of nasal discs and saddles to mark birds.

Risk-reducing measures. Nasal discs or saddles are probably more suitable for waterfowl that do not dive because they are less likely to get caught in vegetation or fishing nets underwater. The risk of harm to animal welfare is probably higher in cold environments where the nasal markers are likely to become covered in ice.

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Neck bands*

Description of method. Neck bands are attached around the neck of birds to enable easy visual identification of individuals from a distance. Neck bands are most often applied to long-necked waterfowl, particularly geese and swans. The neck bands are typically made of lightweight and durable materials, such as lightweight hard plastics, with a unique colour, symbol, or alphanumeric code for individual recognition. When durability is a priority and weight of the band is not a significant concern, neckbands of lightweight metals such as aluminium can be used.

Impacts on animal welfare. For neck bands, the **risk** of negative impacts on animal welfare is assessed as **Low to High**, with Low confidence (Figure 23). Our risk assessment partially **confirms and** partly **upgrades** VKM 2013 (table 5) which suggested that use of neck bands in waterfowl had a Low risk for negative impacts on animal welfare. Well-fitted neck bands on geese may have only low and short-term impacts on comfort (3a) and behavior (4b), but results vary substantially among and within species (Figure 23). Some studies have found that survival is reduced in geese with neckbands (4c), and that the reduced survival may result from increased nonhunting mortality, especially icing on the neck band (2d) and increased conspicuousness which can increase predation risk and hunting mortality (4g). Reduced body condition of individuals with neck bands has also been documented (1d), but most studies found no effects. Results on impacts on reproduction (4f) are divergent. For swans and ducks, the evidence is limited. One study found no effect on survival of neck banded swans, whereas ducks can get their bills stuck in the collars (2d). Some species of geese have natural markings on the throat and neck, including Black Brant *(Branta bernicla),* Emperor Geese (*Anser canagicus*), and Bar-headed Geese (*A. indicus*). Use of neck bands in these species can disrupt social interactions (4d), leading to exclusion and reproductive failure among marked birds (Lesink 1968).

* We evaluated the method based on the Five Domains Model (Table 2) and completed score sheets (Table 3) are available as an electronic Supplementary Information.

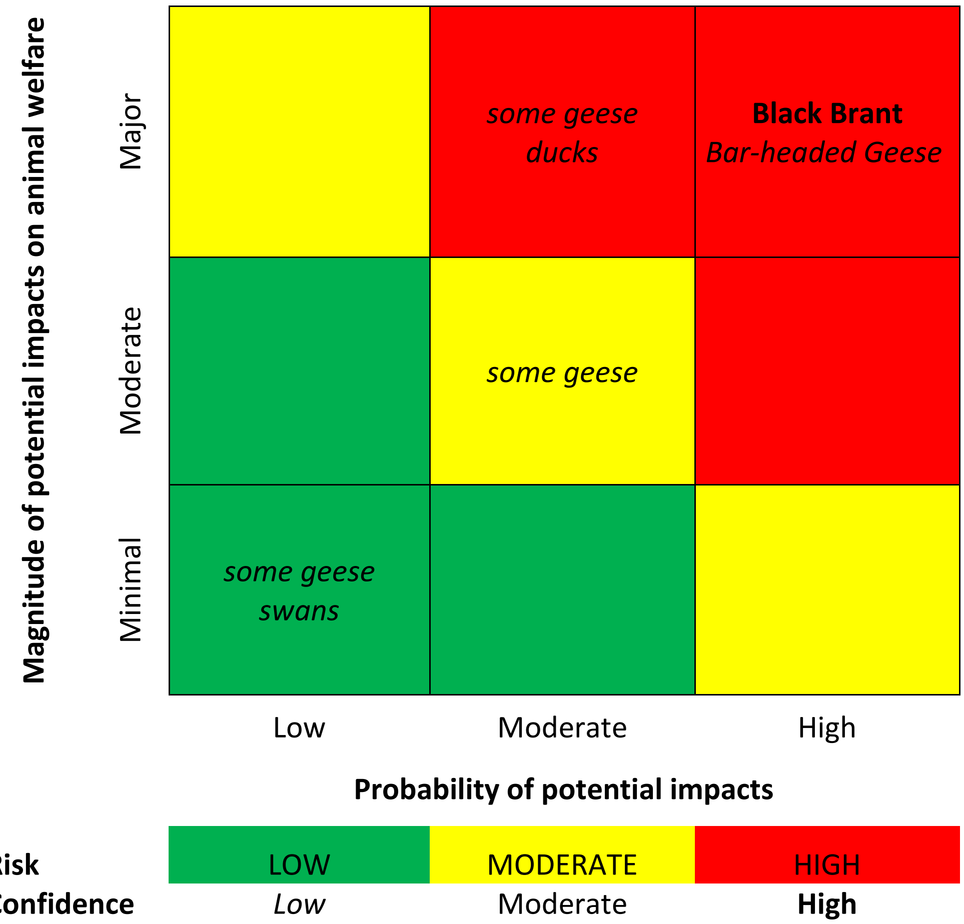

Figure 23. Risk assessment for use of neck bands to mark birds in the order Anseriformes.

Risk-reducing measures. Ensure that neck bands are appropriately sized; neither too tight nor too loose to reduce the risk of entanglement. Choose materials that are lightweight and non-abrasive to minimize discomfort and ensure that edges are smooth and rounded to prevent injuries. Avoid the use of neck bands on bird species with natural markings on the throat of if there is a high probability of ice accumulation.

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Flipper tags on penguins*

Description of method. In penguins, the wings are used for propulsion in water and have evolved into flippers, with parallel evolution of a paddle-like forelimb that is similar to marine reptiles and mammals. The feet have evolved into a rudder. Unlike other birds, therefore, penguins have a knee-joint that renders regular leg rings unsuitable. Therefore, to mark penguins the tags have been applied to the proximal end of the flipper (wing) and not to the leg (but special leg bands are used for attaching geolocators in some penguin species). Flipper tags, termed flipper bands in many publications, have been used to mark penguins for identification in ecological studies for more than 70 years. The flipper tag comprises flat metal strips, made either of stainless-steel or aluminium, moulded to embrace loosely the axillary part of the flipper. The tag is stamped with a unique number that can be read at a distance (see Boersma & Rebstock for a detailed description).

Impacts on animal welfare. For penguins, the **risk** of negative impacts from flipper tags on animal welfare is assessed as **High**, with High confidence (**Figure 24**). Our risk assessment is **an upgraded assessment** compared with VKM 2013 (table 5) which suggested that use of flipper tags in penguins has a Medium risk for negative impacts on animal welfare. A growing body of evidence has shown that flipper tags impair locomotion, foraging efficiency, reproductive success and survival of wild penguins and the technique is now strongly discouraged.

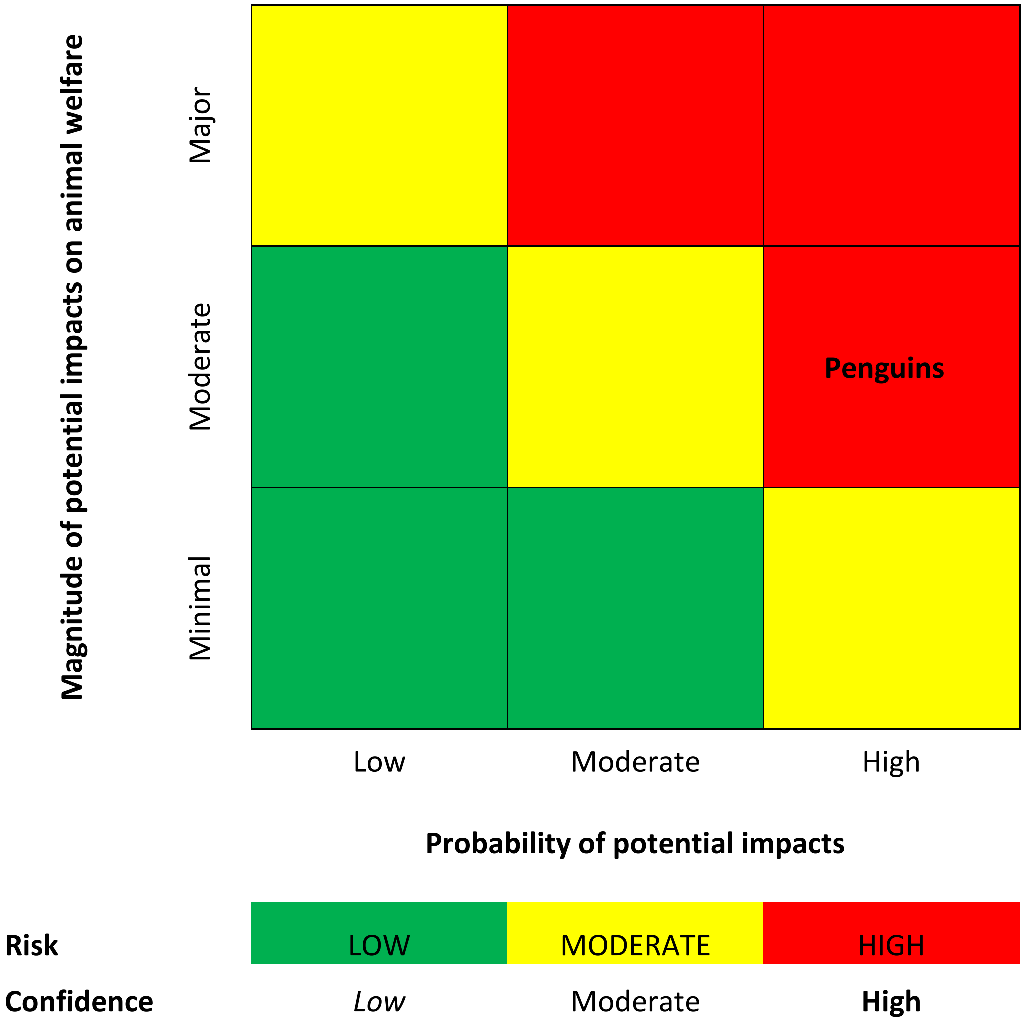

Figure 24. Risk assessment for use of flipper tags to mark penguins

Risk-reducing measures. Use of flipper bands in field studies of penguins is discouraged because of likely effects on animal welfare. Use of flipper tags can be replaced by individual marking with subcutaneous passive transponders (RFID tags), as suggested in review studies (Jackson & Wilson 2002, Le Moho et al. 2011).

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11 Tracking and biologging tags

In this chapter, we describe various tracking and logging devices used to monitor birds' movements and behaviour and collect physiological data. Impacts on animal welfare from each of these devices are usually determined by tag mass, size and physical design, and the method of attachment (Bodey et al., 2017; Brlík et al., 2020; Geen et al., 2019). To avoid redundancy, **risk assessments for the combined effects of the device and method of attachment** are presented in **Chapter 12: Mode of Attachment**. However, in this introductory section, we provide a general account of important aspects to consider, irrespective of device type. Device-specific information is also included in the descriptions of the specific types of tags where relevant.

Attaching tracking and logging devices on wild birds can increase energy expenditure, and it is crucial that the mass of the device is not too heavy relative to the bird's body mass. Traditionally, the informal standard was a 5% limit (Caccamise & Robert, 1985; Cochran, 1980), which was later adjusted downward to a rule of thumb based on a 3% limit in the early 2000s. In Canada and the USA, the regulatory requirements for use of auxiliary markers on wild birds include licensing terms that the total mass of all rings, auxiliary markers and attachment materials should not exceed 2% of body mass for leg attachments and should not exceed 3% of body mass for other types of devices or attachment methods (Bird Banding Lab, 2024). The threshold of 3% has been supported by evidence such as observed negative effects in albatrosses and petrels (Phillips et al., 2003). Experimental tests with tags that were 3-7% of body mass also reduced flight performance of small-bodied songbirds (Tomotani et al., 2018). Yet, in a meta-analysis of 84 papers evaluating the effects of radio transmitters, Barron et al. (2010) discovered that there was no correlation between the proportional mass of the device and the effect size when considering all studies in a regression analysis, but few studies used transmitters that exceeded 5% of body mass. Hence, despite the regulatory requirement of a 2-3% standard, there is no one-size-fits-all solution. Bodey et al. (2018) confirm this finding in their phylogenetically controlled meta-analysis. Negative effects of tag weight were already apparent at 1% of body mass (Figure 25). Bird species vary in susceptibility to increased tag mass, necessitating consideration of each species' body size and natural fluctuations in body mass, morphology, ecology, and behaviour (Burger & Shaffer, 2008).

Physical design of the device and materials also play a role and is addressed in device descriptions below when relevant information exists. On a general note, transmitter size and shape (including any external antenna) that minimizes drag could be as important to consider as weight *per se* (Lameris & Kleyheeg, 2017) and wing morphology and flight characteristics of the bird species in question should be considered when deciding on device load, position on the body (e.g., back, lower back, tail, leg) and mode of attachment (Fair et al., 2023).

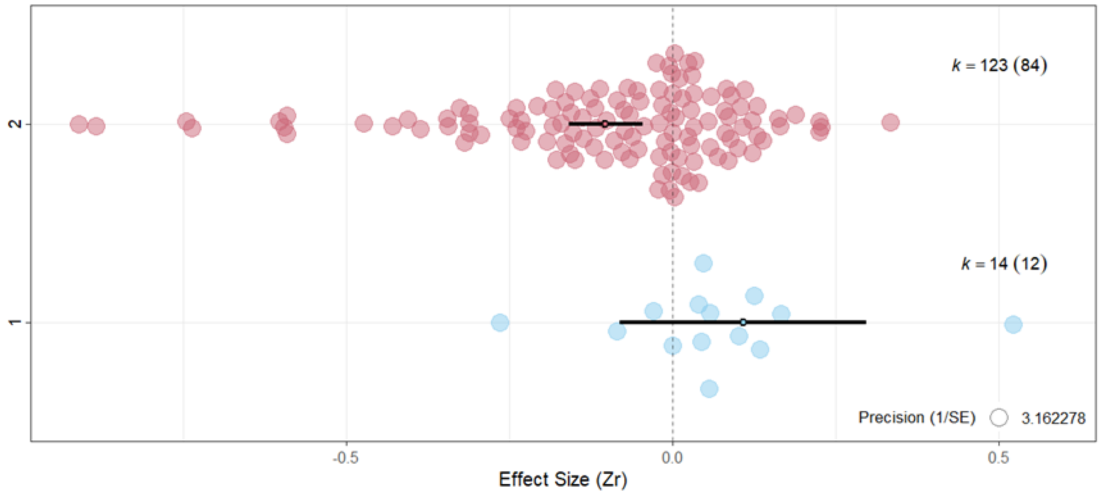

Figure 25. Meta-analysis of the effect of biologger devices on the survival of birds. The tags that were less than 1% of body mass showed no significant effect, whereas tags greater than 1% of body mass showed a significant negative effect on survival. Blue circles indicate studies with tag weight less than 1% body mass and red circles indicate tags greater than 1% of body mass. The small dot and black lines indicate the pooled effect estimate and the associated uncertainty (95% Confidence Intervals)

For tags equipped with an external antenna for transmission of a signal, the antenna design can also influence the risk of negative impacts. For example, Dougill et al. (2000) evaluated two antenna designs in a radio-telemetry study of Hawaiian honeycreepers (*Loxioides bailleui*). Birds equipped with transmitters with a long, limp antenna with bulbous tip were often found entangled in the vegetation during the study (50%, 8 of 16) whereas birds with tags that had a short, stiff antenna without a bulbous tip had no problems with entanglement (0%, 0 of 22).

Radio Frequency Identification (RFID)

Description of method. Monitoring systems based on Radio Frequency Identification (RFID) platforms are a relatively new technology that have been the focus of rapid development in the past two decades. RFID systems consist of a miniature transponder that is attached to the bird and a tag reader that consists of an antenna and a datalogger with a power source. Passive integrated transponder (PIT) tags have no internal battery and are extremely small and lightweight (2x12 mm, <0.1 g) with an effectively unlimited lifespan if undamaged. PIT tags are usually attached to a bird by either subcutaneous injection or by directly attaching them to an external leg band. Active RFID tags require a battery and are larger unit but have been deployed on albatrosses. Double-tagging with an RFID tag and a single metal ring can be used to assess rates of tag loss. PIT tags have a unique registration number and become energized when passing through an electromagnetic field generated by the RFID reader whereas active RFID tags broadcast a signal. Both types of tags communicate within the radio frequency range. Most RFID systems use a low frequency range (125-150 kHz) because the radio signals can penetrate wet tissue and detect implanted PIT tags. Readers are deployed at sites where birds will pass nearby such as the entrance to a bird feeder (Hou et al. 2015), nest site (Michard et al. 1995, Becker and Wendeln 1997), or a ramp into a nesting colony of penguins (Clarke and Kerry 1998). A disadvantage of the system is that the transponder tag must be close to the reader for detection at a maximum read range of <0.3 metres. Still, RFID systems have been used with a variety of species including waterfowl, terns, storks, hummingbirds, and songbirds. Use of PIT tags can allow researchers to circumvent negative impacts of external markers on sensitive species, including the past use of flipper tags on penguins. The challenges with RFID systems have been reducing cost of equipment but have been realized with open science approaches to development of hardware and software (Bridge et al. 2019, Rafiq et al. 2021). The massive amounts of data that can be generated by RFID systems have also required development of new software packages for handling and seeking for patterns that offer new insights into bird activity, movements, and social interactions (Bardon et al. 2023). The extremely small size of PIT tags, applications as an alternative to standard external markers for sensitive species, and new possibilities for collecting large amounts of field data with noninvasive sampling techniques are all key contributions to the 3R concept of *Refinement* in improving animal welfare in field studies of wild birds.

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Light loggers

Description of method. A light-level geolocator, light-level logger or global location sensors (GLS), hereafter a 'geolocator', is a light-weight archival electronic tag. Geolocator tags are basically a recorder of light-level and time and consists of a light-level-sensor and a clock powered by a small battery. A geolocator may also measure additional parameters (like saltwater immersion and temperature) to aid the geolocation or to provide behavioural (time spent in salt water) and environmental data (e.g., sea temperature). Since the geolocators used on birds are archival, they require physical recapture of the bird for retrieving and downloading the data. Light-level geolocation is based on identifying twilight events from the recorded data, at the daytimes when the light level crosses a threshold at dusk and dawn. Changes in light levels are the traditionally threshold method of geolocation and needs some sort of calibration to link the threshold to solar elevation. Then longitude is calculated from the time of mid-day or mid-night, and latitude from the length of day or night. Since several factors can influence light level, positions estimated form geolocators have a low accuracy. Average error is around 180 km but increases in certain seasonal periods (close to equinoxes) and regions of the globe (at Equator, and close to the poles). Estimates of latitude are unreliable for some weeks around autumn and spring equinox, when daylength is constant at all latitudes. Furthermore, positions cannot be estimated during constant daylight or darkness, which occurs at high latitudes during winter (polar night) and summer, respectively. New classes of tags that combine light loggers with pressure sensors offer improvements in position accuracy (Nussbaumer et al. 2023).

Despite the simple technology and some obvious drawbacks, geolocators represent one of the greatest technological advances of modern avian science. The combination of small size, low weight, low cost, and low potential for negative effects on the equipped birds has been a great success for science (ecology, behaviour) and society (conservation and management). The use of geolocators for tracking birds was pioneered by seabird researchers and engineers in the 1990s. British Antarctic Survey started to mass-produce a 9 g waterproof geolocator at low cost around 2004. The geolocators then became widely available and used to study the movements of many large seabirds. Smaller models were rapidly developed, and 1.4 g geolocators were used in 2007 to track Arctic Terns (*Sterna paradisaea*, 125 g), revealing the longest animal migration. The use of geolocators has been extended to other migratory species, including waders, waterbirds, raptors and songbirds as refinements have progressed even further. Today, the smallest geolocators weigh between 0.3 g and 0.5 g, with a battery life of 6 to 12 months. Larger geolocator tags around 3 g have a battery life up to 5 years.

Geolocators are easily attached to seabirds on leg-bands on the tarsus or tibia. Even some species of penguins have geolocators attached with leg-bands (for 6- 24 months). Waders can also have geolocators on special leg-bands such as flag-rings on tibia but can also have geolocators attached using leg-loop harness. Geolocators are usually attached with thoracic wing harness or leg-loop harness on songbirds. Harness-mounted geolocators may risk shading from feathers on the back, and geolocators equipped with a light stalk are used in such cases.

The main advantages of geolocators are the small size, low weight and low cost. Geolocators are usually easily attached to birds, e.g. on leg-bands, with minimal risk for potential negative effects. Therefore, they have been used with great success in large-scale tracking of small to large birds.

The main disadvantage of geolocators is the need to recapture the bird for retrieving the archival data, the low accuracy (often averaging 180 km), seasonal periods with unreliable estimates of latitude (equal daylengths during autumn and spring equinox), and seasonal periods at high latitudes when light conditions do not allow estimation of positions (polar night or constant daylight during winter and summer solstice). Size and shape represent a potential challenge for flight costs or drag mainly for the smallest species.

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VHF radios

Description of method. VHF (Very High Frequency, 30 – 300 MHz) radio telemetry for use on birds was introduced in the 1960s. The system consists of three parts. The bird carries the radio transmitter, which sends radio signals (electromagnetic waves) from an antenna. The researcher uses an antenna (usually a portable Yagi-antenna) to pick up the radio signals, and the antenna is connected to a receiver, which transforms the radio signals to an audible pulse of "beeps". The signals are strongest when the antenna is pointed towards the bird and becomes stronger the closer the bird is. The researcher uses these clues to locate the bird. Because the signals become deflected by objects, including ground, the range is limited to line-of-sight. Within direct sight the range depends on the strength of the emitting signals, which depends on the battery size, and thus on the weight of the radio tag. For a given battery size, there is a trade-off between the strength of the signals and the lifetime of the transmitter, and the balance is determined by the purpose of the study.

Up through the years, advances in VHF technology and battery design have allowed the tags to become smaller, and today the smallest VHF tags weigh less than 0.5 gram. Also, VHF tags are very power-efficient, and even small tags may last for several years. Finally, VHF tags are quite affordable, and cost only a fraction (less than 10%) of GPS tags.

VHF technology has been the "workhorse" in wildlife tracking, and is still often the preferred toolkit, because it allows real-time tracking, which is needed to collect detailed data on the bird´s behavior. VHF tags may also be built into GPS tags to allow the more expensive GPS tags to be located in real time, either to verify the wellbeing of the bird, download data from the GPS at a distance, or to recover the GPS tag in case of technical failure or battery exhaustion, or simply for removal of the tag, by re-trapping the bird.

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GPS tags

Description of method. A GPS tag uses the Global Positioning System to identify and record a bird´s location at preprogrammed time schedule, tailored to the purpose of the study. The data is stored onboard, either permanently (archival) or temporarily (non-archival). In the first case of archival tags, the data are accessible only after the tag has been retrieved after being released from the bird by a drop-off mechanism, or after the bird has been re-trapped. Tag recovery is usually made possible by a VHF tag built into the GPS tag. In the second case of non-archival tags, the data from the tag are intermittently downloaded by use of a portable base station put out sufficiently close to the bird, by use of the GSM mobile phone net, or by relaying via the ARGOS satellite system, and then downloading by use of the internet (PTT).

GPS tags for birds have been available since the 1990s and have become smaller as the technology has advanced. They are still heavier than VHF tags, because they need more power to function, and require heavier batteries. Today the smallest GPS tags weigh only 1 gram. GPS tags are also more expensive than VHF tags, and usually cost ten times as much.

GPS tags are preferred over VHF tags if the bird to study is large, shy, or lives in remote or rugged terrain that is difficult to traverse by foot, and especially if the bird regularly moves long distances during the annual cycle, which is the case in pelagic seabirds and many species of migratory birds in general.

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Satellite tags

Description of method. Satellite tags transmit data to satellites for localization of the tagged animal with no need to retrieve the tag for accessing the data. The main system is ARGOS, and the tags are called Platform Transmitter Terminals (PTTs). The tags use an external antenna to transmit data to ARGOS-equipped polar orbiting weather satellites, which estimate locations at the time of transmission based on the Doppler shift of the signal frequency received. The accuracy of the best location classes (LC) range from 150-250 m (LC 3) to 500-1500 m (LC 1). Other location classes are considered more unreliable and come without any estimate of accuracy.

The first PTT less than 100 g was introduced in 1991, a 95 g battery powered tag. The capability to track birds with PTTs was therefore limited to the largest, and primarily non-migratory species. Since then, development of this technology has progressed in several steps with an increasing range of bird species tracked with a decreasing size of the tags. PTTs of 30 g and 10 g became available around 1993 and 2005, respectively. The smallest PTTs available today are solar powered tags around 2 g.

PTTs attached with a back-pack or leg-loop harness allow year-round and long-term tracking. The tags can also be attached using tape and glue on feathers for shorter term tracking, such as for several weeks during the breeding season or a few months prior to feather moult.

Different models of PTTs exist. They are either solar or battery powered. Solar-powered PTTs have lower weight but are restricted to species and conditions not shading the solar panel. PTTs may also have a GPS onboard to increase the precision of locations. Last, there are implantable PTTs available for diving birds that cannot tolerate a backpack attachment. The external transmitting antenna then penetrates the back of the bird.

The main advantages of using PTTs are that they do not require retrieval of tags and have a global coverage. Hence, they can estimate locations of animals from remote areas and challenging conditions, such as open oceans, deserts, dense rainforests or polar ice caps. Disadvantages include costs of the devices and for processing the data. There has been considerable miniaturization of satellite tags, but size and shape represent a potential challenge for flight costs, drag, and long-term attachment. The accuracy is at best 150 m unless the PTT is equipped with a GPS.

ICARUS is a recent initiative for a new type of satellite-based tracking and as an alternative to ARGOS. It is an international cooperation managed by the Max Planck

Institute. The system aims at tracking birds and other animals with miniature GPS tags which transmit the data to a receiver station in space, which in turn transmits the data to a ground station from where it is sent to the researchers. The receiver station was housed on the International Space Station (ISS), but with the Russian war on Ukraine, the German and Russian space agencies suspended the operations. The project is therefore in a test phase of a new system with a receiver station on a new satellite.

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Accelerometers

Description of method. An accelerometer records the acceleration of a bird, i.e. the change in velocity. The loggers measure acceleration in three axes (x, y, z), which in turn can be used to detect specific behaviours, such as different modes of flight (flapping, soaring), foraging, prey capture, resting, swimming, diving, singing, incubating and preening. It is also possible to use accelerometers to estimate overall energy consumption.

Accelerometers can be small single unit loggers. The units can also be integrated into multi-sensor loggers or transmitters, such as TDR-recorders, GPS loggers, GPS-GSM transmitters and PTTs. Then the accelerometer data can be linked to other variables, such as temperature, depth, altitude and geographic position.

Bird researchers have attached accelerometers in different positions on wild birds. The lower back, tail or belly are most often used on seabirds, while back-pack or leg-loop harnesses are more common in other species, such as raptors, waders and passerines. Weimerskirch et al. (2016) used accelerometers in combination with GPS, altimeter and heart rate loggers and discovered that Great Frigatebirds (*Fragata minor*) can stay airborne for two months during transoceanic flights. To do so, they rely on thermals and wind to soar and gain altitude under clouds and then glide over kilometres at low energy costs. Hedenstrøm et al. (2016) used a logger with an accelerometer and a geolocator (total mass 1.1 g) to reveal that Common Swifts (*Apus apus*) are airborne for 10 months during the entire non-breeding season. While these two species are adapted for an aerial lifestyle, alcids are adapted for efficient diving and have rather high flight cost. Elliot et al. (2013) used accelerometers on Thick-billed Murres (*Uria lomvia*) to estimate their daily energy expenditure (DEE). These field studies provide data on spectacular behaviour and demonstrate how accelerometers can be applied to provide important ecological information.

The main advantage of accelerometers is the small size, the relatively large data memory and long battery life, allowing high resolution data for long periods. For instance, they may be used to estimate DEE over an entire year. The period of deployment is long compared to the conventional methods based on doubly labelled water (DLW), which is used to estimate DEE over a couple of days. The main challenge or disadvantages of accelerometers are the extensive calibration and data analysis needed for translating the values to specific behaviors and movements. Tag position must also be considered, since patterns of tag acceleration may differ among positions on the tail, back and belly.

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Time-depth-recorders (TDR)

Description of method. Time-depth-recorders (TDR recorders) record pressure and time to provide data on diving depth and duration. The casing is built to endure high pressure as some seabirds may regularly dive deeper than 100 meter (maximum 550 meter). Considerations of drag and tag mass are important. TDR recorders are usually cylindrical or rectangular and they are mainly attached to leg-bands, on feathers on the lower back or the tail. Common weight and size ranges are 3-11 g and 8/33 – 13/44 mm, respectively. Tags with a heavy mass in air can be designed to ensure they have a neutral buoyancy in water.

TDR recorders are usually archival loggers that need to be retrieved to download data, and they are powered by a battery without solar charging. The loggers basically contain a pressure sensor and a clock to measure dive depth over time. TDR recorders may also be multi-sensor biologgers including also other sensors, such as temperature, salinity, light (geolocation) and acceleration (accelerometer).

TDR recorders can be used alone or in combination with other tracking tags. When used in combination with a GPS-tracker it is possible to know where the birds have been diving and where the birds have been foraging.

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Other biologgers

Description of method. Other types of biologgers with different types of internal and external sensors have been used with wild birds to address a range of different research questions.

Internal sensors usually measure physiological parameters, such as heart rate and body temperature. Heart rate and body temperature are used for assessing energy expenditure, activity, feeding, stress, immune response and health status. Internal sensors can be implanted in the abdominal cavity under surgical procedures and anaesthesia. One company (Star Oddi) provides small implantable loggers (heart rate and temperature) with a tag mass of 3.3 g and a battery life of 3 months. Use of internal sensors does not always require surgery. For example, large birds can ingest body temperature loggers. Then, body temperature is measured during passage through the gastrointestinal tract. If the temperature logger is archival, it needs to be retrieved to access the data after exit from the digestive tract through the cloaca. Otherwise, the temperature loggers must be able to transmit and allow remote downloading of data.

Heart rate can also be measured with electro cardiogram (ECG) loggers externally attached to the bird. The loggers require electrodes with appropriate skin contact for monitoring the electrical signals of the heart. External attachment can be a less invasive approach than implantable loggers. Heart rate can also be measured with external biologgers not attached to the bird at all, such as on incubating birds. The heart rate logger is then located inside the nest or even inside an artificial egg inside the nest and monitors heart rates of the bird during incubating. Temperature recorders are also commonly used in artificial eggs or inside nests to measure incubation temperature. Such measurements give insights into incubation energetics, incubation consistency, incubation shifts, timing of hatching and nesting failure.

Examples of other external biologgers include pressure sensors (altimeters) for measuring altitude, saltwater immersion and activity sensors for measuring contact with salt water and behaviour, and salinity and temperature sensors for measuring environmental variables. Many sensors can be integrated into one logger or tracking device, so-called multi-sensor biologgers.

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Video cameras

Description of method. Advances and miniaturization of video technology have led to the development of small cameras that can be used to investigate the behaviour of wild birds under natural conditions. Most bird-borne video cameras have been relatively large units (ca. 70+ g) which has restricted applications to large-bodied species of seabirds, penguins, and raptors. Heavy units can have neutral buoyancy in water and have been used to investigate the underwater diving behaviour of marine birds. The smallest video camera with an integrated VHF radio tag is currently about 15 g which has been used with an island population of New Caledonian Crows (*Corvus moneduloides*). Field applications of bird-borne cameras have included deployments on trained cormorants, raptors and falcons that have been habituated to handlers, or to relatively tame species of seabirds, penguins and island birds that can easily be recaptured to recover the device. Attachment techniques include mounting of the camera on top of the head with a helmet, taping a recording unit to the back, or a tail-mounted package where the lens protrudes through the central tail feathers. Head-mounted cameras can be effective because birds often maintain a level gaze with a stable head position during flight and rapid manoeuvring. Owls and raptors have limited eye motion and the camera orientation can track the primary direction of the focused gaze. Video loggers mounted on the back need a relatively wide field of view that spans the lateral movements of the head of the bird. Constraints on package mass include camera size, battery life and needs for onboard storage of images and sound files. Thus, camera deployments are often of short duration and the units are recovered when birds return to a nest or roost site after a single foraging bout. Video cameras provide detailed information on wing beats, biomechanics and behaviour which can be used to calibrate information collected from GPS tags, accelerometers, and other types of biologgers. Recording units have been used to collect information on vocalizations of seabirds away from the breeding colonies. Video recordings have provided new insights into habitat selection and foraging behaviour. In seabirds, video has been used to evaluate the dietary importance of jellyfish, prey selection and hunting success for different types of fish, and the use of discards from commercial fishing boats. New discoveries have included pelagic seabirds hunting in groups and following cetaceans in commensal foraging behaviour. In raptors, video has been used to investigate soaring behaviour and hunting pursuits, including predator responses to prey escape behaviour. In New Caledonian crows, video cameras provided new insights into alternative foraging modes, prey encounters, diet selection, and the ecological context of tool use in a population of wild birds.

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12 Mode of attachment for tags

Tags for tracking and logging can be attached to the birds using different techniques. Impacts of animal welfare can often be attributed to the attachment methods rather than the features of the device itself, although the mass and physical design of the tag can also impact animal welfare (see Chapter 11). In this Chapter, we assess the main modes of attachment used for attaching tracking and logging devices to wild birds.

In the assessments of modes of attachment, we have used the observable and welfare alerting indicators belonging to domains 1: nutrition, 2: physical environment, 3: health, and 4: behavioral interactions in **Table 2** as a checklist. Based on these observable and welfare alerting indicators in domains 1 to 4, domain 5: mental state can inferred, using Table 2. We have filled in domain 5: mental state for the methods marked with (*) and uploaded the score sheet Table 3 to demonstrate how the Five Domains Model can be used to make assumptions about the birds' affective experiences (mental state).

On a general note, we emphasize the importance of seeking appropriate training and the latest guidelines. See also Chapter 13: Risk-reducing measures.

Glue and tape methods

Description of method. Attaching devices to feather shafts or skin using glue or tape is a common practice for short-term projects. When using glue and tape methods, it is important to note that the device will detach when the bird undergoes molting, but often earlier, and premature tag loss is common (Fijn et al. 2014). Common attachment points on the body include the upper or lower back (Fodell et al. 2008, Anich et al. 2009, Barbraud & Weimerskirch 2012, Chivers et al. 2016, Evans et al. 2020) or on the tail feathers (Bolton 2021). To attach a device with glue, a small amount of adhesive is applied to the transmitter, then affixed to the bird's feathers or skin. Clipping the feathers or using a small gauze pad underneath the radio can give better adhesion and longer radio attachment (Mong and Sandercock 2007). Alternatively, a similar method involves using specialized tape to secure the transmitter to the bird's body or feathers. Glue is often used in addition to subcutaneous attachment techniques, and for smaller devices like PIT and TDR tags and geolocators, tags can also be glued or taped onto other markers such as leg rings, leg flags, or neck collars (see separate assessments of these methods for individual marking). For example, attaching devices to leg rings has proven effective for deploying geolocation loggers and small time-depth recorders, especially for diving birds.

Impacts on animal welfare. For glue and tape methods, the **risk** of negative impacts on animal welfare is assessed as **Low to Moderate**, with High confidence (**Figure 26**). The assessment **confirms and upgrades** VKM 2013, which assessed the use of glue methods as Low risk. Negative effects on reproduction (2f) such as increased nest abandonment (Sun et al. 2020) and reduced colony attendance (Söhle et al. 2000) may be related to increased energy expenditure from carrying extra load (1d) rather than the glue or tape itself. Drag (2c) appears to be particularly important in diving birds (Wilson et al. 2004, Vandenabeele et al. 2015). Hill and Elphick (2011) gathered information for more than 60 passerine species and found that entanglement (2d) with vegetation or body parts and non-entanglement related injuries (3b) affected 27% and 19% of species, respectively. The occurrence of negative transmitter effects was similar for transmitters attached with glue or harnesses. Ground-foraging passerines were more likely than other passerines to have experienced entanglement and non-entanglement injuries and their found a clustering of problems in grassland passerines. Notably, even if the impacts of the tagging *per se* are only minimal or moderate, a high rate of premature loss of tags means that birds are impacted unnecessarily and also leads to wasted research effort (Hill and Elphick, 2011).

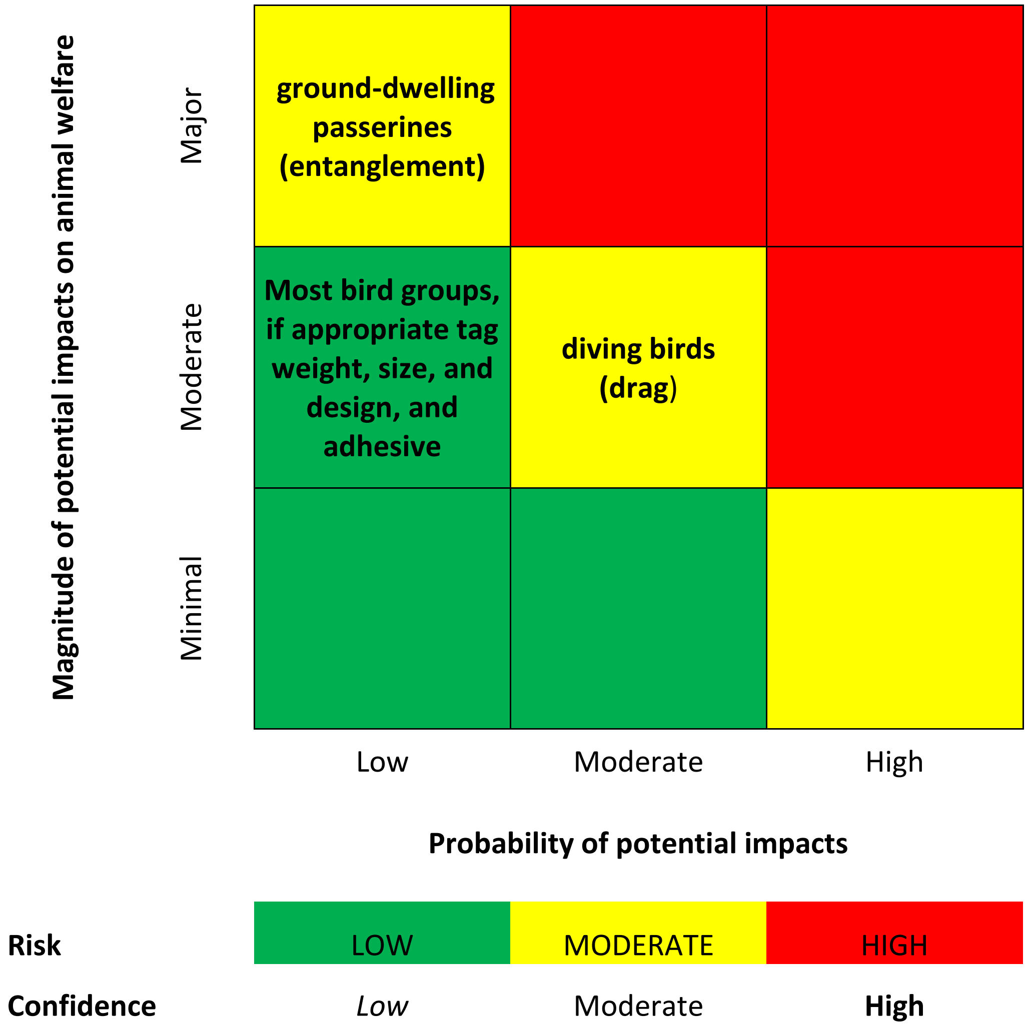

Figure 26. Risk assessment for use of glue and tape methods as mode of attachment of tagging device when marking birds.

Risk-reducing measures. Avoid glue that contains toxic compounds and glues that are thermogenic and release heat when they are curing. If trimming back feathers with small scissors before attachment to increase access to the skin and bases of trimmed feather shafts, it is important to not trim feathers or attach tags in areas with actively growing body feathers with a blood supply. Care must be taken to apply the glue sparingly, ensuring it does not impede the bird's flight or preening abilities. If tags are affixed to the back or rump of the bird, care should be taken to avoid getting glue or tape on the uropygial preen gland at the base of the tail. Similarly, if tape is used as adherent, it is crucial to apply the tape meticulously to avoid discomfort or hindered movement for the bird. Minimize the potential for entanglement by ensuring that glue is dry before release. Consider the potential for drag, and position of the device on the bird's body relative to centre of gravity.

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Sutures, subcutaneous anchors, and subcutaneous PIT tags*

Description of method: Subcutaneous attachment of tracking devices is an attractive method for projects where long-term attachment is required, but can have greater impacts on animal welfare because all subcutaneous methods are invasive procedures. The methods therefore require aseptic technique and anaesthesia. Invasive procedures always pose a risk of infections even with the best aseptic technique. Time is always a risk factor for infection when penetrating part of the skin barrier, and time is a risk factor when you anesthetize birds. Also, more equipment is needed, like subcutaneous attachment material but also equipment to keep the bird anaesthetized (drugs, vaporizer, needles, syringes, disinfectants etc), and instruments for the operator.

Subcutaneous anchors are sterilized and a common site for their insertion is through the skin at the intersection of the cervical and thoracic vertebrae, dorsally between the shoulder blades.

Sutures are also used to attach devices at the back of birds. Important considerations are the size, angel and sharpness of the needle and the strength, size and tissue compatibility of the suture material. Important to make sure that your stitches are firm but not too tight as this will restrict the blood supply to the area.

PIT tags are injected subcutaneously, usually on the back, and anaesthesia is not needed for this procedure. No adverse effects compared to ringed birds are found in four studies on species from the order Passeriformes, making PIT tags an attractive method for individual identification of wild birds.

Impacts on animal welfare. For subcutaneous anchors and sutures, the **risk** of negative impacts on animal welfare is assessed as **Moderate to High**, with <u>Moderate</u> confidence (**Figure 27** and an electronic Supplementary Information). For PIT tags in passerines, the **risk** of negative impacts on animal welfare is assessed as **Low**, with <u>Moderate</u> confidence (**Figure 27**). Our risk assessment **confirms** VKM 2013 (table 5) which suggested that use of PIT tags has a Low risk for negative impacts on animal welfare. Otherwise, VKM 2013 did not evaluate the effects of sutures or anchors for marking or tagging of wild birds.

* We evaluated the method based on the Five Domains Model (Table 2) and completed score sheets (Table 3) are available as a electronic Supplementary Information.

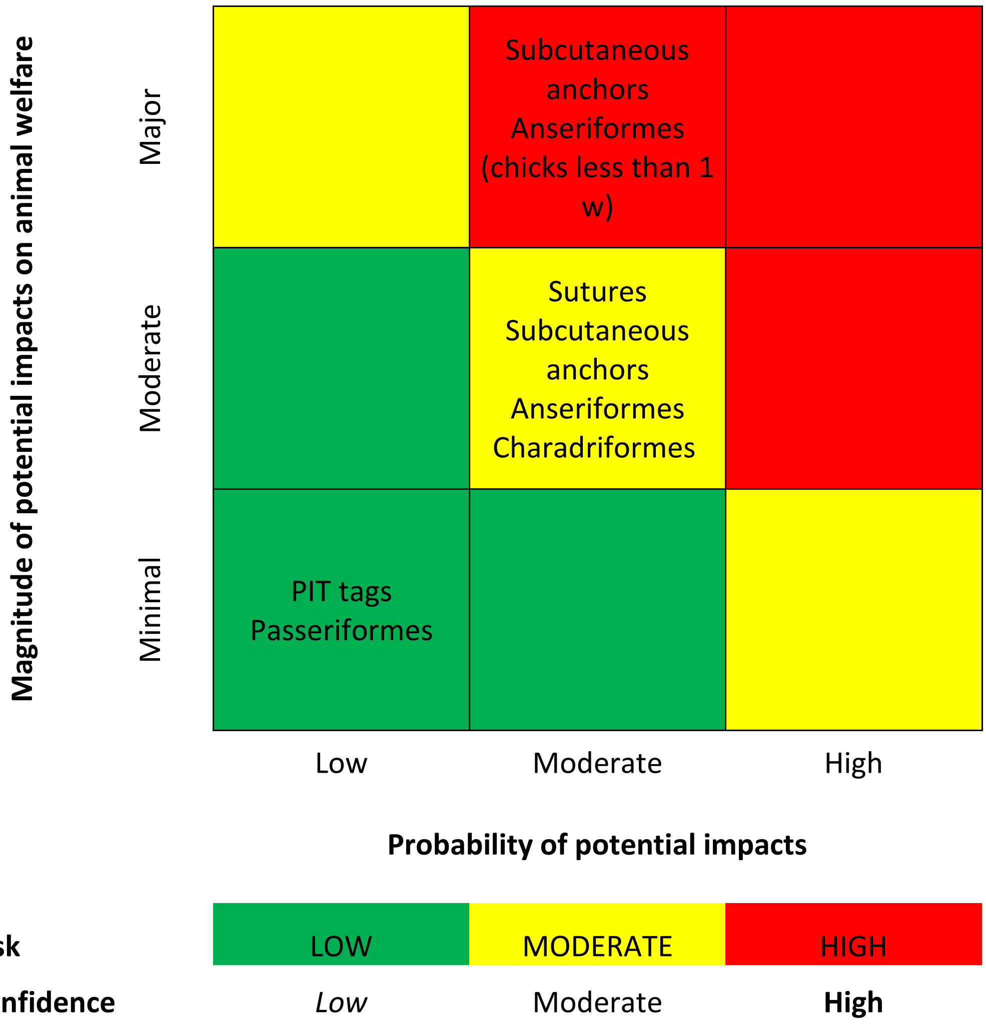

Figure 27. Risk assessment for use of sutures, subcutaneous anchors, and injected PIT tags as modes of attachment for tagging devices when marking birds.

Risk-reducing measures. Aseptic conditions, minimization of feather removal and aim for a minimization of tissue damage from the subcutaneous sutures or anchors. Optimize your anaesthetic protocol to a point where the bird is well anesthetized and at the same time has a short and smooth recovery. Gaining competence in any given practical technique require a step-by-step approach involving literature search, videos and simulation tools for the technique (mock-up or cadaver if available) to become familiar with anatomy, restraining- and sampling technique, and then team up with experienced personnel to be properly trained.

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Tail mounted tags*

Description of method. On smaller birds, such as a European Nightjar (*Caprimulgus europaeus*), the tag is glued to one of the two central rectrices (Shewring et al., 2020). The tag has a shallow groove in the epoxy resin on the underside of the same diameter as the proximal section of the central rectrices. It is attached to the base of one of the two central rectrices, glued to the dorsal surface of the rachis so that the grove covers the rachis like a saddle. The antennae will align freely along the central rectrices without being glued to them. Care must be taken to avoid contaminating any other feathers with glue. The attaching procedure requires two people; one to hold the bird and the other to attach the tag. The procedure takes about 30 minutes. On larger birds with thicker rectrices, such as a Northern Goshawk (*Accipiter gentilis*), the tag is sewn on one of the central rectrices (Kenward, 1978). Also, the antenna of the radio transmitter is fixed to the tail feather(s) by use of a thinner thread than the one that holds the tag. The attaching procedure requires two people; one to hold the bird and one to attach the tag. With practice, the procedure would take 30-45 minutes. Longer handling time may reduce the survival of tagged birds (Noel et al., 2013). Duration of the tracking period will be limited to the time until shedding of the rectrices, which will be in late summer or fall, depending on sex. A limitation of tail mounts compared to back mounts is that the tag is positioned further from the bird's center of gravity. Consequently, it must be smaller and lighter, resulting in a shorter lifespan.

Impacts on animal welfare. For tail mounted tags, the **risk** of negative impacts on animal welfare is assessed as **Low**, with high confidence (**Figure 28**). VKM 2013 did not include a risk assessment for use of tail mounts for marking or tagging of wild birds. Our assessment is based on consistent results among studies of species from several orders of birds, consistently low scores on a range of Five Domains observable and welfare alerting indicators (An electronic Supplementary Information), fairly large or large sample sizes, and no reason to suspect much variation among species. One possible exception is alcids, for the **risk** of negative impacts on animal welfare is assessed as **moderate**, with low confidence (**Figure 28**). This assessment is based on a rather old study (Wanless et al. 1989) which found that among breeding Common Murres (*Uria aalge*) and Razorbills (*Alca torda*), tagged birds made fewer foraging trips and each trip lasted longer for tagged birds than for control birds (4b), and the proportion of arrivals at the nest with fish tended to be lower for tagged birds than for control birds (4f).

A general advantage of tail mounted tags is that the tag will automatically be removed from the bird when the rectrix on which the tag is fastened is shed.

* We evaluated the method based on the Five Domains Model (Table 2) and completed score sheets (Table 3) are available as an electronic Supplementary Information.

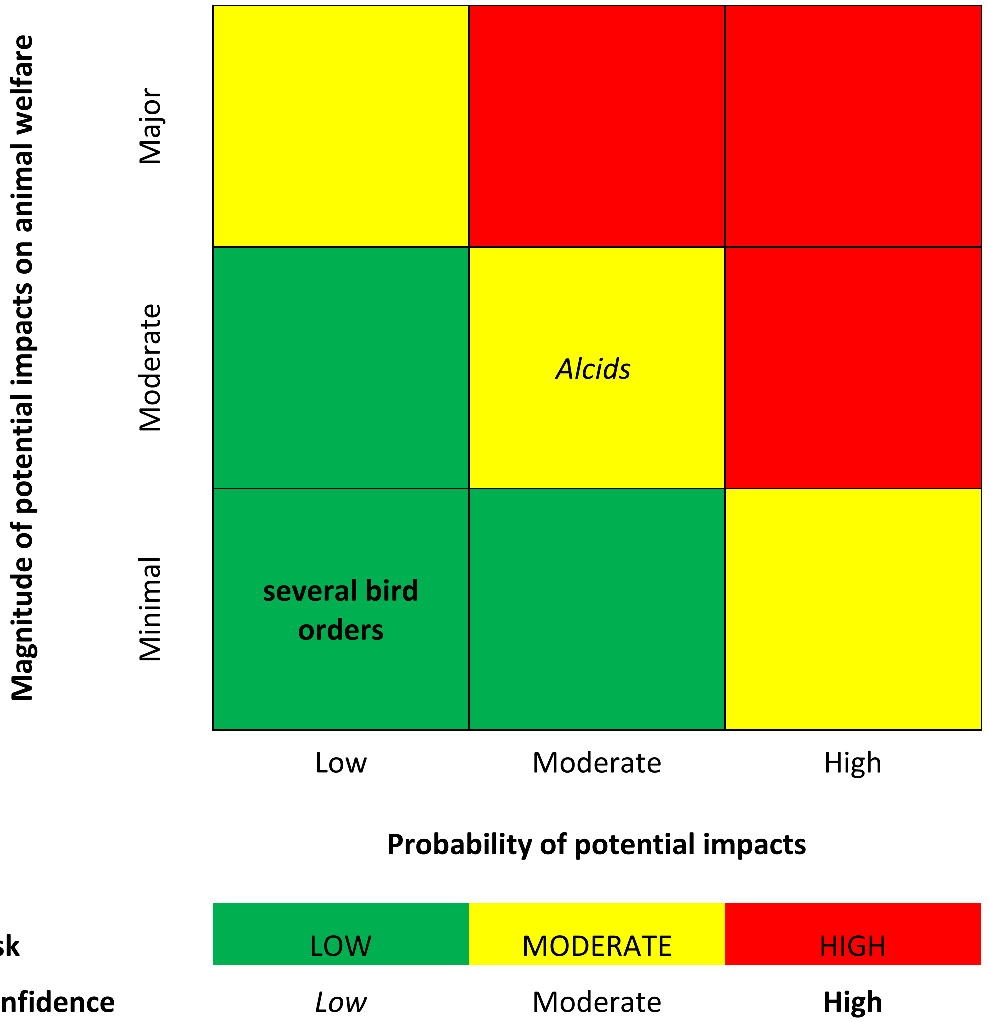

Figure 28. Risk assessment for use of tail mounted tags as mode of attachment of tagging device (radio transmitter) when marking birds.

Risk-reducing measures. Careful consideration of tag weight and antenna design, in particular for diving birds (consider potential for drag). If glue is used for attachment to tail feathers, use non-toxic glues and avoid contaminating any other feathers with glue.

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Leg mounted tags*

Description of method. In addition to marking birds with numbered metal or plastic bands (rings) for individual recognition, over the last 20-30 years, it has become increasingly common to mount tracking devices and biologgers on leg bands. Use of leg bands is related to the fact that the devices have become smaller and are regarded safe to mount on birds' legs. Small tracking devices that can be attached to leg bands or leg flags include RFID tags, geolocators (GLS), TDR loggers, and PIT tags, but also GPS and VHF tags (Haig et al. 2002). Mounting geolocators on leg bands is now widespread (Geen et al., 2019). Leg attachment is mainly utilized for flying seabirds and waders (25% and 32% of studies reviewed by Geen et al. 2019, respectively), but it is also used on other bird groups. Devices and attachment methods have become much refined over the last decades and tracking devices can be deployed on the smallest species of waders (~21 grams) and up to the largest species of seabirds (>10 kg).

Impacts on animal welfare. VKM 2013 did not include a risk assessment for use of leg mounts for marking or tagging of wild birds.

Murres, puffins and other alcids. For geolocators and TDR tags mounted on leg rings the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence for alcids (Figure 29). Empirical studies comparing equipped and control birds report low risk of injury (3b), and no or weak effect effects on body condition and growth rates (energy expenditure; 1d), activity patterns and foraging (4b), return rates (4c), and provisioning behaviour and reproductive success (4f).

Gulls and terns. For leg mounted light-level geolocators, GLS and temperature loggers mounted on leg rings the **risk** of negative impacts on animal welfare is assessed as **Low**, with Moderate confidence for gulls and terns (Figure 29). Empirical studies comparing equipped and control birds report no adverse physiological effects (1d), only short-term increase in preening activity (discomfort; 3d), no signs of leg injuries (3b), and no effects on feeding behaviour (4b), phenology (arrival and laying date) or survival (4c). Kürten et al. (2019) found no negative effects on the share of incubation, provisioning rate, reproductive performance of Common Terns (*Sterna hirundo*). However, Becker et al. (2016) recorded a strong and significant reduction of hatching success of terns marked with geolocators from 86 to 43% due to eggshell breakage.

Waders. For leg mounted geolocators the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence for most shorebirds, but **High** with Moderate confidence for small-bodied waders (Figure 29). Empirical studies comparing equipped and control birds have generally found no or weak effects on body condition (1d), risk of injury (3b), phenology and migration (4c) and reproduction (4f). However, for some small-bodied species, negative effects on reproduction and survival have been found to be substantial (Pakanen et al. 2020, Weiser et al. 2016).

Petrels and shearwaters. For leg mounted geolocators tags the **risk** of negative impacts on animal welfare is assessed as **Low**, with High confidence for petrels and shearwaters (Figure 29). Empirical studies comparing equipped and control birds have found no or weak negative effects on adult and chick body condition (1d), return rates (4c), reproduction (4f) and low incidence of injuries (3b). However, Quillfeldt et al. (2012) found that is a small petrel species, Thin-billed Prions (*Pachyptila belcheri*), tagged and untagged adults differed in their hormonal response to stress 1 year after tagging. The findings suggest that carrying a logger can be energetically costly, but that adults adapt physiologically to a higher workload while maintaining a normal breeding performance (Quillfeldt et al. 2012).

For leg mounted VHF and GLS tags the **risk** of negative impacts on animal welfare is assessed as **Low**, with Moderate confidence for gannets and cormorants (Figure 29). Empirical studies comparing equipped and control birds found no negative effects on body condition/mass (1d), diving activity (4b), or reproduction (4f: nest attendance, foraging trip durations, periods when the chick was left alone, chick growth).

Passerines. For leg mounted PIT tags, the **risk** of negative impacts on animal welfare is assessed as **Low**, with Moderate confidence for passerines (Figure 29). Empirical studies comparing equipped and control birds found no long-term effect on annual fitness (1d, 4f), adult body mass (1d) or adult survival (4c).

Other groups. Miniature geolocators (light loggers) were attached to plastic leg rings of Barnacle Geese (*Branta leucopsis*) in a study by Eichhorn et al. (2006) and no negative effects on nesting or survival were found. Geolocators mounted on leg rings have been used in a few studies of raptors (Rodríguez et al., 2009, Catry et al., 2011). However, further investigation is required to understand if this is a useful and safe method for marking and tracking birds of prey. Given their reliance on capturing and manipulating prey with their legs and feet, there is a significant risk of tags becoming damaged or broken, and potentially also a risk of entanglement or injury.

Reviews and meta-analyses of several bird taxa. Brlík et al. (2020) conducted a meta-analysis of data from published and unpublished studies deploying geolocators on small bird species (<100 g). About 10% of the records included in the analysis were leg-flag attachment on waders (71% leg loop harness, 19% full body harness). Because different attachment methods are used on different groups of birds, the effect of attachment method was not analyzed. However, regardless of attachment method, the analysis revealed only a weak overall effect of geolocators on apparent survival of tagged birds, while they found no clear overall effect on condition, phenology, and breeding performance. Constantini & Møller (2013) conducted a meta-analysis of studies applying geolocators to wild birds. Their meta-regression model of effect size showed negative effects of geolocators on survival for aerial foragers, small-bodied species, and in studies where geolocators were mounted on a leg band versus a leg-loop harness. In a phylogenetically controlled meta-analysis of the effects of biologging devices on birds, Bodey et al. (2017) used a data set comprising more than 450 published effect sizes in 214 different studies to examine the effects on survival, reproduction, parental care foraging trips and body mass. For leg band attachment specifically, they did not find significant negative effects on any of these key traits, but when using a more conservative 80 % Bayesian credible intervals (instead of 95 % CRI) there was a tendency towards reduced survival using devices mounted on leg bands. Geen et al. (2019) reviewed > 3,400 primary references on tracking device use on wild birds and the reporting of the effects of such devices in individual birds including > 1,500 containing information as to whether effects were looked for and reported. They concluded that the use of leg (and tail) attachment, if appropriate, appears to have fewest adverse effects, compared with other attachment methods.

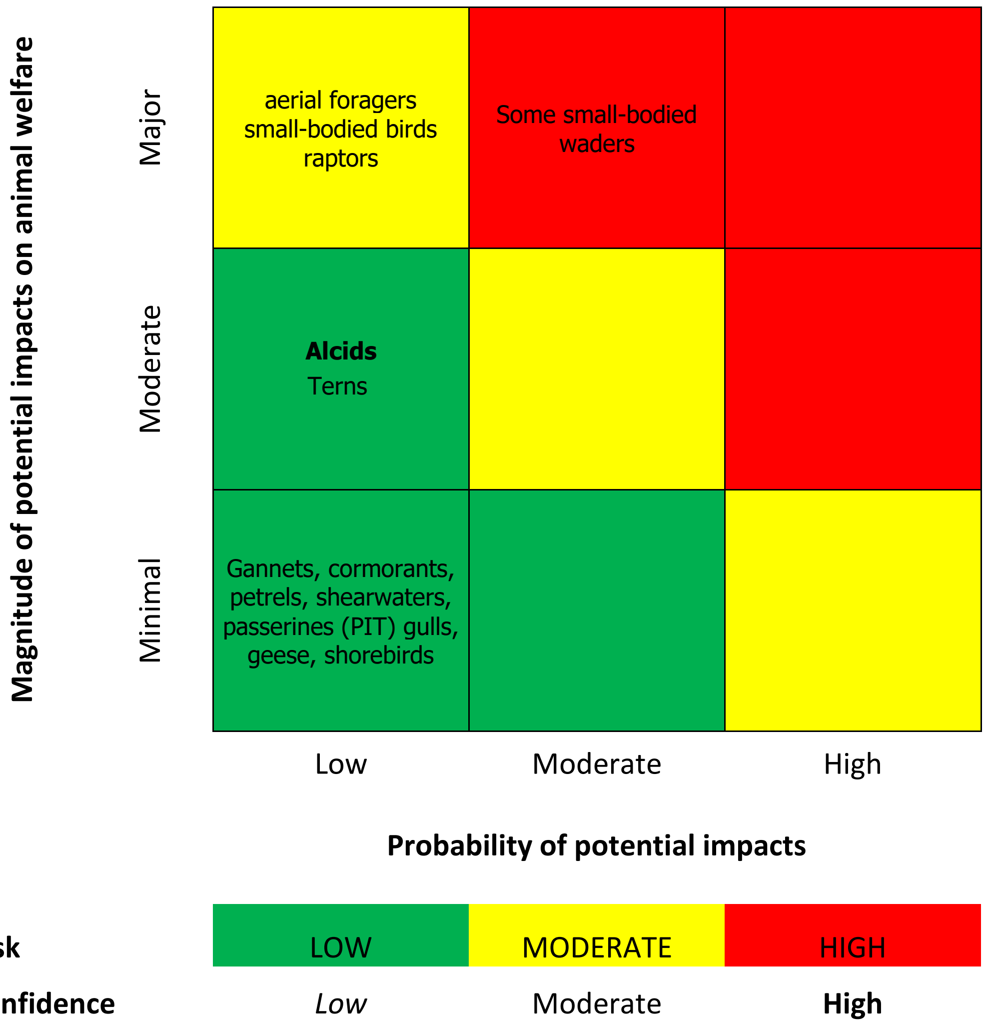

Figure 29. Risk assessment for use of leg mounted tags as mode of attachment of tagging device when marking birds.

Risk-reducing measures. Ensure that the leg band and the tag are fitted properly. Weiser et al. (2016) suggested that negative impacts of geolocators or other leg-mounted tags could be mitigated by minimizing weight (minimize influence on flight efficiency created by an asymmetric load) and by modifying the shape of the tag to reduce damage to eggs or legs. Egg-shell breakage can also be avoided by artificially incubating the eggs (proposed by Becker et al. 2016). Careful consideration when equipping aerial foraging and small-bodied birds with leg mounted tags (Constantini & Møller, 2013, Weiser et al. 2016). The risk of negative impacts of small leg-mounted tags on animal welfare is low for most bird species assessed, and the birds can safely be tagged and tracked over many years. The tags are archival. Recapture for removal or replacement of tags are therefore part of the study protocols, although not all birds can be recaptured. Such tags are intended to stay on for long, but wear and tear may cause safe tag loss. We are not aware of other drop-off mechanisms being applied. To reduce rubbing on the leg, the use of spacer bands below the geolocator has been recommended (Clark et al., 2010).

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Necklace collars

Description of method. Necklace collars are a common method for attachment of radio transmitters and other tracking tags to short-billed species of birds. Necklace collars have been commonly used with gamebirds, with occasional applications to different species of waterfowl, waders, owls, raptors, and parrots. Necklace collars have not been used with seabirds, woodpeckers or songbirds. Early attachment methods included relatively heavy VHF radios and a 'poncho' design that fit over the head of the bird. In the case of geese, radios have been mounted to the wide plastic neck collar also used for individual identification. Modern designs for necklace collars typically have a thin elastic harness that encircles the neck, a small radio transmitter that sits like a pendant on the breast, and a whip antenna that exits from the harness at the nape of the bird and extends over the back. An advantage of necklace collars is that the tag is positioned above the crop of the bird and a relatively loose elastic can be used so that the harness is preened under the feathers of the neck and breast. Prefit harnesses can be quick to attach and remove during handling. The main disadvantage with necklace collars is that birds with longer bills are at risk of becoming 'bridled' if the harness becomes entangled in the gape of the mouth. Harnesses around the neck can also interfere with throat sacs or head feathers and the position of the whip antenna over the back can potentially contact the upstroke of the wing.

Impacts on animal welfare. For gamebirds, the **risk** of negative impacts of necklace collars on animal welfare is assessed as **Low**, with High confidence (**Figure 30**). For small-bodied owls, the **risk** of negative impacts on animal welfare is assessed as **Low**, but with Low confidence. For waterfowl, waders and raptors, the **risk** of negative impacts on animal welfare is assessed as **Moderate**, with Moderate to High confidence. Our new assessment **confirms and upgrades** VKM 2013 (table 5) which ranked use of 'neck collars on waterfowl' as having a Low risk of negative impacts on animal welfare. Necklace collars are typically light weight with loose harnesses that do not affect intake of water and food or energy expenditure (1a-d). Application of necklace collars can be completed quickly while the bird is held with the head and neck in an upright position (2a). Abrasion from necklace collars and other types of harnesses may affect waterproofing of feathers and thermoregulation in waterfowl and other waterbirds (2b). In gamebirds, necklace collars are typically preened into the feathers so that the tag sits on the upper breast. The position of the tag sitting over top of the crop is a natural balance point with minimal disturbance for large-bodied herbaceous birds (2c). The position of the whip antenna over the back does not affect flight performance in large-bodied grouse (Frye et al. 2014), but rotation of the collar around the neck may allow owls, raptors and parrots to break the antenna or remove the collar (Meyers 1996, Gilson 1998, Chipman et al. 2007). Long-billed species of birds have a potential risk of entanglement in the harness (2d). Field tests of necklace collars with diving ducks, plovers and raptors have reported that individual birds occasionally had the harness wedged in the gape of the bill which is fatal if birds cannot free themselves (Sorenson 1989, Gilson 1998, Warnock and Takekawa 2003). Effects of necklace collars on animal health (3a-b) include short-term effects where newly tagged animals may spend more time preening or trying to remove the device, as well as possible feather wear on the back of the neck (Sorenson 1989, Chipman et al. 2007). Necklace collars are unlikely to affect susceptibility to disease (3c). Radio transmitters attached with necklace collars have been widely used to investigate habitat use, activity budgets, and animal movements (4a-c) but comparable data are usually not available for a control group without tracking tags. Attachment of radio transmitters to neck bands can have negative effects on social behavior and pairing success in geese (4d-e, Schmutz and Morse 2000, Demers et al. 2003) but wide plastic neck bands are likely more intrusive than the typical elastic necklace collar. Early studies that used heavy radios attached with ponchos reported negative effects on the reproductive success of gamebirds (4f, Marks and Marks 1987, Burger et al. 1991), but impacts have been minimized with continuing reductions in transmitter size and improvements in harness design. One possible exception is if necklace collars interfere with reproductive behavior of birds that produce vocalizations from inflatable throat sacs (Fremgren et al. 2017). Necklace collars are unlikely to affect competitive interactions (4h) but could affect risk of predation if they are a burden that handicap free-living birds (4g). Nevertheless, several large-scale field studies with large samples of treatment and control birds have found that necklace collars have little to no effect on the demographic performance of gamebirds (Erikstad 1979, Thirgood et al. 1995, Hagen et al. 2006, Palmer and Wellendorf 2007, Terhune et al. 2007). Necklace collars were better than body harnesses for marking Burrowing Owls (*Athene cunicularia*) but both methods reduced annual survival relative to birds marked with rings only (Gervais et al. 2006). Birds marked with necklace collars can have higher mortality rates immediately after release (4i) which could be due to a combination of handling effects and an acclimation period after tagging (Caizergues and Ellison 1998, Bro et al. 1999).

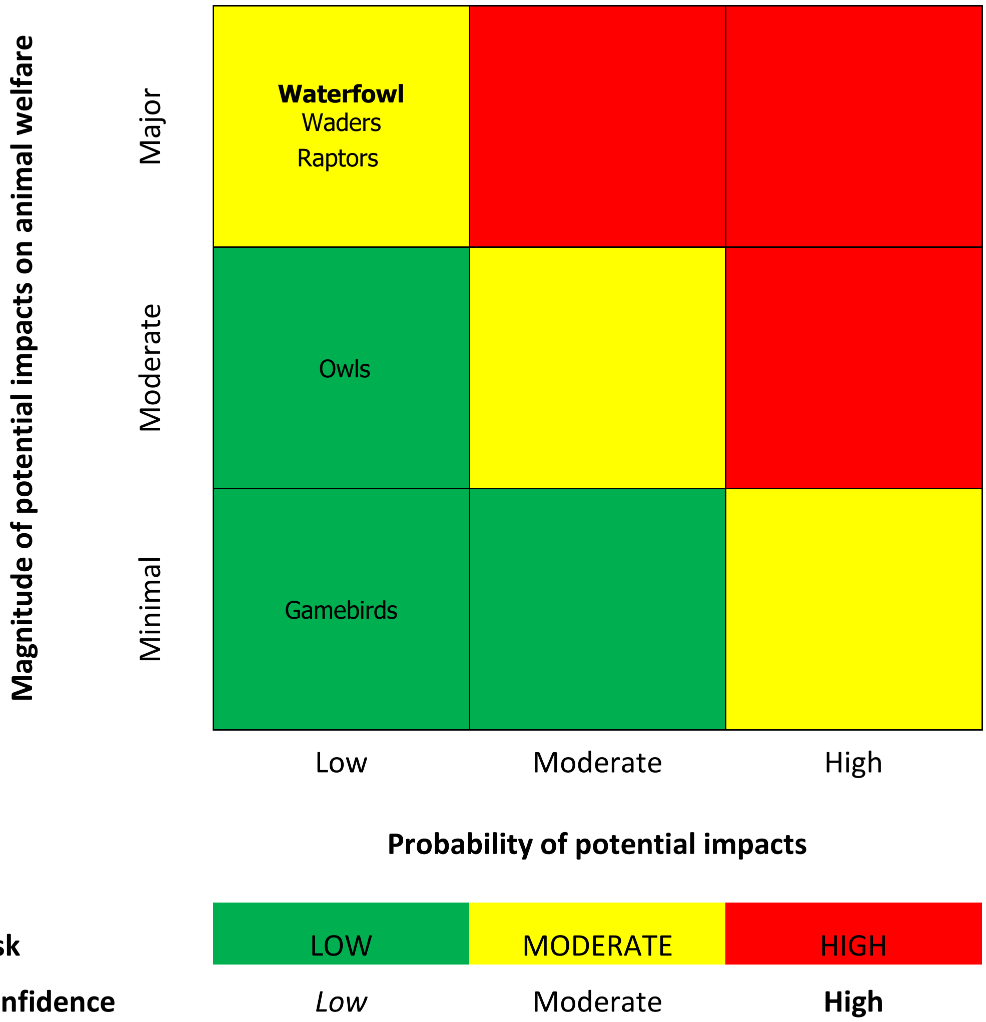

Figure 30. Risk assessment for use of necklace collars as mode of attachment of tagging device when marking birds.

Risk-reducing measures. Necklace collars are a safe and effective method for attaching tracking tags to gamebirds and small-bodied owls if miniature tags are used with light elastic harnesses. Crimping the antenna to lie over the back of the bird can help to reduce the profile and avoid possible interference with the wing stroke. Preparation of the elastic neck loop to a suitable diameter helps ensure that tags can be attached and removed quickly, which reduces handling time. If the transmitter surface is polished or reflective, painting the tracking device to match the plumage coloration can help with concealment and reducing predation risk. Necklace collars should be avoided with most waterfowl because harnesses can affect waterproofing of feathers in diving birds. Similarly, waders and other long-billed birds may have a higher risk of entanglement in the gape of the bill. Owls, raptors and parrots may be able to remove or damage the tracking device by rotating the collar to pull on the antenna and radio and harness materials may need to be more durable to avoid damage (Meyers 1996). In some cases, birds that have become entangled have been successfully recaptured to remove the tag. Necklace collars have been successfully deployed on some long-billed birds such as juvenile woodcock (Daly et al. 2015), and a pilot study could be used to determine if a new study species can successfully carry necklace collars.

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Leg-loop harness

Description of method. Leg-loop harnesses have been widely used to attach geolocators, VHF radios, and other tracking tags to small-bodied species of birds with relatively long legs, including waders, seabirds, woodpeckers, and songbirds. The technique has also been used occasionally with different species of gamebirds, raptors and owls. Some rails and waders with a compact body shape have relatively short thighs and will slip out of leg-harnesses unless the harness design also includes an additional body loop (Haramis and Kearns 2000, Chan et al. 2016, Scarpignato et al. 2016). Leg-loop harnesses usually cannot be used with short-legged species of nightjars, swifts, and doves. Leg-loop harnesses can also be used with fledglings if the harness is designed to expand during juvenile growth or if the young are similar in body size to adults (Naef-Danzer et al. 2001, Rae et al. 2009). The method was originally developed for small songbirds (Rappole and Tipton 1991) but has been since adapted and refined for other groups of birds (Sanzenbacher et al. 2000, Mallory and Gilbert 2008, Streby et al. 2015). The typical design is a pair of leg loops that fit around the legs so that the harness lies between the inner part of the thigh and the lower breast. The tracking device sits on the lower back above the synsacrum and anterior to the uropygial preen gland, where it is often preened into the feathers on the back. If desired, the tag position can be adjusted to be centre- or rear-weighted (Buck et al. 2022). The whip antennas of VHF transmitters extend back over the tail of the bird whereas light stalks on geolocators and solar panels on GPS tags may protrude above the back of the bird. Different harness materials have been used including elastic beading cord or silicone rubber, or inflexible cotton thread, nylon cord, or Teflon ribbon. Leg-loop harnesses can be prepared in advance with a standard loop size or can be custom fit to the bird during handling. A drop of quick-drying glue is often used to secure any knots and to avoid fraying of harness materials. Harness designs with weak links can be used to ensure that tracking tags are shed after a shorter period of attachment (Karl and Clout 1987, Doerr and Doerr 2002, Kesler 2011). Attachment of tracking tags with leg-loop harnesses requires less handling time than glue methods and offers better radio retention (Mong and Sandercock 2007, Streby et al. 2015). Leg-loop harnesses can be a better design than necklace, wing or body harnesses because they are less likely to interfere with head or wing movements thereby ensuring unimpaired foraging and flight (Bowman and Aborn 2001, Mallory and Gilbert 2008). The harness and tag fit closely to the body of the bird which minimizes both the effects of drag and the risk of entanglement with the bill or vegetation. Field applications of leg-loop harnesses have facilitated successful tracking of individual birds for the entire annual cycle with long-distance migratory movements up to 20,000 km and across major geographic barriers with sustained flights of up to a week in duration (Gill et al. 2009, Snell et al. 2018, Hill et al. 2019).

Impacts on animal welfare. For waders, gulls, terns and songbirds, the **risk** of negative impacts from use of leg-loop harnesses on animal welfare is assessed as **Low**, with High confidence (Figure 31). The risk of negative impacts is assessed as **Moderate to High** with Low confidence for waders that undergo large seasonal changes in body mass to fuel long migrations, and also for large-bodied species of woodpeckers that use their hindlimbs to climb trees. VKM 2013 (table 5) evaluated 'body harnesses' as having High risk for negative welfare for wild birds. The risk assessment for leg-loop harnesses **has been downgraded** because continuing refinements and a growing number of field studies have shown that leg-loop harnesses can be a safe and effective method for marking small-bodied species of birds. Leg-loop harnesses position the tracking tag on the back of the bird and are unlikely to affect access to food or water (1a-c) by impacts on foraging rates (Neudorf and Pitcher 1997, Bell et al. 2017). Carrying a harness could affect energy expenditure (1d), but controlled studies have reported no effects on body condition between tagged and untagged birds (Powell et al. 1998, Rae et al. 2009, Gow et al. 2011, Townsend et al. 2012). Similarly, stress responses to tag attachment with leg harnesses are transitory and can return to normal after 48 hours (Suedkamp Wells et al. 2003). One advantage of leg-loop harnesses is that they can reduce handling time (2a, Biles et al. 2023), with some designs that can be fit to a bird in less than a minute (Streby et al. 2015). Leg-loop harnesses are less likely to affect thermoregulation (2b) than glue techniques because the skin and feathers do not need to be prepared before use of adhesives. The tracking tag is often preened into the back feathers, and problems with heat and icing have not been reported. Feather cover can be a disadvantage for charging of tags with solar panels (Thaxter et al. 2014). Leg-loop harnesses place the tag on the central axis of the bird so that the weight load is balanced but the total mass could still affect aerodynamics or locomotion (2c). Heavy tags that are >3% of body mass can reduce flight performance (Tomotani et al. 2019). Other effects on aerodynamics of small-bodied birds have mainly been due to features of the tracking tag including the protruding light stalks of geolocators (McKinnon et al. 2013, Scandolara et al. 2014, Blackburn et al. 2016, Taff et al. 2018) or antenna design (Dougill et al. 2000). Leg-loop harnesses have a clear negative effect on large woodpeckers which is related to their specialized mode of locomotion of 'hitching' up and down trees while foraging. Use of leg-loop harnesses reduced survival rates of Pileated Woodpeckers, possibly because motion of the hindlegs was handicapped (Noel et al. 2013). The risk of entanglement (2d) is reduced with leg-loop harnesses and tags on the rump because birds are less likely to entangle their bill than in a necklace or body harness (Bowman and Aborn 2001). Similarly, entanglement with vegetation (2d) is a rare event for leg-loop harnesses because both the harness and the tracking tags lay close to the body surface (Streby et al. 2015). Field studies with leg-loop harnesses have reported reductions in comfort (3a), with increased preening or birds attempting to remove the device after attachment but the effects are usually temporary (Sykes et al. 1990, Bowman and Aborn 2001, Smith et al. 2017). Leg-loop harnesses pose a low risk of injury to wild birds (3b) with rare cases of skin abrasion and occasional feather wear (Sanzenbacher et al. 2000, Gow et al. 2011, Arlt et al. 2013, Lislevand and Hahn 2913, Scandolara et al. 2014, Blackburn et al. 2016). Field tests of different materials have shown that soft elastic harnesses can improve animal welfare compared to nonelastic nylon thread or other materials (Streby et al. 2015, Blackburn et al. 2016). Harnesses do not affect susceptibility to disease (3c). Evaluation of effects of leg-loop harnesses on habitat use, time budgets and migratory movements (4a-c) are impossible to compare to ringed birds without tracking devices but can be compared to alternative modes of tag attachment. Leg-loop harnesses are often better for animal welfare than wing or body harnesses (Bowman and Aborn 2001, Mallory and Gilbert 2008). On the other hand, alternative attachment methods can be better for selected species such as necklace collars in Greater Sage-Grouse (Severson et al. 2019), wing harnesses for Great Skuas and American Kestrels (Thaxter et al. 2014, Biles et al. 2023), and tail mounts for large woodpeckers (Noel et al. 2013). Leg-loop harnesses generally have little effect on social and mating behavior (4d-e) because rump-mounted tracking tags do not interfere with natural behavior. Effects on reproductive performance (4f) are mixed with many studies reporting no effects (Gow et al. 2011, Streby et al. 2013, Bell et al. 2017, Buck et al. 2022) and others reporting small differences in phenology or reproductive success (Arlt et al. 2013, Scandolara et al. 2014). One caution is that use of leg-loop harnesses to tag nestling songbirds can induce the parents to reject the young and remove them from the nest (Mattsson et al. 2006). Leg-loop harnesses may increase predation risk (4g) if the tracking tag has a reflective solar panel or is a heavy package (Scandolara et al. 2014, Severson et al. 2019). In many wild birds, use of leg-loop harnesses has no effect on annual return rates or apparent survival (Powell et al. 1998, Naef-Danzer et al. 2001, Townsend et al. 2012, Lislevand et al. 2013, Summers et al. 2014, Blackburn et al. 2016, Bell et al. 2017, Smith et al. 2017, Buck et al. 2022), or the treatment group has a small reduction compared to controls that are ringed only (Mong and Sandercock 2007, Arlt et al. 2013, Scandolara et al. 2014, Taff et al. 2018). For species of conservation concern, any potential reductions in survival may be unacceptable (Chang et al. 2020). For abundant species, the value of reducing the numbers of experimental birds by using new tracking tags to obtain high resolution movement data must be balanced against a potential for small reductions in animal welfare of individual birds. Leg-loop harnesses are not known to affect competitive interactions or the risk of kleptoparasitism (4h) but have the advantage that handling time is often reduced compared to other attachment methods for tracking tags (4i).

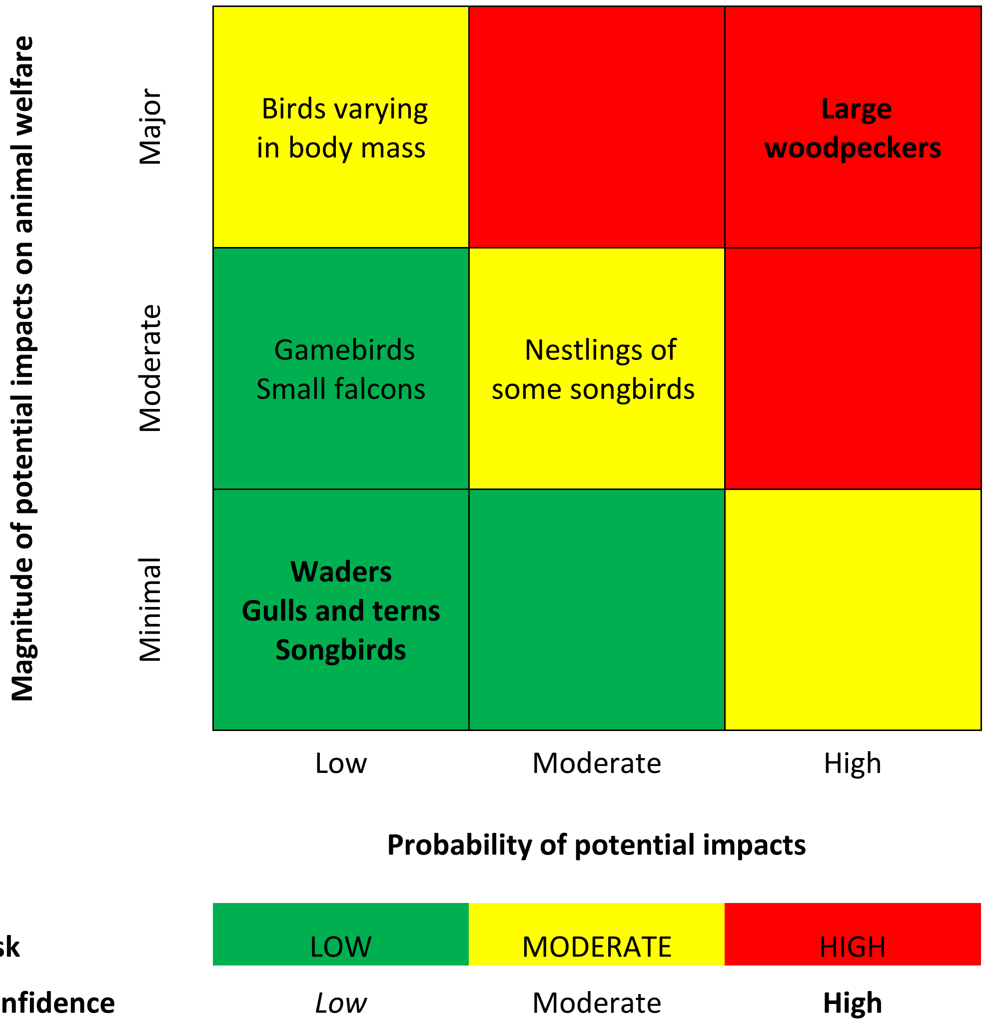

Figure 31. Risk assessment for use of leg loop harness as mode of attachment of tagging device when marking birds.

Risk-reducing measures. Leg-loop harnesses have been successfully deployed on a wide range of small-bodied birds, but other attachment techniques have given better results for a few different species. Pilot studies of captive birds or testing alternative attachment methods can reduce risk if starting a new project with a bird species of unusual body shape. Field tests with common species can also help to evaluate tag designs before field applications to a population of conservation concern. Deployment of tags on nestlings in the nest led to parental rejection in one songbird and waiting until young have fledged could reduce risk of abandonment. In general, tags and harnesses should be lightweight if applied to small-bodied birds. If total mass of supplementary marking is a concern, use of leg bands or other marks could be omitted if the tracking tags already provide individual identification. One challenge in deploying leg-loop harnesses is ensuring that the tension of the harness is adjusted correctly and is not too tight, which is often easier to accomplish with two people working together as a team. Leg-loops should be used with caution with young birds that have not completed growth or birds that have variable body mass associated with fat deposition to fuel migratory movements. Close monitoring of birds after tag deployment can help with early detection of problems of harness fit and might allow birds to be recaptured to remove the harness and tag. A loose fit is less of a problem because birds easily shed the leg-loop harness although the poor retention caused by tag loss can create logistical problems for tracking studies. Preparing harnesses in advance can reduce handling time whereas attachment during handling can ensure that the harness is custom fit to each individual bird. A variety of materials have been used for leg-loop harnesses and some birds perform better with elastic cord with a soft coating and a flexible core that allows for seasonal changes in body mass. Nonelastic or more durable materials may be required for better radio retention on birds with strong bills that are capable of removing the harness, and the fit might be adjusted to be looser than the equivalent elastic harness. Some field studies require only short-term retention to match the duration of expected battery life or to facilitate recovery of a shed tag. In such cases, use of silk thread, absorbable suture cord, or other organic materials can ensure that the harness will dissolve and break after several weeks of environmental exposure. Alternatively, weak links can be incorporated in the harness to ensure faster shedding or to allow breakage if risk of entanglement is a concern. Durability of harness materials can be evaluated with field tests before applications to wild birds, for example by investigators testing different materials as wristbands. The location of the tag on the lower back can increase conspicuousness of birds that rely on cryptic coloration to reduce predation risk. Tags can be painted to match the background coloration of the bird, at least if the power source is a battery and not a solar panel. The uropygial gland of birds is located at the base of the tail and produces waxy secretions that are essential for feather maintenance. All tags should be located anterior to the gland where the tag position will not interfere with normal preening behaviour. Preening of feathers over the tag can create problems for tags with solar panels that require access to light for charging. Tags with a raised platform for the solar panel can ensure proper tag function but at a potential trade-off with aerodynamic performance. Continuing refinements to harness and tag design can improve animal welfare via use of lightweight harness materials, smaller tags with a flat aerodynamic profile, reducing the length of light stalks on geolocators, or trimming antennas on tracking tags to reduce risks of entanglement.

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Backpack (thoracic) harness*

Description of method. Different tracking tags have alternative designs for anchoring harnesses to the tag (Kenward, 1985; Steenhof et al., 2006; Peniche et al., 2011; Lameris et al., 2018; Clewley et al., 2021; Fijn et al., 2024). Some tags have attachment points on the sides (2 on each side), and some have tubular channels running across the tag's underside, one at the front and one at the end. Other tags have attachment points formed as channels under the front and rear end of the device, usually forming a type of 3- or 4 -point attachment. The tubular channels allow harness straps to be threaded through, and the attachment points allow knots for securing the harness. The advantage of having the attachment points as channels under the tags, is that the knots are well hidden and cannot be reached by the bird's beak.

For large birds, the harness is often crafted from a tubular Teflon ribbon of suitable diameter. Alternatively, nylon thread or dental floss of appropriate thickness may be used, possibly enclosed in stiffer materials like silicone rubber. Some studies have also used harnesses of biodegradable materials. Constructing the harness involves several steps. First, threading the ribbon through the front tube, ensuring equal lengths of ribbon on each side of the bird. Next, guiding the two strap segments around each respective wing. Last, sliding both ends of the harness through the tube at the back. The loops around the wings are fastened together on or across the bird's chest using various techniques. Some techniques require that these steps are completed before the harness is threaded through the tube at the back. The ends of the harness on each side of the tube are secured and trimmed to prevent any loose threads from trailing or entangling the bird. There are several methods for attaching the ribbon loops to the bird's chest and securing the ends. One useful approach for larger landbirds involves using short cylinders of sterling silver. The cylinders can be gradually flattened with pliers in multiple steps, allowing for individual adjustment of the harness to fit each bird perfectly. A good fit is crucial, and it is essential to ensure symmetry so that both sides of the harness are equal length. It is important that the harness is sufficiently loose to allow full flexibility of the bird's movements and to accommodate potential changes in body mass, while at the same time not being too loose so that the bird risks being entangled in vegetation. The attaching procedure typically requires two or three people: one to hold the bird and one or two to attach the harness. With practice, the process of attaching the harness can be completed in about 15 minutes. The technique for constructing the harness varies somewhat among studies. Additionally, the terms backpack/wing/full body/thoracic harness are often used interchangeably in the literature, and it is often unclear exactly how the harness was constructed.

An advantage of backpack mounted tags is that the tag is located near the gravity centre of the bird, so that a larger (heavier) – and thus more long-lasting – tag may be used. A drawback is that the tag remains on the bird until the harness is demounted. However, harnesses can be designed with a weak-link that will ensure a drop-off, and this design has worked for some species, such as Lesser Black-backed Gulls (*Larus fuscus*) and Herring Gulls (*L. argentatus*, Clewley et al. 2021). When suitably designed, the weak-link harness detaches from the bird safely, reducing the risk for negative effects and prevent tagging for life. If the harness drops off earlier than planned for data collection, premature tag loss does not impact animal welfare. Safe solutions for harness detachment remain to be developed for many other bird groups (see Risk-reducing measures below).

Impacts on animal welfare varies substantially among species and orders. Scientific papers that have collated and analysed data across several studies have documented heterogeneity in impacts (Barron et al. 2010, Hill & Elphick 2011, Lameris & Kleyheeg 2017, Brlík et al. 2020) which makes is challenging to draw general conclusions even within groups of similar species. Drawing generalities is further complicated by the fact that the heterogeneity, even between studies of the same species, may also be caused by use of slightly different methods of constructing the harness, different personal experience and dexterity, and different ecological conditions, the latter affecting the performance of the tagged birds.

VKM 2013 (table 5) evaluated 'body harnesses' as having High risk for negative welfare for wild birds. The risk assessment for backpack harnesses is **confirmed** for some waterfowl, rails, and corvids where negative impacts have been reported. The risk assessment for backpack harnesses **has been downgraded** for several groups of species because continuing refinements and a growing number of applications in other countries have shown that backpack harnesses are a safe and effective method for a subset of bird species.

For hawks and falcons, the **risk** of negative impacts on animal welfare is assessed as **Moderate**, with <u>High</u> confidence (**Figure 32).** The backpack harness may cause decreased comfort (3a) and more rarely injury (3b). Welfare impact is major (mortality) in rare cases, otherwise minimal. Impacts on migration/movement (4c) and reproduction (4f) is generally found to be low.

For owls the **risk** of negative impacts on animal welfare is assessed as **Low**, with <u>Moderate</u> confidence (**Figure 32**). The backpack harness may cause decreased comfort and distraction (3a). Petty et al. (2004) found reduced survival of radio tagged juveniles compared to untagged ones in Tawny Owls *Strix aluco*, whereas Sunde (2006) found no negative impacts on welfare of radio tagged juveniles for the same species.

For passerines the **risk** of negative impacts varies substantially among species (**Figure 32**). A study of >60 passerine species found that negative transmitter impacts were reported for ≥1 bird for 38% of species but concluded that most serious problems are probably short-lived and affect few individuals within any one study (Hill & Elphick, 2011). Furthermore, species that had transmitters attached using harnesses or glue were equally likely to experience entanglement (2d) (19% vs. 13% of species) and non-entanglement injury (3b) (17% vs. 13% of species). For some corvids, **risk** is assessed **High** with <u>Moderate</u> confidence, based on the findings that radio-tagged Florida Scrub-Jays (*Aphelocoma coerulescens*) may withdraw or be excluded from social interactions (4d), change their activity pattern and time budget (4b), as well as show signs of discomfort (3a).

Brlík et al. (2018) conducted a quantitative review of published and unpublished studies deploying geolocators attached with full-body harness, leg-loop harness or on leg-flags on small bird species (body mass <100g). The review revealed only a weak overall effect of geolocators on apparent survival (4c) of tagged birds while they found no clear overall effect on body condition (1d), phenology (4c), and breeding performance (4f). They did not compare the tagging effects of different attachment types due to their use in specific groups of species (e.g. the full-body harnesses in nightjars and swifts and the leg-flagged attachment in shorebirds only).

For swifts and nightjars, **risk** is assessed as **Low** with <u>Moderate</u> confidence. For some rails, **risk** is assessed as **High** with <u>Moderate</u> confidence, based on the finding that 10 of 16 individuals of the flightless New Zealand Takahē (*Porphyrio hochstetteri*) that had worn a harness (63%) had mild, moderate, or severe injuries (3b).

For waterfowl, large differences have been found in the occurrence and type of negative effects between species and studies, even if the same tracking methods were used (Lameris & Kleyheeg, 2017). For waterfowl, the **risk** of negative impacts on animal welfare is assessed as **Low to High**, with <u>High</u> confidence (**Figure 32**). The main negative effects of harness backpacks are that they can cause skin abrasion (3b) and drag (2c), disrupt waterproof plumage (2b) and that the harness may be too loose or too tight (2c-d,3b) especially if body weight fluctuates throughout the year. Reduced survival and return rates (4c) have been found in several studies, as well as behavioural changes - long term or persistent over time – such as increased maintenance (3a) or reduced foraging (4b). Furthermore, backpack mounted tags can increase the cost of migration, reducing body condition (1d) and migration distances (4c) and lead to later arrival on breeding grounds (4c), which can carry over to reduced breeding success (4f). Yet, for some duck and geese species, only minimal impacts on aerodynamics/drag (2c), comfort (3c), movements and migration (4c) and reproduction (4f) have been documented or inferred.

For order Charadriiformes, the **risk** of negative impacts on animal welfare is assessed as **Low** for some gulls, such as Lesser Black-backed Gulls (*Larus fuscus*) and Herring Gulls (*L. argentatus*), whereas for terns, skuas and other gulls, such as Black-legged Kittiwakes (*Rissa tridactyla*), it is assessed as **Moderate**, with <u>High</u> confidence in both cases (**Figure 32**). Some incidents of decreased comfort (3a) and injuries (3c) and a few cases of fatalities have been reported for terns. Minimal impacts on migration, movements, or return rates have been found in gulls (4c), as well as minimal impacts on reproduction in gulls, terns, and skuas (4f).

For other seabirds, the **risk** of negative impacts on animal welfare is assessed as **High**, but with <u>Low</u> confidence for albatrosses (injury: 3c) (**Figure 32**) and as **Low** with <u>Low</u> confidence for pelicans where long handling time led to decreased breeding success (4f,4i).

* We evaluated the method based on the Five Domains Model (Table 2) and completed score sheets (Table 3) are available as an electronic Supplementary Information.

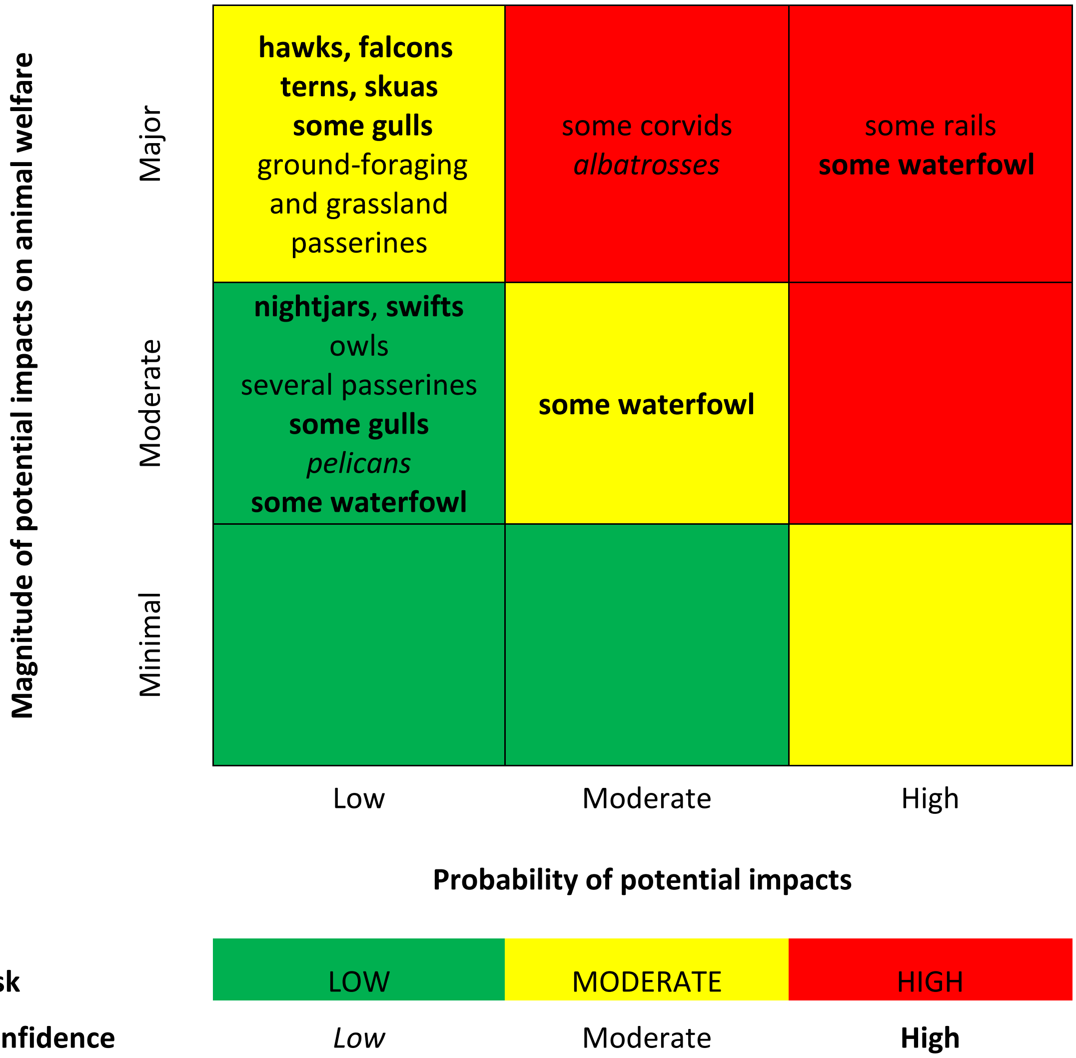

Figure 32. Risk assessment for use of backpack harness as method for attaching tracking or logging device when marking various bird groups.

Risk-reducing measures. Equipping a bird with a well-fitted backpack transmitter requires experience and skills, and the risk to animal welfare will largely depend on the person conducting the tagging. Proper fitting requires skills and dexterity that cannot be acquired through a standard animal care course. When tagging with backpack transmitters, it is particularly important to adhere to the general risk-reducing measures mentioned in Chapter 13, that is, following best practices, conducting pilot and effects studies, consulting experienced ornithologists, and assuring proper and sufficient training.

Safe solutions for harness detachment without recapture remain to be developed for most bird groups. However, safe drop-off solutions may be readily available in the future, so there will be no need to recapture animals that have been tagged to remove the transmitter and harness after the study is completed. A few published studies have tested self-releasing harness material solutions (Clewley et al. 2021, Fijn et al. 2024). Clewley at al. (2021) found that harnesses of weak-link materials using cotton thread, cotton piping cord, and nitrile rubber were suitable for Herring Gull and Lesser Black-backed Gull, and harnesses detached safety and completely. However, Fijn et al.

(2024) reported that entanglement of cases Sandwich Terns (*Thalasseus sandvicensis*) fitted with harness of degradable material was incidentally observed in three cases. Further testing on other bird species is needed to ensure that birds do not get tangled in partially detached harnesses. Tagging fully grown adults may be associated with lower risk than tagging juveniles that have not yet reached full body size. However, Hill & Elphick (2021) found that the occurrence of negative transmitter effects was similar for adults and juveniles in passerines.

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Surgical implants*

Description: Surgical implantation is a procedure for attachment of devices that are directly implanted within the body of the individual bird and used for measurement of physiological variables (body temperature, heart rate, body movement) or logging data on spatial position (diving depth, position). Different types of devices can either store data that must be retrieved physically at a later point of time, or they can transmit the data to a receiver network. To facilitate good connection and transmission, implanted biologgers are sometimes used together with a second external device (necklace collar, backpack harness) which receives the data from the implant and then forwards the information to the receiver. Surgical implants can be subcutaneous and inserted between the skin (epidermis and dermis) and underlying tissues, or they can be inserted directly into the body cavity of the bird, the coelom, or into the right abdominal air sac. Surgical implants require use of a combination of both general and local anesthetics to immobilize the bird during the procedure. Implants are most often used for instrumentation of birds where external devices are thought to have negative impacts, for example to avoid buoyance and increased drag on diving birds, where external devices are thought to create a high risk of entanglement or other disadvantages, or where the researchers need reliable data on physiological variables that are difficult to obtain by use of external devices. Implants of tracking devices may also be advantageous for migratory birds that undergo dramatic seasonal fluctuations in body mass if fat reserves are used for long-distance migratory flights. Most of the literature describes use of *coelomic implants* (also called abdominal implants) in relatively large species of diving birds such as penguins, auks, sea ducks, and other waterfowl. There are also reports of use of implants in curlews and godwits as large-bodied species of waders and a single report on use in falcons.

Impacts on animal welfare. For large diving birds, ducks and geese, the **risk** of negative impacts on animal welfare is assessed as **Low**, with <u>Medium</u> confidence. (**Figure 33**). Large scale studies in ducks have showed little impact on welfare, but studies in other species show larger impacts. Abdominal implants of radio transmitters in godwits did not affect migratory movements but negatively affected reproduction with females producing deformed eggs. Reports of direct mortality are uncommon in the literature but should be expected to occur in rare cases. For large waders, the risk of negative impacts on animal welfare is assessed as **moderate**, with low confidence.

In VKM 2013, coelomic implants were considered to constitute a medium risk of negative welfare because of (quote) "*the hazard connected to the surgical procedure and the possible impact of the implant to the physiological functions of the peritoneal cavity*." The evaluation seems obvious, but little published evidence is available to support the statement, and the proportion of birds that die as a direct consequence of the surgery and implant seem to be very low or low in the studied populations. On the contrary, many studies, some of them including large numbers of birds (ducks), describe that there are few if any detectable impacts of the instrumentation, and some conclude that surgical implants may constitute a less harmful way of marking birds than many external devices. Other studies point out that energy use and performance

may be affected over long time even when no immediate effects are observed. However, as with marking methods, the size, shape and weight of the implanted device relative to the size and shape of the bird is critical. Of special concern are devices that occupy a large volume, even though they may be light and have an ergonomic design, they may decrease the respiratory capacity of the implanted birds and thereby affect feeding efficiency, flight endurance, or other aspects of performance. We also suspect that implants with an external antenna penetrating the coelomic wall may constitute a significantly different risk to animal welfare than implants that only lie within the coelomic cavity but have not found any studies investigating the two designs.
* We evaluated the method based on the Five Domains Model (Table 2) and completed score sheets (Table 3) are available as an electronic Supplementary Information.

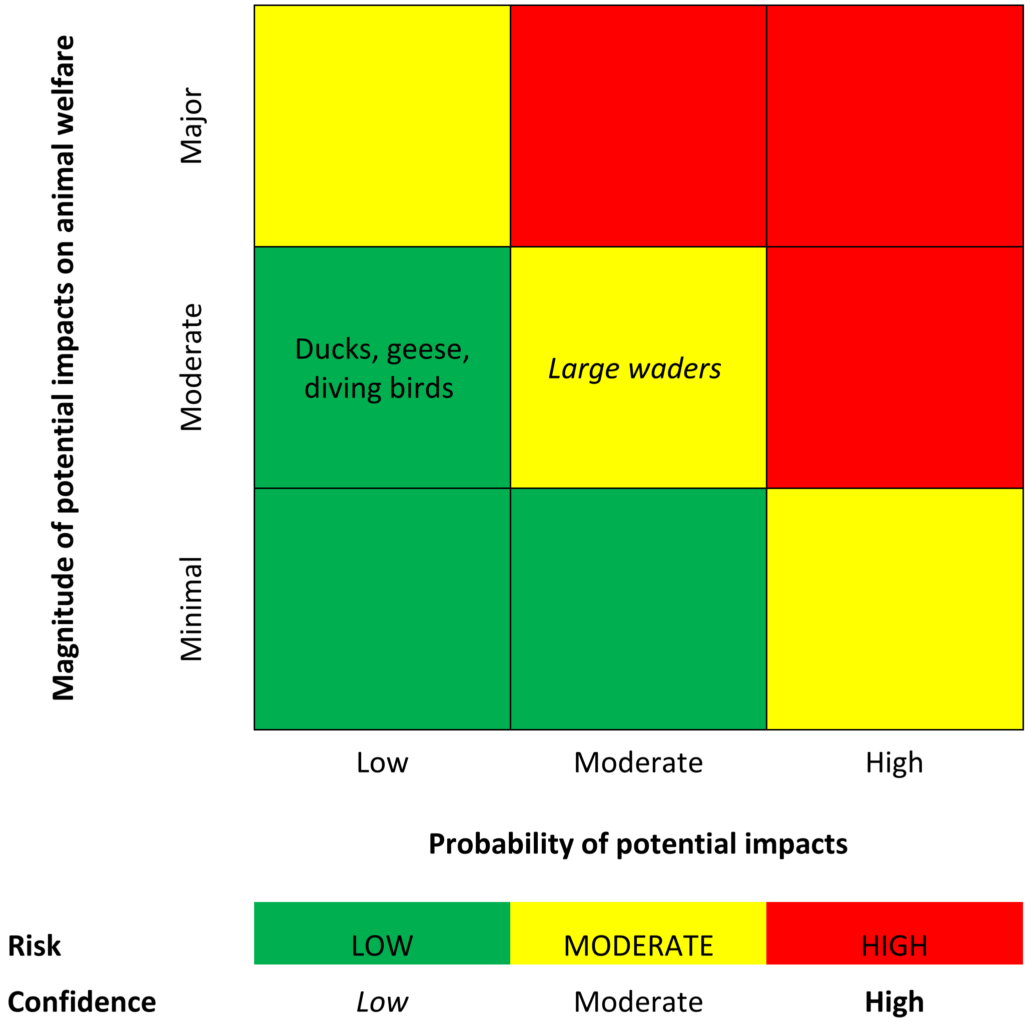

Figure 33. Risk assessment for use of surgical implants as mode of attachment for tagging devices when marking birds.

Risk-reducing measures. Successful surgical implantation that minimizes the risk of harm to animal welfare relies upon the methods applied and the training and competence of the team that is performing the surgery. It is important that both the veterinary surgeon and the anaesthesiologist are well educated and well trained. Training of the team should be started under controlled circumstances for example in a well-equipped surgery with domestic birds before it is implemented in the field and with the relevant species. Aseptic conditions, minimization of feather removal and incision length and proper anaesthesia are prerequisites. A quality insurance system that is well suited to register deviations and long-term negative impacts and thereby can be used for learning and adaptation is highly recommended. The devices used should be as small and light as possible, have a shape that is rounded and a surface that is smooth and biocompatible without evoking a deleterious inflammatory reaction. Devices with external parts attached to the implant should if possible be avoided, because they could increase the risk of discomfort, pain and infection, but it must be admitted that little to no data are available on the frequency of adverse impacts associated with such devices. Timing of surgery relative to the phenology of the bird species in question should be carefully considered, as a short-term impact on the birds' capability to cope with the environment should be expected. Last, but not least, it should be emphasized that the impact of instrumentation on the validity of the results and the risk of harm to animal welfare should be reported and discussed in all papers reporting such studies. It is also important to encourage publishing of studies where the instrumentation caused invalid results and/or poor animal welfare, so that other researchers can learn and avoid the same pitfalls.

White et al. (2013) synthesised 440 estimates from 55 studies of 49 species which were found from a search of Google Scholar and Web of Science (called Web of Knowledge at the time). They conclude from a meta-analysis that device implantation is preferable to external attachment (once the risk of surgery itself is mitigated for). This conclusion is however based on out-dated methods in evidence synthesis. Re-analysing their data shows that there is no clear difference between the effects of external or internal devices. We used a random effects meta-analysis, taking in to account non-independence between effects sizes within a study, and also assessed the relationship between effect size and duration of attachment (implantation) (**Figure 34, Figure 35**).

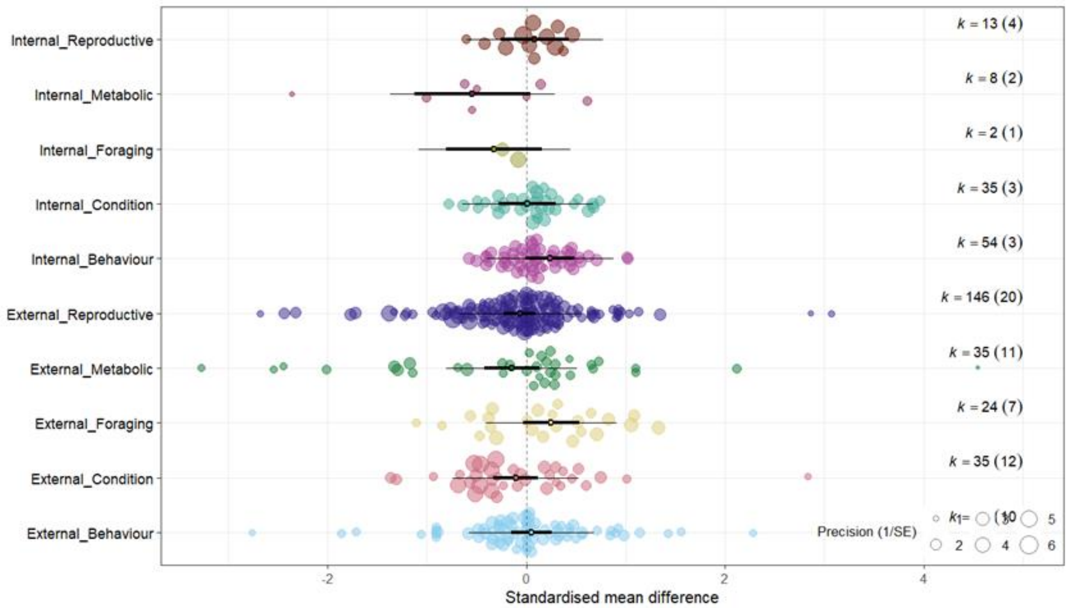

Figure 34. Orchard plot of the standardised mean difference between effects of internal versus external attachment of devices on five different outcome measures (reproduction, metabolic, foraging, condition and behaviour). The 95 % Confidence intervals of the pooled effect (thick black horizontal lines) of all outcomes regardless of being internal or external cross the line of no effect (the dotted line at 0) meaning that there is no evidence of a significance effect of implantation.

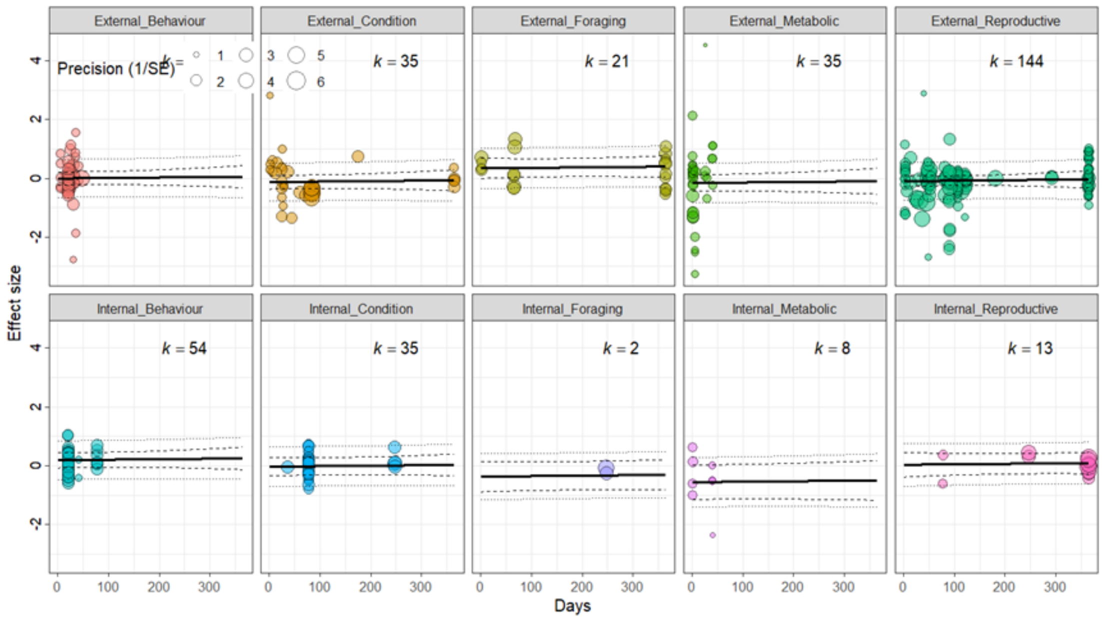

Figure 35 Bubble plot of the standardised mean difference (the effect size) of internal versus external attachment of devices on five different outcome measures (reproduction, metabolic, foraging, condition and behaviour) regressed against the number of days the device was attached/implanted. Comparing between external and internal devices for each outcome measure there is little difference in the slope of the regression lines all of which are close to zero (i.e. no effect).

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13 Risk-reducing measures

For all capture, handling, sampling, and marking techniques, responses differ among groups of birds and even among different individuals within species, and investigators should systematically evaluate any possible impacts on animal welfare. Risk-reducing measures have been outlined for each of the specific methods evaluated in Chapters 8-12. Additionally, the VKM project team has identified five key measures to significantly minimize the risk of direct and lifelong adverse impacts of scientific research on the animal welfare of wild birds:

1. **Best Practices**. We have reviewed the state of the field for the best practices associated with different techniques for capture, handling and marking of wild birds. Many of the field methods are under ongoing evaluation and are being continuously refined by different research groups. A good starting point for avoiding adverse effects is to review the available background information on the known pitfalls for different methods and species. Check for best practise guidelines or protocols from relevant organizations such as British Trust for Ornithology (BTO) in the UK or the Ornithological Council (OC) in North America. Negative effects may be unpublished, and it is also useful to consult experienced scientists who are currently using a method with different groups of birds under field conditions.

2. **Pilot and Effect Studies**. Before undertaking a full-scale field study using a novel method or applying existing methods to a new species or group of birds, it can be valuable to conduct pilot studies with different types of tags and modes of attachment and to assess the potential effects on animal welfare. New tag and harness designs have sometimes been tested on domestic or wild birds held in aviaries which offer more control over the experimental design and opportunities for follow-up monitoring.

3. **Training Routines**. Implementing routines that ensure individuals intending to use a specific method have sufficient training, practical experience, and proficiency with that method is essential. Many techniques require practice and using new methods in the field under supervision of experienced ornithologists can help build essential competence and assure best practices.

4. **Assessment and Reporting**. It is valuable to take a holistic approach for evaluation of the effects of different field methods on animal welfare. We have used a Five Domains Model in this VKM report which provides a comprehensive list of possible effects of capture and marking on animal welfare. We have adapted the model for wild birds and not all elements or domains will be possible to assess for all field studies of free-living birds under natural conditions. Nevertheless, the Five Domains Model provides a useful framework for assessing the possible effects of a study protocol and a possible foundation for standardized reporting to the Norwegian Food Safety Authority and the Norwegian Environment Agency.

5. **Continuing efforts to address the 3Rs** with refinement and reduction to improve animal welfare.

Incorporating information on animal welfare consequences when publishing results in scientific journals, alongside findings related to ecological research questions, would contribute to long-term risk reduction (Bodey et al., 2017; Brlík et al., 2020; Geen et al., 2019) and advance evidence-based decision-making in wildlife management (Lameris & Kleyheeg, 2017).

14 Data gaps

There is a growing documentation in the scientific literature on animal welfare impacts resulting from the capture, handling, sampling, and marking of wild birds, but many field studies have implemented a technique without using a control group to test for possible effects and negative effects may be unpublished for selected species (Hill & Elphick, 2011; Vandenabeele et al., 2011). Avian responses can be heterogeneous and field techniques that work well for one group of birds can have negative effects on other birds that differ in morphology, behaviour, or ecology. Some responses maybe easier to observe and record in the field than others, for example breeding success is more often recorded in studies of device effects on marine species (Vandenabeele et al., 2011).

In addition to a lack of knowledge about the short- and long-term impacts, there is a substantial gap in our knowledge about the immediate effects on welfare of wild birds during capture, handling, and sampling procedures. This is largely due to the scarcity of standardized studies that comprehensively assess bird behavior during such procedures.

Individual studies in the primary literature assessing the effect of devices on birds are less frequent compared to the number of studies using such devices without a control group. Of the 732 studies where data were extracted, 648 were controlled studies that compared birds with devices to birds that were ringed but not tagged with a device. Controlled studies typically had small sample sizes (mean = 98.6; median = 21; range= 2 to 5171) and short study durations (mean = 2.9 years; median =1 year; range = 0.003 to 29 years). These features increase the potential for errors in inference through false positives, false negatives, inflated effect sizes and incorrect direction of effects (Cleasby et al., 2021).

From the 732 studies included in the review, a majority were focused on some form of VHF/Radio transmitters (225 studies), followed by geolocators (165 studies) and then Satellite tags (58 studies). As is indicated by the ratio of studies to articles (190 included articles, comprising 732 studies), there was an average of 3.85 outcomes for each study. Heterogeneity between studies was high where it was quantified in the meta-analyses, which reflects either the true variability in the effect due to natural variation, true variation among species/age class responses; and methodological differences among study designs and approaches that increase risk of bias such as small sample sizes or methodological artifacts. We cannot determine how much of the heterogeneity can be attributed to each of these factors, which is why we recommend better study designs and reporting to reduce heterogeneity stemming from methodological artifacts. This option would allow the heterogeneity from biological realities to be quantified and explored to obtain a better understanding of how responses to devices differ across species and across device/attachments.

The ability to categorise outcomes in one of the 5 domains sub-categories for each study proved difficult. Decreased comfort (D3a) and Injury (D3b) were often reported due to birds removing tags or observed feather damage or skin abrasions from tagging. Information included negative reporting such as "*there was no effect of the* *device on the bird in terms of injury*". There was heterogeneity in the way that authors of the primary literature assessed the level of effect which may have implications for future use of this model. For example, for the category Energy expenditure (D1d), authors could have compared mass differences between control and intervention groups, looked at variation in time-budgets (increased or decreased activity), levels of stress hormones or observed/perceived differences between the subjects. The different outcome measures may not be a good proxy for energy expenditure, but this needs to be investigated.

Researchers in several countries are required to address the 3Rs (Replacement, Reduction, Refinement) when developing proposals and research protocols that must be approved by Ethical Committees and/or Animal Welfare Authorities, but they may not ever report findings for the 3Rs in the publications resulting from the approved work. Consequently, studies of wild birds that explicitly refer to the 3R framework remain scarce in the scientific literature (de Jong, 2019; Zemanova, 2021).

15 Uncertainties

Wild birds are difficult to track and observe under natural conditions. Challenges of working with free-living birds make monitoring of possible effects on welfare difficult. While impacts of capture, handling, or marking could be occasionally severe, many effects are probably subtle or temporary, which could make them difficult to detect and study (Hill & Elphick, 2011).

Methods that work well for one group of birds can have negative effects on other birds that differ in morphology, behaviour, or ecology. There can also be heterogenous responses within the same species, depending on factors such as age, sex, and physical condition, which are, in turn, linked to environmental variability. Variation in impact may arise from individual differences and local conditions during the study, but variation within a species based on local environmental factors have generally been overlooked in existing literature. Background factors, along with personnel experience and protocols, have been underexplored in the literature, underscoring the need for continuous evaluation rather than simply adopting conclusions from published studies.

Study design and methodological approaches vary greatly among independent studies that report on the impacts on animal welfare. The variation includes the choice of study design between observational or experimental methods, as well as discrepancies in the reference levels used in experiments. There are also notable differences in the animal welfare indicators measured, sample sizes, and analytical approach. Behavioral signs associated with state of welfare can vary greatly between species and are rarely described in detail in the literature. A lack of indicators is often the case for capture, handling, and sampling situations, where normal behavior is restricted, and the bird may be in a state of fear.

Reporting standards for core variables that should be measured and reported by authors could be proposed and implemented by funding agencies and journals so that future studies on new tags can be synthesised in a robust way. For example, studies should explain steps in selecting the sample size using power-analysis or a simulation; share all raw data and code openly and not just summarised data; report deployment times in a standard format (days/months/years) to avoid confusion with device failure time; report processes used to systematically or randomly select control individuals; and report basic information on the mass of study individuals and devices.

Last, inferring impacts on mental state or affective experience from observable and welfare-altering indicators, is inherently associated with uncertainty. It is also essential to recognize that the impacts on animal welfare will also depend on the background training and skills of field observers employing a marking or tagging method with wild birds.

16 Conclusions (with answers to the terms of reference)

If conducted by trained and skilled personnel following best practices, all the methods for capture, handling, or sampling evaluated in this report were assessed as low or moderate risk for short-term or long-lasting harm to animal welfare (see overview of risk assessments in Table 4). Among the marking methods, temporary feather dyes and PIT tags were assessed as low risk, while glue and tape methods, tail mounted tags, necklace collars, and surgical implants were assessed as low to moderate risk, and flipper tags on penguins as high risk. Metal and color rings, leg flags, patagial wing and web tags, neck bands, nasal discs and saddles, sutures and subcutaneous anchors, leg mounted tags, leg-loop and backpack (thoracic) harness were assessed as low, moderate, or high risk, depending on the group of birds.

1. **Reassessments for standard methods.** We have updated the descriptions of the methods for capturing and marking of wild birds outlined in VKM 2013 (see Chapters 8-12). Compared with VKM 2013, we have downgraded the risk for mistnetting. Regarding marking methods, we have confirmed the risk for temporary feather dyes and upgraded the risk for flipper bands on penguins. The risk was confirmed or upgraded – depending on the group of bird – for metal rings, color rings and leg flags, patagial wing and web tags, nasal discs and saddles, neck bands, and glue and tape methods. The risk was confirmed or downgraded – depending on the group of bird – for harness methods (leg-loop, backpack, thoracic) and surgical implants.

2. **New assessments of emerging methods.** We have included new descriptions of additional methods that were not assessed in VKM 2013 (see Chapters 8-12). Unlike VKM 2013, our current report encompasses all bird groups found in mainland Norway, as well as in waters or other areas where Norwegian law applies, and descriptions and assessments of commonly used sampling methods.

3. **Framework for animal welfare.** We have assessed the risk of reduced animal welfare when using the methods mentioned in points 1 and 2, both the direct effects and the consequences from a lifespan perspective (see Chapters 8-12). See **Table 4** for an overview of the assessments. Regarding the 3Rs approach, this report does not address whether field studies of wild birds should be <u>replaced</u> with alternate approaches but instead focuses on the <u>refinement</u> of methods in cases where marking is regarded as the most appropriate and adequate method which contributes to <u>reductions</u> in the number of marked birds needed for research projects. As a framework for assessing the risk of the specific methods for capturing, handling, sampling, and marking wild birds, we used the Five Domains Model.

4. **Best practices for animal welfare.** Risk-reducing measures are outlined for each specific method evaluated in Chapters 8-12. Additionally, the VKM project team has identified five key measures to significantly minimize the risk of direct and lifelong adverse impacts of scientific research on the animal welfare of wild birds (see Chapter 13).

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Wiley, R. H. (1974). Evolution of social organization and life-history patterns among grouse. *The Quarterly Review of Biology*, *49*(3), 201-227. http://www.jstor.org/stable/2822821

WOAH. (2023). *Terrestrisl Code Online Access*. https://www.woah.org/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmfile=chapitre_aw_introduction.htm

Zemanova, M. (2021). Making room for the 3Rs principles of animal use in ecology: potential issues identified through a survey. *European Journal of Ecology*, *7*. https://doi.org/10.17161/eurojecol.v7i2.14683

Zuberogoitia, I., Martínez, J., Zabala-Albizua, J., Calvo, J., Azkona, A., & Pagán, I. (2008). The Dho-gaza and mist net with Eurasian Eagle-Owl (*Bubo bubo*) lure: effectiveness in capturing thirteen species of European raptors. *Journal of Raptor Research*, *42*, 48-51. https://doi.org/10.3356/JRR-05-31.1

18 Appendix I

PICO form

The PICO framework includes four key elements: P – problem or population, I – Intervention, C – Comparison, control or comparator, and O – Outcomes. The project group completed a PICO form based on the template used by the university library at the Norwegian University of Life Sciences (NMBU). In addition to common names for the bird groups in the PICO form, we sent a list of Latin family and order names for the same bird groups to the university librarians who would conduct the search. Note that outcomes/endpoints in the leftmost column of the PICO form are structured according to the five domains in the five Domains model.

Table 8. PICO form

<table>
<tr><td colspan="4">Kontaktperson(er):
VKM – Danica Grahek-Ogden og Jo Skeie Hermansen</td></tr>
<tr><td colspan="4">Hva er formålet med søket?
Find scientific papers on:
effects on animal welfare when marking and tracking wild birds; methods for marking/tagging, modes of attachment, and type of tags/loggers</td></tr>
<tr><td colspan="4">Problemstilling formulert som et presist spørsmål:
Effects of marking, tracking devices and dataloggers, and mode of attachment, on animal welfare</td></tr>
<tr><th>Pasientgruppe, populasjon el. problem.

HVEM</th><th>Intervensjon, tiltak el. eksponering.

HVA</th><th>Sammenligning el. alternative tiltak.

ALTERNATIVER</th><th>Utfall, Endepunkter.

RESULTAT, EFFEKT</th></tr>
<tr><td>Wild birds</td><td colspan="2">Methods for marking and tracking of free-living birds under natural conditions</td><td>Bird responses (direct and indirect indicators of welfare)</td></tr>
<tr><td>avian
bird*
ornithol*
waterfowl, duck, goose, swan, quail, pheasant, grouse, ptarmigan, dove, pigeon, swift, rail, coot, wader, shorebird, gull,</td><td colspan="2">Marking, dye, ring, band, color ring, color flag, leg flag, RFID, PIT tag, PIT transponder, patagial wing tag, neck band, neck collar, nasal disk, nasal saddle, flipper tag</td><td>Domain 1 (nutrition)
body condition, body composition, diet, fat score, hydration, water balance, corticosterone
Domain 2 (environment)
predation, thermoregulate, heat stress, cold stress, flight pattern, drag, aerodynamics,</td></tr>
</table>

loon, seabird, wading bird, heron, egret, passerine, eagle, hawk, owl, nightjar, woodpecker, falcon, songbird, landbird, crow, jay, swallow, warbler, thrush, sparrow, raptor, teal, eider, scoter, goldeneye, merganser, capercaillie, grebe, cuckoo, crane, oystercatcher, plover, lapwing, dotterel, sandpiper, woodcock, snipe, redshank, greenshank, phalarope, skua, jaeger, murre, razorbill, guillemot, puffin, tern, petrel, fulmar, shearwater, stork, gannet, cormorant, shag, osprey, harrier, buzzard, shrike, jackdaw, rook, raven, tit, lark, martin, starling, redstart, stonechat, dunnock, wagtail, pipit, finch, crossbill, bunting	***Tracking,*** *biologging, tagging, data logger, radio transmitter, radio tag, light logger, geolocator, GPS transmitter, satellite transmitter, VHF radio, video camera, accelerometer, GPS-GSM transmitter, TDR, argos, multi-sensor tag* ***Attachment,*** *leg-loop harness, wing-loop harness, backpack harness, glue, suture, subcutaneous anchor, backpack mounted, tail mounted, feather mounted, back mounted, necklace collar, neck collar, surgical implant, leg ring, leg flag, logger*	*breed(ing)/hatch(ing)/nest(ing) success/failure, recruitment, reproduction, mortality, survival, vital rate, lifetime fitness, fledging, lay date, clutch size, return rate, reproductive performance* ***Domain 3 (health)*** *health, physical fitness, feather wear, feather abrasion, lesion, immune/immuno-suppression, disease, sickness, lameness, wound, capture myopathy, injury, energetics, stress response, metabolic rate, energy expenditure, functional capacity* ***Domain 4 (behavioural interactions)*** *escape behaviour, activity, foraging, mate choice, mating success, migration, movement, clutch abandonment, brood abandonment, nest abandonment, behavioral change, energy budget, time budget, diving, preening, social behaviour, escape distance, flight distance, nest attendance, brood attendance, parental care, feeding rate* ***Domain 5 (mental state)*** *welfare, pain, anxiety, exhaustion, mental state, depression, distress, orientation, vigilance, fear* *Other words:* *Annual cycle/return/survival, life history, temporal scale*
Sentrale studier, artikler innen temaet: *List of benchmark papers*		

Hvilken type litteratur er av interesse (sett eventuelt flere kryss): ☒ Systematiske oversikter ☒ Primærstudier
Er det aktuelt med søk i Lovdata etter lover og forskrifter? ☐ Ja ☒ Nei
Er det aktuelt med søk etter grå litteratur? ☐ Ja ☒Nei *Peer-reviewed literature is already extensive.*
Eventuelle begrensninger: *English, Scandinavian languages, German*
Inklusjonskriterier: *Take all hits*
Eksklusjonskriterier: *Wild and not captive birds, not domestic chickens in production facilities* *-captive -poultry -chicken -laying hens* *Not tropical birds* *Not birds in zoological gardens*
Ytterligere kommentarer: *Interessert i fugler fra geografiske områder med liknende forhold som Norge.*

Comprehensiveness check

Table 9. Comprehensiveness check for search strategy. The presence of each benchmark article (i.e. articles that were thought to be key for the review by the author team) in each of the three platforms searched was used to assess the comprehensiveness of the search terms used. Of the 92 benchmarks, 13 were not found on any of the search platforms. It is important to note that in our case, the missing articles were due to a lack of indexing of book chapters and small society publications rather than deficiencies in our search strategy.

Date: 3. juli 2023		Found in search				
No.	**Key articles available in databases**	**Bio Ab**	**Scopus**	**WoS**	**SUM**	**Availability**
1	Amat, J. A. (1999). Foot losses of metal banded Snowy Plovers. Journal of field ornithology, 70(4), 555-557.	1	1	1	3	1
2	Barron, D. G., Brawn, J. D. & Weatherhead, P. J. (2010). Meta-analysis of transmitter effects on avian behaviour and ecology. Methods in Ecology and Evolution, 1(2), 180-187.	0	0	1	1	1
3	Bart, J., Battaglia, D. & Senner, N. (2001). EFFECTS OF COLOR BANDS ON SEMIPALMATED SANDPIPERS BANDED AT HATCH. Journal of field ornithology, 72(4), 521-526. https://doi.org/10.1648/0273-8570-72.4.521	1	1	1	3	1
4	Becker, P. H. & Wendeln, H. (1997). A New Application for Transponders in Population Ecology of the Common Tern. The Condor (Los Angeles, Calif.), 99(2), 534-538. https://doi.org/10.2307/1369963	1	1	1	3	1
5	Belant, J. L. & Seamans, T. W. (1993). Evaluation of Dyes and Techniques to Color-Mark Incubating Herring Gulls (Evaluación de tintes y técnicas para marcar individuos de Larus argentatus durante el período de incubación). Journal of field ornithology, 64(4), 440-451.	1	0	1	2	1
6	Berg, M. & Ribot, R. (2008). A simple, inexpensive trap for capturing parrots and other cavity nesting birds.	1	1	0	2	1
7	Bodey, T. W., Cleasby, I. R., Bell, F., Parr, N., Schultz, A., Votier, S. C. & Bearhop, S. (2018). A phylogenetically controlled meta-analysis of biologging device effects on birds: Deleterious effects and a call for more standardized reporting of study data. Methods in Ecology and Evolution, 9(4), 946-955.	0	1	1	2	1
8	Bonter, D. N. & Bridge, E. S. (2011). Applications of radio frequency identification (RFID) in ornithological research: a review. Journal of field ornithology, 82(1), 1-10. https://doi.org/10.1111/j.1557-9263.2010.00302.x	1	1	1	3	1
9	Bouten, W., Baaij, E. W., Shamoun-Baranes, J. & Camphuysen, K. C. J. (2013). A flexible GPS tracking system for studying bird behaviour at multiple scales. Journal of ornithology, 154(2), 571-580. https://doi.org/10.1007/s10336-012-0908-1	1	1	1	3	1

10	Bowlin, M. S., Henningsson, P., Muijres, F. T., Vleugels, R. H. E., Liechti, F. & Hedenström, A. (2010). The effects of geolocator drag and weight on the flight ranges of small migrants: Effects of geolocators. Methods in ecology and evolution, 1(4), 398-402. https://doi.org/10.1111/j.2041-210X.2010.00043.x	1	0	0	1	1
11	Bowman, J., Wallace, M. C., Ballard, W. B., Brunjes Iv, J. H., Miller, M. S. & Hellman, J. M. (2002). Evaluation of two techniques for attaching radio transmitters to turkey poults. Journal of field ornithology, 73(3), 276-280. https://doi.org/10.1648/0273-8570-73.3.276	1	1	1	3	1
12	Bridge, E. S., Wilhelm, J., Pandit, M. M., Moreno, A., Curry, C. M., Pearson, T. D. & Proppe, D. S. (2019). An Arduino-Based RFID Platform for Animal Research. Frontiers in ecology and evolution, 7. https://doi.org/10.3389/fevo.2019.00257	1	1	1	3	1
13	Britten, M. W., Kennedy, P. L. & Ambrose, S. (1999). Performance and Accuracy Evaluation of Small Satellite Transmitters. The Journal of wildlife management, 63(4), 1349-1358. https://doi.org/10.2307/3802854	1	1	1	3	1
14	Brlík, V., Koleček, J., Burgess, M., Hahn, S., Humple, D., Krist, M., Ouwehand, J., Weiser, E. L., Adamik, P., Alves, J. A., Arlt, D., Barišić, S., Becker, D., Belda, E. J., Beran, V., Both, C., Bravo, S. P., Briedis, M., Chutný, B., Ćiković, D., Cooper, N. W., Costa, J. S., Cueto, V. R., Emmenegger, T., Fraser, K., Gilg, O., Guerrero, M., Hallworth, M. T., Hewson, C. M., Jiguet, F., Johnson, J. A., Kelly, T., Kishkinev, D., Leconte, M., Lislevand, T., Lisovski, S., López, C., McFarland, K. P., Marra, P. P., Matsuoka, S. M., Matyjasiak, P., Meier, C. M., Metzger, B., Monrós, J. S., Neumann, R., Newman, A., Norris, R., Pärt, T., Pavel, V., Perlut, N. G., Piha, M., Reneerkens, J., Rimmer, C. C., Roberto-Charron, A., Scandolara, C., Sokolova, N., Takenaka, M., Tolkmitt, D., van Oosten, H., Wellbrock, A. H. J., Wheeler, H., van der Winden, J., Witte, K., Woodworth, B. & Procházka, P. (2020). Weak effects of geolocators on small birds: A meta-analysis controlled for phylogeny and publication bias. J Anim Ecol, 89(1), 207-220. https://doi.org/10.1111/1365-2656.12962	1	1	1	3	1
15	Burns, F., Székely, T. & Bolton, M. (2010). Leg flags versus colour rings: a comparison of marking methods using a small shorebird, the St Helena Wirebird. Wader Study Group Bulletin 117, 131–134. https://www.waderstudygroup.org/article/2216/	0	0	0	0	0
16	Byers, S. M. (1987). Extent and Severity of Nasal Saddle Icing on Mallards (Extensión y severidad de congelamiento de marbetes nasales en Anas platyrhynchos). Journal of field ornithology, 58(4), 499-504.	1	0	1	2	1

17	Bäckman, J., Andersson, A., Pedersen, L., Sjöberg, S., Tøttrup, A. P. & Alerstam, T. (2017). Actogram analysis of free-flying migratory birds: new perspectives based on acceleration logging. J Comp Physiol A Neuroethol Sens Neural Behav Physiol, 203(6-7), 543-564. https://doi.org/10.1007/s00359-017-1165-9	1	1	1	3	1
18	Calvo, B. & Furness, R. (1992). A review of the use and the effects of marks and devices on birds. Ringing & Migration, 13(3), 129-151.	1	1	0	2	1
19	Casper, R. M. (2009). Guidelines for the instrumentation of wild birds and mammals. Animal behaviour, 78(6), 1477-1483. https://doi.org/10.1016/j.anbehav.2009.09.023	1	1	1	3	1
20	Chipman, E. D., McIntyre, N. E., Ray, J. D., Wallace, M. C. & Boal, C. W. (2007). Effects of Radiotransmitter Necklaces on Behaviors of Adult Male Western Burrowing Owls. The Journal of wildlife management, 71(5), 1662-1668. https://doi.org/10.2193/2006-335	1	1	1	3	1
21	Clark, N., Gillings, S., Baker, A., Gonzalez, P. & Porter, R. (2005). The production and use of permanently inscribed leg flags for waders. Wader Study Group Bulletin 108, 38. https://www.waderstudygroup.org/article/3184/	0	0	0	0	0
22	Clausen, K. K. & Madsen, J. (2014). Effects of neckbands on body condition of migratory geese. Journal of ornithology, 155(4), 951-958. https://doi.org/10.1007/s10336-014-1080-6	1	1	1	3	1
23	Cleasby, I. R., Morrissey, B. J., Bolton, M., Owen, E., Wilson, L., Wischnewski, S. & Nakagawa, S. (2021). What is our power to detect device effects in animal tracking studies? Methods in Ecology and Evolution, 12(7), 1174-1185.	1	1	1	3	1
24	Clewley, G. D., Clark, N. A., Thaxter, C. B., Green, R. M., Scragg, E. S. & Burton, N. H. (2021). Development of a weak-link wing harness for use on large gulls (Laridae): methodology, evaluation and recommendations. in Seabird. http://www.seabirdgroup.org.uk/seabird-33-18	0	0	0	0	0
25	Clewley, G. D., Cook, A. S. C. P., Davies, J. G., Humphreys, E. M., O'Hanlon, N. J., Weston, E., Boulinier, T. & Ponchon, A. (2021). Acute impacts from Teflon harnesses used to fit biologging devices to Black-legged Kittiwakes Rissa tridactyla. Ringing & migration, 36(2), 69-77. https://doi.org/10.1080/03078698.2022.2151065	1	1	0	2	1
26	Costantini, D. & Møller, A. P. (2013). A meta-analysis of the effects of geolocator application on birds. Acta Zoologica Sinica, 59(6), 697-706. https://doi.org/10.1093/czoolo/59.6.697	1	1	1	3	1
27	Cresswell, W., Lind, J., L. Quinn, J., Minderman, J. & Philip Whitfield, D. (2007). Ringing or colour-banding does not increase predation mortality in redshanks Tringa totanus. Journal of avian biology, 38(3), 309-316. https://doi.org/10.1111/j.2007.0908-8857.03925.x	1	1	1	3	1

28	Deane, C. E., Rotella, J. J., Warren, J. M., Garrott, R. A. & Koons, D. N. (2021). Nasal Discs and the Vital Rates of Lesser Scaup. The Journal of wildlife management, 85(4), 723-739. https://doi.org/10.1002/jwmg.22025	1	1	1	3	1
29	Fair, J., Paul, E., Jones, J., Clark, A., Davie, C. & Kaiser, G. (2010). Guidelines to the use of wild birds in research (3rd Ed.). (3. utg.). Ornithological Council, Washington, DC.	0	0	0	0	0
30	Fleming, D. (2023). Wildlife research in Australia: practical and applied methods: edited by: Bradley Smith, Helen Waudby, Corinne Alberthsen, Jordan Hampton, Clayton South, VIC, CSIRO Publishing, 2022, 656 pp., A$200.00 (ePUB), ISBN: 9781486313464. I(Bd. ahead-of-print, s. 1-2). Taylor & Francis.	0	0	0	0	0
31	Gauthier-Clerc, M., Gendner, J. P., Ribic, C. A., Fraser, W. R., Woehler, E. J., Descamps, S., Gilly, C., Bohec, C. L. & Le Maho, Y. (2004). Long–term effects of flipper bands on penguins. Proc Biol Sci, 271(Suppl 6), S423-S426. https://doi.org/10.1098/rsbl.2004.0201	0	1	1	2	1
32	Geen, G. R., Robinson, R. A. & Baillie, S. R. (2019). Effects of tracking devices on individual birds–a review of the evidence. Journal of Avian Biology, 50(2).	0	1	1	2	1
33	Gervais, J. A., Catlin, D. H., Chelgren, N. D. & Rosenberg, D. K. (2006). Radiotransmitter Mount Type Affects Burrowing Owl Survival. The Journal of wildlife management, 70(3), 872-876. https://doi.org/10.2193/0022-541X(2006)70[872:RMTABO]2.0.CO2	1	1	1	3	1
34	Gessaman, J. A. & Nagy, K. A. (1988). Transmitter Loads Affect the Flight Speed and Metabolism of Homing Pigeons. The Condor (Los Angeles, Calif.), 90(3), 662-668. https://doi.org/10.2307/1368356	1	0	1	2	1
35	Green, J. A., Tanton, J. L., Woakes, A. J., Boyd, I. L. & Butler, P. J. (2004). Effects of long-term implanted data loggers on macaroni penguins Eudyptes chrysolophus. Journal of Avian Biology, 35(4), 370-376. https://doi.org/10.1111/j.0908-8857.2004.03281.x	1	1	1	3	1
36	Hagen, C. A., Sandercock, B. K., Pitman, J. C., Robel, R. J. & Applegate, R. D. (2006). Radiotelemetry Survival Estimates of Lesser Prairie-Chickens in Kansas: Are There Transmitter Biases? Wildlife Society bulletin, 34(4), 1064-1069. https://doi.org/10.2193/0091-7648(2006)34[1064:RSEOLP]2.0.CO2	1	1	1	3	1
37	Haig, S. M., Oring, L. W., Sanzenbacher, P. M. & Taft, O. W. (2002). Space Use, Migratory Connectivity, and Population Segregation among Willets Breeding in the Western Great Basin. The Condor (Los Angeles, Calif.), 104(3), 620-630. https://doi.org/10.1043/0010-5422(2002)104(0620:SUMCAP)2.0.CO2	1	1	1	3	1

38	Hallworth, M. T. & Marra, P. P. (2015). Miniaturized GPS Tags Identify Non-breeding Territories of a Small Breeding Migratory Songbird. Sci Rep, 5(1), 11069-11069. https://doi.org/10.1038/srep11069	1	1	1	3	1
39	Heggøy, O., Aarvak, T., Øien, I. J., Jacobsen, K.-O., Solheim, R., Zazelenchuk, D., Stoffel, M. & Kleven, O. (2017). Effects of satellite transmitters on survival in Snowy Owls Bubo scandiacus.	1	1	0	2	1
40	Holder, K. & Montgomerie, R. (1993). Red Colour Bands Do Not Improve the Mating Success of Male Rock Ptarmigan. Ornis Scandinavica, 24(1), 53-58. https://doi.org/10.2307/3676410	1	1	0	2	1
41	Hooijmeijer, J. C. E. W., Gill, R. E., Jr., Mulcahy, D. M., Tibbitts, T. L., Kentie, R., Gerritsen, G. J., Bruinzeel, L. W., Tijssen, D. C., Harwood, C. M. & Piersma, T. (2014). Abdominally implanted satellite transmitters affect reproduction and survival rather than migration of large shorebirds. Journal of ornithology, 155(2), 447-457. https://doi.org/10.1007/s10336-013-1026-4	1	1	1	3	1
42	Iglay, R. B. (2022). The Wildlife Techniques Manual (Volume 1: Research. Volume 2: Management, 8th edition). NovaJ.Silvy, editor. 2022. Johns Hopkins University Press, Baltimore, Maryland, USA. 1373 pp. (Volume 1, 759 pp.; Volume 2, 614 pp.). $174.95 hardback (set). ISBN: 978-1-4214-3669-2. The Journal of wildlife management, 86(4). https://doi.org/10.1002/jwmg.22187	0	0	0	0	0
43	Iglay, R. B. (2022). The Wildlife Techniques Manual (Volume 1: Research. Volume 2: Management, 8th edition). Nova J.Silvy, editor. 2022. Johns Hopkins University Press, Baltimore, Maryland, USA. 1373 pp. (Volume 1, 759 pp.; Volume 2, 614 pp.). $174.95 hardback (set). ISBN: 978-1-4214-3669-2. The Journal of wildlife management, 86(4). https://doi.org/10.1002/jwmg.22187	0	0	0	0	0
44	Kavelaars, M. M., Stienen, E., Matheve, H., Buijs, R.-J., Lens, L. & Müller, W. (2018). GPS tracking during parental care does not affect early offspring development in lesser black-backed gulls. Marine biology, 165(5), 1-8. https://doi.org/10.1007/s00227-018-3347-6	1	1	0	2	1
45	Kenward, R. E. (1978). Radio Transmitters Tail-Mounted on Hawks. Ornis Scandinavica, 9(2), 220-223. https://doi.org/10.2307/3675885	0	0	1	1	1
46	Korschgen, C. E., Kenow, K. P., Gendron-Fitzpatrick, A., Green, W. L. & Dein, F. J. (1996). Implanting Intra-Abdominal Radiotransmitters with External Whip Antennas in Ducks. The Journal of wildlife management, 60(1), 132-137. https://doi.org/10.2307/3802047	1	1	1	3	1
47	Lameris, T. K. & Kleyheeg, E. (2017). Reduction in adverse effects of tracking devices on waterfowl requires better measuring and reporting. Animal Biotelemetry, 5, 1-14.	0	1	0	1	1

48	Lewis, T. L. & Flint, P. L. (2008). Modified method for external attachment of transmitters to birds using two subcutaneous anchors. Journal of field ornithology, 79(3), 336-341. https://doi.org/10.1111/j.1557-9263.2008.00180.x	1	1	1	3	1
49	Lindsjo, J., Fahlman, A. & Tornqvist, E. (2016). ANIMAL WELFARE FROM MOUSE TO MOOSE—IMPLEMENTING THE PRINCIPLES OF THE 3RS IN WILDLIFE RESEARCH. J Wildl Dis, 52(2s), S65-S77. https://doi.org/10.7589/52.2S.S65	0	1	1	2	1
50	Mallory, M. & Gilbert, C. (2008). Leg-loop harness design for attaching external transmitters to seabirds. Marine Ornithology, 36, 183-188.	1	1	0	2	1
51	McKinnon, E. A. & Love, O. P. (2018). Ten years tracking the migrations of small landbirds: Lessons learned in the golden age of bio-logging. The Auk: Ornithological Advances, 135(4), 834-856.	1	1	1	3	1
52	Menu, S., Hestbeck, J. B., Gauthier, G. & Reed, A. (2000). Effects of Neck Bands on Survival of Greater Snow Geese. The Journal of wildlife management, 64(2), 544-552. https://doi.org/10.2307/3803252	1	1	1	3	1
53	Mong, T. W. & Sandercock, B. K. (2007). Optimizing Radio Retention and Minimizing Radio Impacts in a Field Study of Upland Sandpipers. The Journal of wildlife management, 71(3), 971-980. https://doi.org/10.2193/2005-775	1	1	1	3	1
54	Mulcahy, D. M., Gartrell, B., Gill, R. E., Tibbitts, T. L. & Ruthrauff, D. R. (2011). Coelomic Implantation of Satellite Transmitters in the Bar-tailed Godwit (Limosa lapponica) and the Bristle-thighed Curlew (Numenius tahitiensis) Using Propofol, Bupivacaine, and Lidocaine. J Zoo Wildl Med, 42(1), 54-64. https://doi.org/10.1638/2010-0040.1	1	1	1	3	1
55	Murray, D. L. & Fuller, M. R. (2000). A critical review of the effects of marking on the biology of vertebrates. I L. Boitani & T. K. Fuller (Red.), Research techniques in animal ecology: controversies and consequences (s. 15-64). New York: Columbia University Press.	0	0	0	0	0
56	Nicolaus, M., Bouwman, K. M. & Dingemanse, N. J. (2008). Effect of PIT Tags on the Survival and Recruitment of Great Tits Parus major. Ardea, 96(2), 286-292. https://doi.org/10.5253/078.096.0215	1	1	1	3	1
57	Pakanen, V.-M., Rönkä, N., Thomson, R. L. & Koivula, K. (2015). No strong effects of leg-flagged geolocators on return rates or reproduction of a small long-distance migratory shorebird. Ornis Fennica, 92(3).	1	1	1	3	1
58	Palmer, W. E. & Wellendorf, S. D. (2007). Effect of Radiotransmitters on Northern Bobwhite Annual Survival. The Journal of wildlife management, 71(4), 1281-1287. https://doi.org/10.2193/2005-639	1	1	1	3	1

59	Peniche, G., Vaughan-Higgins, R., Carter, I., Pocknell, A., Simpson, D. & Sainsbury, A. (2011). Long-term health effects of harness-mounted radio transmitters in red kites (Milvus milvus) in England. Vet Rec, 169(12), 311-311. https://doi.org/10.1136/vr.d4600	0	1	1	2	1
60	Penny, H. (2004). Bio-logging and animal welfare: practical refinements. Memoirs of National Institute of Polar Research. Special issue, 58, 58-68.	0	0	0	0	0
61	Perry, M. C., Haas, G. H. & Carpenter, J. W. (1981). Radio Transmitters for Mourning Doves: A Comparison of Attachment Techniques. The Journal of wildlife management, 45(2), 524-527. https://doi.org/10.2307/3807939	0	0	1	1	1
62	Phillips, R. A., Xavier, J. C. & Croxall, J. P. (2003). EFFECTS OF SATELLITE TRANSMITTERS ON ALBATROSSES AND PETRELS. The Auk, 120(4), 1082-1090. https://doi.org/10.1642/0004-8038(2003)120[1082:EOSTOA]2.0.CO2	1	1	1	3	1
63	Portugal, S. J., White, C. R. & Börger, L. (2018). Miniaturization of biologgers is not alleviating the 5% rule. Methods in ecology and evolution, 9(7), 1662-1666. https://doi.org/10.1111/2041-210X.13013	1	1	0	2	1
64	Raim, A. (1978). A Radio Transmitter Attachment for Small Passerine Birds. Bird-banding, 49(4), 326-332. https://doi.org/10.2307/4512391	0	0	0	0	0
65	Rakhimberdiev, E., Senner, N. R., Verhoeven, M. A., Winkler, D. W., Bouten, W. & Piersma, T. (2016). Comparing inferences of solar geolocation data against high-precision GPS data: annual movements of a double-tagged black-tailed godwit. J Avian Biol, 47(4), 589-596. https://doi.org/10.1111/jav.00891	1	1	1	3	1
66	Rappole, J. H. & Tipton, A. R. (1991). New Harness Design for Attachment of Radio Transmitters to Small Passerines (Nuevo Diseño de Arnés para Atar Transmisores a Passeriformes Pequeños). Journal of field ornithology, 62(3), 335-337.	0	0	1	1	1
67	Reed, E. T., Gauthier, G. & Pradel, R. (2005). EFFECTS OF NECK BANDS ON REPRODUCTION AND SURVIVAL OF FEMALE GREATER SNOW GEESE. The Journal of wildlife management, 69(1), 91-100. https://doi.org/10.2193/0022-541X(2005)069<0091:EONBOR>2.0.CO2	1	1	1	3	1
68	Reed, J. M. & Oring, L. W. (1993). Banding Is Infrequently Associated with Foot Loss in Spotted Sandpipers (El Asociar con Poca Frecuencia el Anillamiento a la Pérdida de Patas por Parte de Individuos de Actitis macularia). Journal of field ornithology, 64(2), 145-148.	1	0	1	2	1
69	Rutz, C., Bluff, L. A., Weir, A. A. S. & Kacelnik, A. (2007). Video Cameras on Wild Birds. Science, 318(5851), 765-765. https://doi.org/10.1126/science.1146788	1	1	1	3	1

70	Rutz, C., Troscianko, J. & Hodgson, D. (2013). Programmable, miniature video-loggers for deployment on wild birds and other wildlife. Methods in ecology and evolution, 4(2), 114-122. https://doi.org/10.1111/2041-210x.12003	0	1	1	2	1
71	Saunders, D. (1988.). Patagial tags-do benefits outweigh risks to the animal? . Wildlife Research, 15, 565-569.	1	1	1	3	1
72	Sedgwick, J. A. & Rodney, J. K. (1997). Injury Due to Leg Bands in Willow Flycatchers (Heridas Producidas en las Patas por Anillas en Individuos de Empidonax traillii). Journal of field ornithology, 68(4), 622-629.	1	1	1	3	1
73	Smallwood, G. & Natale, C. (1998). The effect of patagial tags on breeding success in American Kestrels. North American Bird Bander, 23, 73-78.	0	0	0	0	0
74	Smith, K. W., Trevis, B. E. & Reed, M. (2017). The effects of leg-loop harnesses and geolocators on the diurnal activity patterns of Green Sandpipers Tringa ochropus in winter. Ringing & migration, 32(2), 104-109. https://doi.org/10.1080/03078698.2017.1437886	1	1	0	2	1
75	Soulsbury, C. D., Gray, H. E., Smith, L. M., Braithwaite, V., Cotter, S. C., Elwood, R. W., Wilkinson, A., Collins, L. M. & Fisher, D. (2020). The welfare and ethics of research involving wild animals: A primer. Methods in ecology and evolution, 11(10), 1164-1181. https://doi.org/10.1111/2041-210X.13435	1	1	1	3	1
76	Sunde, P. (2006). Effects of Backpack Radio Tags on Tawny Owls. The Journal of wildlife management, 70(2), 594-599. https://doi.org/10.2193/0022-541X(2006)70[594:EOBRTO]2.0.CO2	1	1	1	3	1
77	Sutherland, W., Newton, I. & Green, R. (2004). Bird ecology and conservation: a handbook of techniques. Oxford University Press, Oxford, UK.	0	0	0	0	0
78	Taylor, P. D., Crewe, T. L., Mackenzie, S. A., Lepage, D., Aubry, Y., Crysler, Z., Finney, G., Francis, C. M., Guglielmo, C. G., Hamilton, D. J., Holberton, R. L., Loring, P. H., Mitchell, G. W., Norris, D. R., Paquet, J., Ronconi, R. A., Smetzer, J. R., Smith, P. A., Welch, L. J. & Woodworth, B. K. (2017). The Motus Wildlife Tracking System: a collaborative research network to enhance the understanding of wildlife movement. Avian conservation and ecology, 12(1), 8. https://doi.org/10.5751/ACE-00953-120108	1	1	1	3	1
79	Terhune, T. M., Sisson, D. C., Grand, J. B. & Stribling, H. L. (2007). Factors Influencing Survival of Radiotagged and Banded Northern Bobwhites in Georgia. The Journal of wildlife management, 71(4), 1288-1297. https://doi.org/10.2193/2005-640	1	1	1	3	1

80	Thaxter, C. B., Ross-Smith, V. H., Clark, J. A., Clark, N. A., Conway, G. J., Masden, E. A., Wade, H. M., Leat, E. H. K., Gear, S. C., Marsh, M., Booth, C., Furness, R. W., Votier, S. C. & Burton, N. H. K. (2016). Contrasting effects of GPS device and harness attachment on adult survival of Lesser Black-backed Gulls Larus fuscus and Great Skuas Stercorarius skua. Ibis, 158(2), 279-290. https://doi.org/10.1111/ibi.12340	0	1	1	2	1
81	Tinbergen, J. M., Tinbergen, J. & Ubels, R. (2014). Is Fitness Affected by Ring Colour? Ardea, 101(2), 153-163. https://doi.org/10.5253/078.101.0210	1	1	1	3	1
82	Trefry, S. A., Diamond, A. W. & Jesson, L. K. (2013). Wing marker woes: a case study and meta-analysis of the impacts of wing and patagial tags. Journal of ornithology, 154(1), 1-11. https://doi.org/10.1007/s10336-012-0862-y	1	1	1	3	1
83	Tremblay, Y., Thiebault, A., Mullers, R. & Pistorius, P. (2014). Bird-borne video-cameras show that seabird movement patterns relate to previously unrevealed proximate environment, not prey. PLoS One, 9(2), e88424-e88424. https://doi.org/10.1371/journal.pone.0088424	1	1	0	2	1
84	Vandenabeele, S. P., Shepard, E. L., Grogan, A. & Wilson, R. P. (2012). When three per cent may not be three per cent; device-equipped seabirds experience variable flight constraints. Marine Biology, 159, 1-14.	1	1	0	2	1
85	Wanless, S., Harris, M. P. & Morris, J. A. (1989). Behavior of Alcids with Tail-Mounted Radio Transmitters. Colonial waterbirds, 12(2), 158-163. https://doi.org/10.2307/1521336	1	0	1	2	1
86	Warnock, N. & Warnock, S. (1993). Attachment of radio-transmitters to sandpipers: review and methods. Wader Study Group Bulletin, 70, 60-61.	0	0	0	0	0
87	Wascher, C. A. F., Kotrschal, K. & Arnold, W. (2018). Free-living greylag geese adjust their heart rates and body core temperatures to season and reproductive context. Sci Rep, 8(1), 2142-2148. https://doi.org/10.1038/s41598-018-20655-z	1	1	1	3	1
88	Weiser, E. L., Lanctot, R. B., Brown, S. C., Alves, J. A., Battley, P., Bentzen, R., Bêty, J., Bishop, M. A., Boldenow, M., Bollache, L., Casler, B., Christie, M., T. Coleman, J., Conklin, J., B. English, W., Gates, H. R., Gilg, O., Giroux, M.-A., Gosbell, K., Hassell, C. J., Helmericks, J., Johnson, A., Katrínardóttir, B., Koivula, K., Kwon, E., Lamarre, J.-F., Lang, J., Lank, D. B., Lecomte, N., Liebezeit, J., Loverti, V., McKinnon, L., Minton, C. D. T., Mizrahi, D., Nol, E., Pakanen, V.-M., Perz, J., Porter, R., Rausch, J., Reneerkens, J., Rönkä, N., Saalfeld, S., Senner, N., Sittler, B., Smith, P. A., Sowl, K., Taylor, A., Ward, D. H., Yezerinac, S. & Sandercock, B. K. (2016). Effects of geolocators on hatching success, return rates, breeding movements, and change in body mass in 16	0	1	1	2	1

	species of Arctic-breeding shorebirds. Mov Ecol, 4(12), 12-12. https://doi.org/10.1186/s40462-016-0077-6					
89	Weiser, E. L., Lanctot, R. B., Brown, S. C., Gates, H. R., Bentzen, R. L., Boldenow, M. L., Cunningham, J. A., Doll, A., Donnelly, T. F., English, W. B., Franks, S. E., Grond, K., Herzog, P., Hill, B. L., Kendall, S., Kwon, E., Lank, D. B., Liebezeit, J. R., Rausch, J., Saalfeld, S. T., Taylor, A. R., Ward, D. H., Woodard, P. F. & Sandercock, B. K. (2018). Effects of leg flags on nest survival of four species of Arctic-breeding shorebirds. Journal of field ornithology, 89(3), 287-297. https://doi.org/10.1111/jofo.12264	1	1	1	3	1
90	White, C. R., Cassey, P., Schimpf, N. G., Halsey, L. G., Green, J. A. & Portugal, S. J. (2013). Implantation reduces the negative effects of bio-logging devices on birds. J Exp Biol, 216(Pt 4), 537-542. https://doi.org/10.1242/jeb.076554	1	1	1	3	1
91	Wilson, R. P., Holton, M., Wilson, V. L., Gunner, R., Tysse, B., Wilson, G. I., Quintana, F., Duarte, C. & Scantlebury, D. M. (2019). Towards informed metrics for examining the role of human-induced animal responses in tag studies on wild animals. Integr Zool, 14(1), 17-29. https://doi.org/10.1111/1749-4877.12328	0	1	1	2	1
92	Wilson, R. P. & McMahon, C. R. (2006). Measuring Devices on Wild Animals: What Constitutes Acceptable Practice? Frontiers in ecology and the environment, 4(3), 147-154. https://doi.org/10.1890/1540-9295(2006)004[0147:MDOWAW]2.0.CO2	0	1	1	2	1
	SUM	64	69	66		85.8 %

Search history

Databases searched, settings, and search terms.

Table 10. **Web of Science Core Collection:** Science Citation Index (SCI) 1945-present, Arts & Humanities Citation Index (AHCI) 1975-present

<table>
<tr><td colspan="2">Date: 6 July 2023</td></tr>
<tr><td>Interface: Clarivate Analytics</td><td>Field labels:
TI = title
AB = Abstract
NEAR/x = within x words, regardless of order
$ = wildcard, e.g., colo$r finds color, colour
* = truncation of word for alternate endings
Note: sometimes "quotation marks" are needed for single search terms to avoid automatic term mapping (lemmatization).

Exact Search was activated to limit the search to the exact terms entered into the search field.</td></tr>
<tr><td colspan="2">#1 TI=("influenza" OR "poultry" OR laying-hen* OR "Zoo" OR "Zoos" OR bird-market* OR "rail track*" OR "crane track*" OR "crane rail*" OR "overhead crane*" OR asphalt* OR "bird flu" or "avian flu" OR "videofluoro*")

#2 ("Avian" OR "bird" OR "birds" OR "fowl*" OR "ornitholog*" OR "waterfowl*" OR "duck" OR "ducks" OR "mallard*" OR "goose" OR "geese" OR "swan" OR "swans" OR "quail*" OR "pheasant*" OR "grouse*" OR "ptarmigan*" OR "dove" OR "doves" OR "pigeon" OR "pigeons" OR "swift" OR "swifts" OR "rail" OR "rails" OR "coot" OR "coots" OR "wader" OR "waders" OR wading-bird* OR "shorebird*" OR "gull" OR "gulls" OR "loon" OR "loons" OR "seabird*" OR "heron" OR "herons" OR "egret" OR "egrets" OR "passerine*" OR "eagle*" OR "hawk*" OR "owl" OR "owls" OR "nightjar*" OR "woodpecker*" OR "falcon*" OR "songbird*" OR "landbird*" OR "crow" OR "crows" OR "jay" OR "jays" OR "swallow" OR "swallows" OR "warbler*" OR "thrush*" OR "sparrow*" OR "raptor*" OR "teal" OR "teals" OR "eider*" OR "scoter*" OR "goldeneye*" OR "mergus" OR "merganser*" OR "capercaillie" OR "grebe" OR "grebes" OR "cuckoo" OR "cuckoos" OR "crane" OR "cranes" OR "oystercatcher*" OR "plover*" OR "lapwing*" OR "dotterel" OR "sandpiper*" OR "woodcock*" OR "snipe" OR "snipes" OR "redshank*" OR "greenshank*" OR "phalarope*" OR "skua" OR "skuas" OR "jaeger*" OR "murre*" OR "razorbill*" OR "guillemot" OR "puffin*" OR "tern" OR "terns" OR "petrel*" OR "fulmar*" OR "shearwater*" OR "stork" OR "storks" OR "gannet" OR "gannets" OR "cormorant*" OR "shag" OR "shags" OR "osprey*" OR "harrier" OR "buzzard*" OR "shrike*" OR "jackdaw*" OR "rook" OR "rooks" OR "raven*" OR "tit" OR "tits" OR "lark" OR "larks" OR "martin" OR "starling*" OR "redstart*" OR "stonechat" OR "dunnock" OR "wagtail*" OR "pipit*" OR "finch*" OR "crossbill*" OR</td></tr>
</table>

"bunting*" OR "Accipitrid*" OR "Alaudid*" OR "Alcid*" OR "Anatid*" OR "Apodid*" OR "Ardeid*" OR "Calcariid*" OR "Caprimulgid*" OR "Charadriid*" OR "Ciconiid*" OR "Columbid*" OR "Corvid*" OR "Cuculid*" OR "Emberizid*" OR "Falconid*" OR "Fringillid*" OR "Gaviid*" OR "Gruid*" OR "Haematopodid*" OR "Hirundinid*" OR "Laniid*" OR "Larid*" OR "Motacillid*" OR "Muscicapid*" OR "Pandionid*" OR "Parid*" OR "Passerid*" OR "Phalacrocoracid*" OR "Phasianid*" OR "Phylloscopid*" OR "Picid*" OR "Podicipedid*" OR "Procellariid*" OR "Prunellid*" OR "Rallid*" OR "Scolopacid*" OR "Stercorariid*" OR "Strigid*" OR "Sturnid*" OR "Sulid*" OR "Turdid*") NEAR/10 ((("marker*" OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "band*" OR colo$r-ring* OR leg-ring* OR colo$r-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR PIT-tag* OR PIT-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") NEAR/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" NEAR/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "transmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*") NEAR/3 ("glue" OR "glued" OR "gluing" OR "suture*")) OR ("marker*" OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "band*" OR colo$r-ring* OR leg-ring* OR colo$r-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR PIT-tag* OR PIT-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") NEAR/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" NEAR/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "transmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*")) (Title) OR ("Avian" OR "bird" OR "birds" OR "fowl*" OR "ornitholog*" OR "waterfowl*" OR "duck" OR "ducks" OR "mallard*" OR "goose" OR "geese" OR "swan" OR "swans" OR "quail*" OR "pheasant*" OR "grouse*" OR "ptarmigan*" OR "dove" OR "doves" OR "pigeon" OR "pigeons" OR "swift" OR "swifts" OR "rail" OR "rails" OR "coot" OR "coots" OR "wader" OR "waders" OR wading-bird* OR "shorebird*" OR "gull" OR "gulls" OR "loon" OR "loons" OR "seabird*" OR "heron" OR "herons" OR "egret" OR "egrets" OR "passerine*" OR "eagle*" OR "hawk*" OR "owl" OR "owls" OR "nightjar*" OR "woodpecker*" OR "falcon*" OR "songbird*" OR "landbird*" OR "crow" OR "crows" OR "jay" OR "jays" OR "swallow" OR "swallows" OR "warbler*" OR "thrush*" OR "sparrow*" OR "raptor*" OR "teal" OR "teals" OR "eider*" OR "scoter*" OR "goldeneye*" OR "mergus" OR "merganser*" OR "capercaillie" OR "grebe" OR "grebes" OR "cuckoo" OR "cuckoos" OR "crane" OR "cranes" OR "oystercatcher*" OR "plover*" OR "lapwing*" OR "dotterel" OR "sandpiper*" OR "woodcock*" OR "snipe" OR "snipes" OR "redshank*" OR "greenshank*" OR "phalarope*" OR "skua" OR "skuas" OR "jaeger*" OR "murre*" OR "razorbill*" OR "guillemot" OR "puffin*" OR "tern" OR "terns" OR "petrel*" OR "fulmar*" OR "shearwater*" OR "stork" OR "storks" OR "gannet" OR "gannets" OR "cormorant*" OR "shag" OR "shags" OR "osprey*" OR "harrier" OR "buzzard*" OR "shrike*" OR "jackdaw*" OR "rook" OR "rooks" OR "raven*" OR "tit" OR "tits" OR "lark" OR "larks" OR "martin" OR "starling*" OR "redstart*" OR "stonechat" OR "dunnock" OR "wagtail*" OR "pipit*" OR "finch*" OR "crossbill*" OR "bunting*" OR "Accipitrid*" OR "Alaudid*" OR "Alcid*" OR "Anatid*" OR "Apodid*" OR "Ardeid*" OR "Calcariid*" OR "Caprimulgid*" OR "Charadriid*" OR "Ciconiid*" OR "Columbid*" OR "Corvid*" OR "Cuculid*" OR "Emberizid*" OR

"Falconid*" OR "Fringillid*" OR "Gaviid*" OR "Gruid*" OR "Haematopodid*" OR "Hirundinid*" OR "Laniid*" OR "Larid*" OR "Motacillid*" OR "Muscicapid*" OR "Pandionid*" OR "Parid*" OR "Passerid*" OR "Phalacrocoracid*" OR "Phasianid*" OR "Phylloscopid*" OR "Picid*" OR "Podicipedid*" OR "Procellariid*" OR "Prunellid*" OR "Rallid*" OR "Scolopacid*" OR "Stercorariid*" OR "Strigid*" OR "Sturnid*" OR "Sulid*" OR "Turdid*") NEAR/10 ((("marker*" OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "band*" OR colo$r-ring* OR leg-ring* OR colo$r-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR PIT-tag* OR PIT-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") NEAR/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" NEAR/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "transmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*") NEAR/3 ("glue" OR "glued" OR "gluing" OR "suture*")) OR ("marker*" OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "band*" OR colo$r-ring* OR leg-ring* OR colo$r-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR PIT-tag* OR PIT-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") NEAR/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" NEAR/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "transmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*")) (Abstract)

#3 (("body" NEAR/1 ("condit*" OR "composit*" OR "mass*" OR "weight")) OR "diet" OR "diets" OR fat-scor* OR "hydrat*" OR ("water" NEAR/0 "balanc*") OR "corticosterone" OR "predation" OR "thermoregulat*" OR thermo-regul* OR temperature-regul* OR (("heat" OR "cold" OR "winter") NEAR/1 "stress*") OR "drag" OR "aerodynamic*" OR (("breed*" OR "hatch*" OR "nest*") NEAR/1 ("success*" OR "fail*" OR "behavio$r*" OR "effort*")) OR nest-mark* OR "recruit*" OR "reproduct*" OR "mortality" OR "morbid*" OR "death*" OR "dead" OR "deceased" OR "surviv*" OR vital-rate* OR "fitness" OR "fledg*" OR "prefledg*" OR ("lay*" NEAR/0 "date*") OR clutch-size* OR return-rate* OR ("feather*" NEAR/1 ("wear" OR "abrasi*" OR "break*" OR "damag*" OR "degrad*" OR "qualit*" OR "integrit*" OR "hygie*" OR "growth")) OR "lesion*" OR "immune*" OR "immuno*" OR "diseas*" OR "health" OR "sick*" OR "lame*" OR "wound*" OR (("captur*" OR "exert*") NEAR/1 "myopathy") OR "injur*" OR "energetic*" OR ("stress" NEAR/2 ("respon*" OR "react*" OR "level*")) OR ("function*" NEAR/1 ("capacit*" OR "perform*")) OR ("advers*" NEAR/2 ("event*" OR "effect*" OR "affect*" OR "react*" OR "outcome*" OR side-effect* OR "consequenc*")) OR ("escap*" NEAR/2 ("respon*" OR "react*" OR "behavio$r*" OR "flight*" OR "distanc*")) OR "mate*" OR "mating" OR (("clutch*" OR "brood*" OR "breed*" OR "nest*" OR "egg" OR "eggs") NEAR/2 ("abandon*" OR "attend*")) OR ("parent*" NEAR/2 ("care*" OR "caring" OR "duty" OR "duties" OR "invest*" OR "behavio$r*")) OR (("time" OR "energ*" OR "activ*") NEAR/1 ("budget*" OR "expend*")) OR "movement*" OR "dive*" OR "diving" OR "preen*" OR ("flight*" NEAR/1 "distanc*") OR (("food*" OR "feed*" OR "forag*") NEAR/2 "rate*") OR "welfare" OR (("pain" OR "stress" OR "distress*") NEAR/2 ("express*" OR "behavio$r*" OR "scale*" OR "assess*" OR "indicat*" OR "recogn*" OR "respon*" OR "react*" OR "postur*")) OR "exhaust*" OR "disorient*" OR "vigilan*" OR "fear" OR ("annual" NEAR/1 ("cycle*" OR "return*" OR "survival")) OR temporal-scale* OR life-histor* OR "metabolism" OR "metabolic" OR "persist*" OR ("pattern*" NEAR/2 ("movement*" OR "flight*" OR "nest*" OR "region*" OR "season*" OR "Geograph*" OR "activ*" OR "behavio$r*" OR "mating" OR "mate*" OR habitat-use OR "migrat*" OR "reproduct*" OR "social*")) OR ("migrat*" NEAR/3 ("movement*" OR "flight*" OR "season*" OR "Geograph*" OR "activ*" OR "behavio$r*" OR "strateg*" OR "path" OR "paths" OR "route*")) OR (("forag*" OR "social*" OR "food*" OR "feed*" OR "eating") NEAR/2 "behavio$r*")) (Title) OR (("body" NEAR/1 ("condit*" OR "composit*" OR "mass*" OR "weight")) OR "diet" OR "diets" OR fat-scor* OR "hydrat*" OR ("water" NEAR/0 "balanc*") OR "corticosterone" OR "predation" OR "thermoregulat*" OR thermo-regul* OR temperature-regul* OR (("heat" OR "cold" OR "winter") NEAR/1 "stress*") OR "drag" OR "aerodynamic*" OR (("breed*" OR "hatch*" OR "nest*") NEAR/1 ("success*" OR "fail*" OR "behavio$r*" OR "effort*")) OR nest-mark* OR "recruit*" OR "reproduct*" OR "mortality" OR "morbid*" OR "death*" OR "dead" OR "deceased" OR "surviv*" OR vital-rate* OR "fitness" OR "fledg*" OR "prefledg*" OR ("lay*" NEAR/0 "date*") OR clutch-size* OR return-rate* OR ("feather*" NEAR/1 ("wear" OR "abrasi*" OR "break*" OR "damag*" OR "degrad*" OR "qualit*" OR "integrit*" OR "hygie*" OR "growth")) OR "lesion*" OR "immune*" OR "immuno*" OR "diseas*" OR "health" OR "sick*" OR "lame*" OR "wound*" OR (("captur*" OR "exert*") NEAR/1 "myopathy") OR "injur*" OR "energetic*" OR ("stress" NEAR/2 ("respon*" OR "react*" OR "level*")) OR ("function*" NEAR/1 ("capacit*" OR "perform*")) OR ("advers*" NEAR/2 ("event*" OR "effect*" OR "affect*" OR "react*" OR "outcome*" OR side-effect* OR "consequenc*")) OR ("escap*" NEAR/2 ("respon*" OR "react*" OR "behavio$r*" OR "flight*" OR "distanc*")) OR "mate*" OR "mating" OR (("clutch*" OR "brood*" OR "breed*" OR "nest*" OR "egg" OR "eggs") NEAR/2 ("abandon*" OR "attend*")) OR ("parent*" NEAR/2 ("care*" OR "caring" OR "duty" OR "duties" OR "invest*" OR "behavio$r*")) OR (("time" OR "energ*" OR "activ*") NEAR/1 ("budget*" OR "expend*")) OR "movement*" OR "dive*" OR "diving" OR "preen*" OR ("flight*" NEAR/1 "distanc*") OR (("food*" OR "feed*" OR "forag*") NEAR/2 "rate*") OR "welfare" OR (("pain" OR "stress" OR "distress*") NEAR/2 ("express*" OR "behavio$r*" OR "scale*" OR "assess*" OR "indicat*" OR "recogn*" OR "respon*" OR "react*" OR "postur*")) OR "exhaust*" OR "disorient*" OR "vigilan*" OR "fear" OR ("annual" NEAR/1 ("cycle*" OR "return*" OR "survival")) OR temporal-scale* OR life-histor* OR "metabolism" OR "metabolic" OR "persist*" OR ("pattern*" NEAR/2 ("movement*" OR "flight*" OR "nest*" OR "region*" OR "season*" OR "Geograph*" OR "activ*" OR "behavio$r*" OR "mating" OR "mate*" OR habitat-use OR "migrat*" OR "reproduct*" OR "social*")) OR ("migrat*" NEAR/3 ("movement*" OR "flight*" OR "season*" OR "Geograph*" OR "activ*" OR "behavio$r*" OR "strateg*" OR "path" OR "paths" OR "route*")) OR (("forag*" OR "social*" OR "food*" OR "feed*" OR "eating") NEAR/2 "behavio$r*")) (Abstract)

#4 #3 AND #2
#5 (#4) NOT #1
#6 (#4) NOT #1 and English or German (Languages)

Scopus

Date: 7 July 2023	
Interface: Elsevier	**Field labels:** • TITLE = title • ABSTRACT = Abstract • W/x = within x words, regardless of order • * = truncation of word for alternate endings

#1 TITLE (("Avian" OR "bird" OR "birds" OR "fowl*" OR "ornitholog*" OR "waterfowl*" OR "duck" OR "ducks" OR "mallard*" OR "goose" OR "geese" OR "swan" OR "swans" OR "quail*" OR "pheasant*" OR "grouse*" OR "ptarmigan*" OR "dove" OR "doves" OR "pigeon" OR "pigeons" OR "swift" OR "swifts" OR "rail" OR "rails" OR "coot" OR "coots" OR "wader" OR "waders" OR wading-bird* OR "shorebird*" OR "gull" OR "gulls" OR "loon" OR "loons" OR "seabird*" OR "heron" OR "herons" OR "egret" OR "egrets" OR "passerine*" OR "eagle*" OR "hawk*" OR "owl" OR "owls" OR "nightjar*" OR "woodpecker*" OR "falcon*" OR "songbird*" OR "landbird*" OR "crow" OR "crows" OR "jay" OR "jays" OR "swallow" OR "swallows" OR "warbler*" OR "thrush*" OR "sparrow*" OR "raptor*" OR "teal" OR "teals" OR "eider*" OR "scoter*" OR "goldeneye*" OR "mergus" OR "merganser*" OR "capercaillie" OR "grebe" OR "grebes" OR "cuckoo" OR "cuckoos" OR "crane" OR "cranes" OR "oystercatcher*" OR "plover*" OR "lapwing*" OR "dotterel" OR "sandpiper*" OR "woodcock*" OR "snipe" OR "snipes" OR "redshank*" OR "greenshank*" OR "phalarope*" OR "skua" OR "skuas" OR "jaeger*" OR "murre*" OR "razorbill*" OR "guillemot" OR "puffin*" OR "tern" OR "terns" OR "petrel*" OR "fulmar*" OR "shearwater*" OR "stork" OR "storks" OR "gannet" OR "gannets" OR "cormorant*" OR "shag" OR "shags" OR "osprey*" OR "harrier" OR "buzzard*" OR "shrike*" OR "jackdaw*" OR "rook" OR "rooks" OR "raven*" OR "tit" OR "tits" OR "lark" OR "larks" OR "martin" OR "starling*" OR "redstart*" OR "stonechat" OR "dunnock" OR "wagtail*" OR "pipit*" OR "finch*" OR "crossbill*" OR "bunting*" OR "Accipitrid*" OR "Alaudid*" OR "Alcid*" OR "Anatid*" OR "Apodid*" OR "Ardeid*" OR "Calcariid*" OR "Caprimulgid*" OR "Charadriid*" OR "Ciconiid*" OR "Columbid*" OR "Corvid*" OR "Cuculid*" OR "Emberizid*" OR "Falconid*" OR "Fringillid*" OR "Gaviid*" OR "Gruid*" OR "Haematopodid*" OR "Hirundinid*" OR "Laniid*" OR "Larid*" OR "Motacillid*" OR "Muscicapid*" OR "Pandionid*" OR "Parid*" OR "Passerid*" OR "Phalacrocoracid*" OR "Phasianid*" OR "Phylloscopid*" OR "Picid*" OR "Podicipedid*" OR "Procellariid*" OR "Prunellid*" OR "Rallid*" OR "Scolopacid*" OR "Stercorariid*" OR "Strigid*" OR "Sturnid*" OR "Sulid*" OR "Turdid*") W/10 ((("marker*" OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "band*" OR color-ring* OR leg-ring* OR color-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR pit-tag* OR pit-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") W/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" W/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "transmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*") W/3 ("glue" OR "glued" OR "gluing" OR "suture*")) OR ("marker*" OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "band*" OR color-ring* OR leg-ring* OR color-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR pit-tag* OR pit-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") W/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" W/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "tra nsmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*"))) OR ABS (("Avian" OR "bird" OR "birds" OR "fowl*" OR "ornithol og*" OR "waterfowl*" OR "duck" OR "ducks" OR "mallard*" OR "goose" OR "geese" OR "swan " OR "swans" OR "quail*" OR "pheasant*" OR "grouse*" OR "ptarmigan*" OR "dove" OR "dov es" OR "pigeon" OR "pigeons" OR "swift" OR "swifts" OR "rail" OR "rails" OR "coot" OR "coot s" OR "wader" OR "waders" OR wading-bird* OR "shorebird*" OR "gull" OR "gulls" OR "loon" OR "loons" OR "seabird*" OR "heron" O R "herons" OR "egret" OR "egrets" OR "passerine*" OR "eagle*" OR "hawk*" OR "owl" OR "o wls" OR "nightjar*" OR "woodpecker*" OR "falcon*" OR "songbird*" OR "landbird*" OR "crow" OR "crows" OR "jay" OR "jays" OR "swallow" OR "swallows" OR "warbler*" OR "thrush*" OR "sparrow*" OR "raptor*" OR "teal" OR "teals" OR "eider*" OR "scoter*" OR "goldeneye*" OR "mergus" OR "merganser*" OR "capercaillie" OR "grebe" OR "grebes" OR "cuckoo" OR "cuckoo s" OR "crane" OR "cranes" OR "oystercatcher*" OR "plover*" OR "lapwing*" OR "dotterel" OR "sandpiper*" OR "woodcock*" OR "snipe" OR "snipes" OR "redshank*" OR "greenshank*" OR " phalarope*" OR "skua" OR "skuas" OR "jaeger*" OR "murre*" OR "razorbill*" OR "guillemot" OR "puffin*" OR "tern" OR "terns" OR "petrel*" OR "fulmar*" OR "shearwater*" OR "stork" O R "storks" OR "gannet" OR "gannets" OR "cormorant*" OR "shag" OR "shags" OR "osprey*" O R "harrier" OR "buzzard*" OR "shrike*" OR "jackdaw*" OR "rook" OR "rooks" OR "raven*" OR "tit" OR "tits" OR "lark" OR "larks" OR "martin" OR "starling*" OR "redstart*" OR "stonechat" OR "dunnock" OR "wagtail*" OR "pipit*" OR "finch*" OR "crossbill*" OR "bunting*" OR "Accipi trid*" OR "Alaudid*" OR "Alcid*" OR "Anatid*" OR "Apodid*" OR "Ardeid*" OR "Calcariid*" OR "Caprimulgid*" OR "Charadriid*" OR "Ciconiid*" OR "Columbid*" OR "Corvid*" OR "Cuculid*" OR "Emberizid*" OR "Falconid*" OR "Fringillid*" OR "Gaviid*" OR "Gruid*" OR "Haematopodid *" OR "Hirundinid*" OR "Laniid*" OR "Larid*" OR "Motacillid*" OR "Muscicapid*" OR "Pandioni d*" OR "Parid*" OR "Passerid*" OR "Phalacrocoracid*" OR "Phasianid*" OR "Phylloscopid*" OR "Picid*" OR "Podicipedid*" OR "Procellariid*" OR "Prunellid*" OR "Rallid*" OR "Scolopacid*" O R "Stercorariid*" OR "Strigid*" OR "Sturnid*" OR "Sulid*" OR "Turdid*") W/10 ((("marker*" OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "band *" OR color-ring* OR leg-ring* OR color-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR pit-tag* OR pit-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") W/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" W/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "tra nsmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*") W/3 ("glue" OR "glued" OR "gluing" OR "suture*")) OR ("marker* " OR "marking*" OR "marked" OR "dye" OR "dyes" OR "dyeing" OR "ring" OR "rings" OR "ban d*" OR color-ring* OR leg-ring* OR color-flag* OR leg-flag* OR "RFID*" OR radio-frequency-identificat* OR passive-integrated-transponder* OR pit-tag* OR pit-transponder* OR "patagial*" OR neck-band* OR "neckband*" OR neck-collar* OR nasal-disk* OR nasal-saddle* OR "tracking" OR "tracker*" OR "biologg*" OR bio-logg* OR "tag" OR "tags" OR "tagging" OR (("tag" OR "tags" OR "tagging") W/1 ("wing*" OR "flipper*" OR "leg" OR "legs" OR "position*" OR "back" OR "location*")) OR light-logg* OR ("logg*" W/1 "data") OR "geolocat*" OR "GPS*" OR "GSM*" OR "satellite*" OR "transmitter*" OR "radio*" OR "video*" OR "camera*" OR "accelerometer*" OR "TDR" OR time-depth-record* OR "argos" OR multi-sensor-tag* OR "attach*" OR "harness*" OR "subcutaneous*" OR necklace-collar* OR "implant*" OR automated-data-collect* OR miniature-transmitt* OR "telemet*"))))

#2 TITLE ((("body" W/1 ("condit*" OR "composit*" OR "mass*" OR "weight")) OR "diet" OR "diets" OR fat-scor* OR "hydrat*" OR ("water" W/0 "balanc*") OR "corticosterone" OR "predation" OR "thermoregulat*" OR thermo-regul* OR temperature-regul* OR (("heat" OR "cold" OR "winter") W/1 "stress*") OR "drag" OR "aerodynamic*" OR (("breed*" OR "hatch*" OR "nest*") W/1 ("success*" OR "fail*" OR "behavior*" OR "effort*")) OR nest-mark* OR "recruit*" OR "reproduct*" OR "mortality" OR "morbid*" OR "death*" OR "dead" OR "deceased" OR "surviv*" OR vital-rate* OR "fitness" OR "fledg*" OR "prefledg*" OR ("lay*" W/0 "date*") OR clutch-size* OR return-rate* OR ("feather*" W/1 ("wear" OR "abrasi*" OR "break*" OR "damag*" OR "degrad*" OR "qualit*" OR "integrit*" OR "hygie*" OR "growth")) OR "lesion*" OR "immune*" OR "immuno*" OR "diseas*" OR "health" OR "sick*" OR "lame*" OR "wound*" OR (("captur*" OR "exert*") W/1 "myopathy") OR "injur*" OR "energetic*" OR ("stress" W/2 ("respon*" OR "react*" OR "level*")) OR ("function*" W/1 ("capacit*" OR "perform*")) OR ("advers*" W/2 ("event*" OR "effect*" OR "affect*" OR "react*" OR "outcome*" OR side-effect* OR "consequenc*")) OR ("escap*" W/2 ("respon*" OR "react*" OR "behavior*" OR "flight*" OR "distanc*")) OR "mate*" OR "mating" OR (("clutch*" OR "brood*" OR "breed*" OR "nest*" OR "egg" OR "eggs") W/2 ("abandon*" OR "attend*")) OR ("parent*" W/2 ("care*" OR "caring" OR "duty" OR "duties" OR "invest*" OR "behavior*")) OR (("time" OR "energ*" OR "activ*") W/1 ("budget*" OR "expend*")) OR "movement*" OR "dive*" OR "diving" OR "preen*" OR ("flight*" W/1 "distanc*") OR (("food*" OR "feed*" OR "forag*") W/2 "rate*") OR "welfare" OR (("pain" OR "stress" OR "distress*") W/2 ("express*" OR "behavior*" OR "scale*" OR "assess*" OR "indicat*" OR "recogn*" OR "respon*" OR "react*" OR "postur*")) OR "exhaust*" OR "disorient*" OR "vigilan*" OR "fear" OR ("annual" W/1 ("cycle*" OR "return*" OR "survival")) OR temporal-scale* OR life-histor* OR "metabolism" OR "metabolic" OR "persist*" OR ("pattern*" W/2 ("movement*" OR "flight*" OR "nest*" OR "region*" OR "season*" OR "Geograph*" OR "activ*" OR "behavior*" OR "mating" OR "mate*" OR habitat-use OR "migrat*" OR "reproduct*" OR "social*")) OR ("migrat*" W/3 ("movement*" OR "flight*" OR "season*" OR "Geograph*" OR "activ*" OR "behavior*" OR "strateg*" OR "path" OR "paths" OR "route*")) OR (("forag*" OR "social*" OR "food*" OR "feed*" OR "eating") W/2 "behavior*"))) OR ABS ((("body" W/1 ("condit*" OR "composit*" OR "mass*" OR "weight")) OR "diet" OR "diets" OR fat-scor* OR "hydrat*" OR ("water" W/0 "balanc*") OR "corticosterone" OR "predation" OR "thermoregulat*" OR thermo-regul* OR temperature-

regul* OR (("heat" OR "cold" OR "winter") W/1 "stress*") OR "drag" OR "aerodynamic*" OR (("breed*" OR "hatch*" OR "nest*") W/1 ("success*" OR "fail*" OR "behavior*" OR "effort*")) OR nest-
mark* OR "recruit*" OR "reproduct*" OR "mortality" OR "morbid*" OR "death*" OR "dead" OR "deceased" OR "surviv*" OR vital-
rate* OR "fitness" OR "fledg*" OR "prefledg*" OR ("lay*" W/0 "date*") OR clutch-
size* OR return-
rate* OR ("feather*" W/1 ("wear" OR "abrasi*" OR "break*" OR "damag*" OR "degrad*" OR "qualit*" OR "integrit*" OR "hygie*" OR "growth")) OR "lesion*" OR "immune*" OR "immuno*" OR "diseas*" OR "health" OR "sick*" OR "lame*" OR "wound*" OR (("captur*" OR "exert*") W/1 "myopathy") OR "injur*" OR "energetic*" OR ("stress" W/2 ("respon*" OR "react*" OR "level*")) OR ("function*" W/1 ("capacit*" OR "perform*")) OR ("advers*" W/2 ("event*" OR "effect*" OR "affect*" OR "react*" OR "outcome*" OR side-
effect* OR "consequenc*")) OR ("escap*" W/2 ("respon*" OR "react*" OR "behavior*" OR "flight*" OR "distanc*")) OR "mate*" OR "mating" OR (("clutch*" OR "brood*" OR "breed*" OR "nest*" OR "egg" OR "eggs") W/2 ("abandon*" OR "attend*")) OR ("parent*" W/2 ("care*" OR "caring" OR "duty" OR "duties" OR "invest*" OR "behavior*")) OR (("time" OR "energ*" OR "activ*") W/1 ("budget*" OR "expend*")) OR "movement*" OR "dive*" OR "diving" OR "preen*" OR ("flight*" W/1 "distanc*") OR (("food*" OR "feed*" OR "forag*") W/2 "rate*") OR "welfare" OR (("pain" OR "stress" OR "distress*") W/2 ("express*" OR "behavior*" OR "scale*" OR "assess*" OR "indicat*" OR "recogn*" OR "respon*" OR "react*" OR "postur*")) OR "exhaust*" OR "disorient*" OR "vigilan*" OR "fear" OR ("annual" W/1 ("cycle*" OR "return*" OR "survival")) OR temporal-scale* OR life-
histor* OR "metabolism" OR "metabolic" OR "persist*" OR ("pattern*" W/2 ("movement*" OR "flight*" OR "nest*" OR "region*" OR "season*" OR "Geograph*" OR "activ*" OR "behavior*" OR "mating" OR "mate*" OR habitat-
use OR "migrat*" OR "reproduct*" OR "social*")) OR ("migrat*" W/3 ("movement*" OR "flight*" OR "season*" OR "Geograph*" OR "activ*" OR "behavior*" OR "strateg*" OR "path" OR "paths" OR "route*")) OR (("forag*" OR "social*" OR "food*" OR "feed*" OR "eating") W/2 "behavior*"))))

#3 #1 AND #2

#4 TITLE ("influenza" OR "poultry" OR laying-hen* OR "Zoo" OR "Zoos" OR bird-
market* OR "rail track*" OR "crane track*" OR "crane rail*" OR "overhead
crane*" OR asphalt* OR "bird flu" OR "avian flu" OR "videofluoro*")

#5 #3 NOT #4

#6 #5 AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "German") OR LIMIT-TO (LANGUAGE , "Undefined") OR LIMIT-TO (LANGUAGE , "Swedish") OR LIMIT-TO (LANGUAGE , "Norwegian"))

Biological Abstracts (1985 to May 2023)

Date: 12 July 2023

Interface: Ovid		**Field labels:** • TI = title • AB = Abstract • ADJx = within x words, regardless of order • ? = wildcard, e.g., colo?r finds color, colour • * = truncation of word for alternate endings
1	(("Avian" or "bird" or "birds" or "fowl*" or "ornitholog*" or "waterfowl*" or "duck" or "ducks" or "mallard*" or "goose" or "geese" or "swan" or "swans" or "quail*" or "pheasant*" or "grouse*" or "ptarmigan*" or "dove" or "doves" or "pigeon" or "pigeons" or "swift" or "swifts" or "rail" or "rails" or "coot" or "coots" or "wader" or "waders" or wading-bird* or "shorebird*" or "gull" or "gulls" or "loon" or "loons" or "seabird*" or "heron" or "herons" or "egret" or "egrets" or "passerine*" or "eagle*" or "hawk*" or "owl" or "owls" or "nightjar*" or "woodpecker*" or "falcon*" or "songbird*" or "landbird*" or "crow" or "crows" or "jay" or "jays" or "swallow" or "swallows" or "warbler*" or "thrush*" or "sparrow*" or "raptor*" or "teal" or "teals" or "eider*" or "scoter*" or "goldeneye*" or "mergus" or "merganser*" or "capercaillie" or "grebe" or "grebes" or "cuckoo" or "cuckoos" or "crane" or "cranes" or "oystercatcher*" or "plover*" or "lapwing*" or "dotterel" or "sandpiper*" or "woodcock*" or "snipe" or "snipes" or "redshank*" or "greenshank*" or "phalarope*" or "skua" or "skuas" or "jaeger*" or "murre*" or "razorbill*" or "guillemot" or "puffin*" or "tern" or "terns" or "petrel*" or "fulmar*" or "shearwater*" or "stork" or "storks" or "gannet" or "gannets" or "cormorant*" or "shag" or "shags" or "osprey*" or "harrier" or "buzzard*" or "shrike*" or "jackdaw*" or "rook" or "rooks" or "raven*" or "tit" or "tits" or "lark" or "larks" or "martin" or "starling*" or "redstart*" or "stonechat" or "dunnock" or "wagtail*" or "pipit*" or "finch*" or "crossbill*" or "bunting*" or "Accipitrid*" or "Alaudid*" or "Alcid*" or "Anatid*" or "Apodid*" or "Ardeid*" or "Calcariid*" or "Caprimulgid*" or "Charadriid*" or "Ciconiid*" or "Columbid*" or "Corvid*" or "Cuculid*" or "Emberizid*" or "Falconid*" or "Fringillid*" or "Gaviid*" or "Gruid*" or "Haematopodid*" or "Hirundinid*" or "Laniid*" or "Larid*" or "Motacillid*" or "Muscicapid*" or "Pandionid*" or "Parid*" or "Passerid*" or "Phalacrocoracid*" or "Phasianid*" or "Phylloscopid*" or "Picid*" or "Podicipedid*" or "Procellariid*" or "Prunellid*" or "Rallid*" or "Scolopacid*" or "Stercorariid*" or "Strigid*" or "Sturnid*" or "Sulid*" or "Turdid*") adj11 ((("marker*" or "marking*" or "marked" or "dye" or "dyes" or "dyeing" or "ring" or "rings" or "band*" or colo?r-ring* or leg-ring* or colo?r-flag* or leg-flag* or "RFID*" or radio-frequency-identificat* or passive-integrated-transponder* or PIT-tag* or PIT-transponder* or "patagial*" or neck-band* or "neckband*" or neck-collar* or nasal-disk* or nasal-saddle* or "tracking" or "tracker*" or "biologg*" or bio-logg* or "tag" or "tags" or "tagging" or (("tag" or "tags" or "tagging") adj2 ("wing*" or "flipper*" or "leg" or "legs" or "position*" or "back" or "location*")) or light-logg* or ("logg*" adj2 "data") or "geolocat*" or "GPS*" or "GSM*" or "satellite*" or "transmitter*" or "radio*" or "video*" or "camera*" or "accelerometer*" or "TDR" or time-depth-record* or "argos" or multi-sensor-tag* or "attach*" or "harness*" or "subcutaneous*" or necklace-collar* or "implant*" or automated-data-collect* or miniature-transmitt* or "telemet*") adj4 ("glue" or "glued" or "gluing" or "suture*")) or ("marker*" or "marking*" or "marked" or "dye" or "dyes" or "dyeing" or "ring" or "rings" or "band*" or colo?r-ring* or leg-ring* or colo?r-flag* or leg-flag* or "RFID*" or radio-frequency-identificat* or passive-integrated-transponder* or PIT-tag* or PIT-transponder* or "patagial*" or neck-band* or "neckband*" or neck-collar* or nasal-disk* or nasal-saddle* or "tracking" or "tracker*" or "biologg*" or bio-logg* or "tag" or "tags" or "tagging" or (("tag" or "tags" or "tagging") adj2 ("wing*" or "flipper*" or "leg" or "legs" or "position*" or "back" or "location*")) or light-logg* or ("logg*" adj2 "data") or "geolocat*" or "GPS*" or "GSM*" or	

	"satellite*" or "transmitter*" or "radio*" or "video*" or "camera*" or "accelerometer*" or "TDR" or time-depth-record* or "argos" or multi-sensor-tag* or "attach*" or "harness*" or "subcutaneous*" or necklace-collar* or "implant*" or automated-data-collect* or miniature-transmitt* or "telemet*"))).ti,ab.
2	(("body" adj2 ("condit*" or "composit*" or "mass*" or "weight")) or "diet" or "diets" or fat-scor* or "hydrat*" or ("water" adj1 "balanc*") or "corticosterone" or "predation" or "thermoregulat*" or thermo-regul* or temperature-regul* or (("heat" or "cold" or "winter") adj2 "stress*") or "drag" or "aerodynamic*" or (("breed*" or "hatch*" or "nest*") adj2 ("success*" or "fail*" or "behavio?r*" or "effort*")) or nest-mark* or "recruit*" or "reproduct*" or "mortality" or "morbid*" or "death*" or "dead" or "deceased" or "surviv*" or vital-rate* or "fitness" or "fledg*" or "prefledg*" or ("lay*" adj1 "date*") or clutch-size* or return-rate* or ("feather*" adj2 ("wear" or "abrasi*" or "break*" or "damag*" or "degrad*" or "qualit*" or "integrit*" or "hygie*" or "growth")) or "lesion*" or "immune*" or "immuno*" or "diseas*" or "health" or "sick*" or "lame*" or "wound*" or (("captur*" or "exert*") adj2 "myopathy") or "injur*" or "energetic*" or ("stress" adj3 ("respon*" or "react*" or "level*")) or ("function*" adj2 ("capacit*" or "perform*")) or ("advers*" adj3 ("event*" or "effect*" or "affect*" or "react*" or "outcome*" or side-effect* or "consequenc*")) or ("escap*" adj3 ("respon*" or "react*" or "behavio?r*" or "flight*" or "distanc*")) or "mate*" or "mating" or (("clutch*" or "brood*" or "breed*" or "nest*" or "egg" or "eggs") adj3 ("abandon*" or "attend*")) or ("parent*" adj3 ("care*" or "caring" or "duty" or "duties" or "invest*" or "behavio?r*")) or (("time" or "energ*" or "activ*") adj2 ("budget*" or "expend*")) or "movement*" or "dive*" or "diving" or "preen*" or ("flight*" adj2 "distanc*") or (("food*" or "feed*" or "forag*") adj3 "rate*") or "welfare" or (("pain" or "stress" or "distress*") adj3 ("express*" or "behavio?r*" or "scale*" or "assess*" or "indicat*" or "recogn*" or "respon*" or "react*" or "postur*")) or "exhaust*" or "disorient*" or "vigilan*" or "fear" or ("annual" adj2 ("cycle*" or "return*" or "survival")) or temporal-scale* or life-histor* or "metabolism" or "metabolic" or "persist*" or ("pattern*" adj3 ("movement*" or "flight*" or "nest*" or "region*" or "season*" or "Geograph*" or "activ*" or "behavio?r*" or "mating" or "mate*" or habitat-use or "migrat*" or "reproduct*" or "social*")) or ("migrat*" adj4 ("movement*" or "flight*" or "season*" or "Geograph*" or "activ*" or "behavio?r*" or "strateg*" or "path" or "paths" or "route*")) or (("forag*" or "social*" or "food*" or "feed*" or "eating") adj3 "behavio?r*")).ti,ab.
3	1 and 2
4	("influenza" or "poultry" or laying-hen* or "Zoo" or "Zoos" or bird-market* or "rail track*" or "crane track*" or "crane rail*" or "overhead crane*" or asphalt* or "bird flu" or "avian flu" or "videofluoro*").ti.
5	3 not 4
6	limit 5 to (norwegian or swedish or danish or english or german)

19 Appendix II

CEESTAT Critical Appraisal of summarised evidence (Reviews, Systematic Reciews/Meta-analyses).

Table 11. The criteria for critical appraisal of synthesised evidence. Studies with least potential risk of bias are considered "gold standard" and studies with a potential high risk of bias are coloured red.

Critical Appraisal question	Classification of Risk of bias
1.1 Are the elements of the review question clear?	Gold: The review question or hypothesis is clearly stated and clearly defines key elements, (e.g. PICO, PECO, PO, PIT, etc.) correctly, such as the subject or population of interest, the intervention or exposure type, the comparator and valid measures of outcome.
	Green: The review question or hypothesis is clearly stated, and key-elements are mentioned although not formally defined in terms of PICO, PECO, PO, PIT, etc
	Amber: The question or hypothesis is stated in broad terms but key-elements are unclear or poorly defined. OR Question or hypothesis not stated but problem or issue is stated such that a question can be inferred
	Red: A question, hypothesis or problem is not stated OR There is no stated objective to provide an answer to a question or test of a hypothesis. OR The article does not contain an evidence synthesis (e.g. primary research or descriptive overview)
2.1. Is there an a-priori method/protocol document?	Gold: The review cites a separate a-priori protocol or documented pre-defined method containing details of proposed conduct of all review and synthesis stages (e.g. question, search, eligibility screening, critical appraisal, data extraction and synthesis) AND It is linked from the synthesis (e.g. as supplementary material or hosted on a separate website) AND It was publicly accessible prior to the conduct of the review AND It was submitted to an independent body for peer review and publication.
	Green: The review cites a separate accessible a-priori protocol or documented predefined method containing details of conduct of all review and synthesis stages (e.g. question, search, screening, critical appraisal, data extraction and synthesis) AND It is linked from the synthesis (e.g. as supplementary material or hosted on a separate website) AND It was publicly accessible prior to the conduct of the review.

	Amber: The review cites a separate accessible a-priori protocol or documented predefined method, but this does not contain all details of conduct of all review and synthesis stages or was not publicly accessible prior to the conduct of the review OR The review includes a defined methods section (not a-priori) listing the synthesis stages conducted and providing sufficient detail to enable the method to be replicated (therefore this standard is met only if all of criteria 3.1, 4.1, 6.1 & 7.1 are rated green or above).
	Red: There is no protocol and the review methods are not clearly defined in the methods section of the review or there are no methods reported.
3.1. Is the approach to searching clearly defined, systematic and transparent?	Gold: All search terms and search strings, with Boolean operators ('AND', 'OR' etc.) and wildcards, are clearly stated for each source (e.g. databases, search engines, specialist websites) so that the exact search is replicable by a third party AND There is information about the sources searched, together with dates of search and any limitations justified (e.g. languages, publication date, no grey literature searches).
	Green: All search terms and search strings, with Boolean operators ('AND', 'OR' etc.) and wildcards, are clearly stated for each major source (e.g. databases, search engines) so that the exact search is replicable by a third party but search terms for minor sources (e.g. specialist websites), if used, may be missing. AND There is information about the sources searched and search options selected, together with dates of search but some limitations (reported or evident) not justified (e.g. languages or publication date or no grey literature searches)
	Amber: The search is described but not adequately to be fully replicable by a third party either because the specific search terms are not stated or Boolean operators/wildcards are not stated (so it is unclear how the search terms are combined). OR There is information about the databases searched, but dates of search not given and no limitations justified (e.g. language or publication date or no grey literature searches).
	Red: No information regarding the search strategy (search terms and strings) used.
3.2. Is the search comprehensive?	Gold: Sources of articles searched capture both conventionally published scientific literature and grey literature using a combination of databases, search engines and specialist websites (may also be informed by stakeholders) or limitations are fully justified. AND Comprehensiveness of search is tested using independent samples of articles (test lists should be provided) of the relevant literature to demonstrate adequate sensitivity. NB. Statements such as 'We considered only peer-reviewed material because this is more reliable than grey literature' without evidence that the methodological quality of potentially relevant grey literature was assessed do not indicate that grey literature was objectively considered.

	Green: Sources of articles searched are stated and capture both conventionally published scientific literature and grey literature using a combination of databases, search engines and specialist websites (may also be informed by stakeholders) or limitations are fully justified. NB. Statements such as 'We considered only peer-reviewed material because this is more reliable than grey literature' without evidence that the methodological quality of potentially relevant grey literature was assessed do not indicate that grey literature was objectively considered.
	Amber: Resources used are stated but limited, without justification, to conventionally published scientific literature or just one or two sources.
	Red: Resources used not stated or search is not systematic (i.e. studies appear to have been selected).
4.1. Are eligibility criteria clearly defined?	Gold: Eligibility criteria are precisely defined (e.g. reliance on broad and potentially ambiguous terms should be avoided) and expressly related to each key element of the question (other criteria such as study design may also be considered) AND Criteria are consistent between a-priori protocol and review or differences are fully explained.
	Green: Eligibility criteria are precisely defined (e.g. reliance on broad and potentially ambiguous terms should be avoided) and are expressly related to each key element of the question (other criteria such as study design may also be considered).
	Amber: The questions/scope/objectives of the review are stated such that the type of primary research articles/studies to be included are broadly apparent, but the review does not explicitly identify criteria expressly related to each key element of the question (other criteria such as study design may also be considered). OR Some eligibility criteria are defined but either incomplete or no clear relationship to a review question (possibly because the question is poorly defined).
	Red: No to both amber criteria above (eligibility criteria are not stated).
4.2. Are eligibility criteria consistently applied to all potentially relevant articles and studies found during the search?	Gold: The eligibility criteria are independently applied by more than one reviewer to all of the screened articles/studies (at title screening stage, pragmatic decisions about dual screening of subsamples is justified e.g. because large numbers of titles were screened) AND Replicability of eligibility decisions was measured and reported and all disagreements between reviewers discussed so that the resolutions informed subsequent assessments.

	Green: The eligibility criteria are independently applied by more than one reviewer to a sample of justified size of the screened articles/studies at title, abstract and full text. AND Replicability of eligibility decisions was measured and reported and all disagreements between reviewers discussed so that the resolutions informed subsequent assessments.
	Amber: The eligibility criteria are applied by more than one reviewer to a sample of the screened articles/studies at abstract and full text but reviewer independence is uncertain (i.e. not reported) or absent. AND Replicability of eligibility decisions was examined (but a measure may not be reported) and all disagreements between reviewers discussed so that the resolutions informed subsequent assessments.
	Red: Number of reviewers not reported OR Only one reviewer applied criteria at abstract or full text stage, OR Where two reviewers, consistency of decisions not tested/reported OR No eligibility criteria provided (see 4.1)
4.3. Are eligibility decisions transparently reported?	Gold: The total number of articles and number of unique articles found during the searches (after removal of duplicates) is presented AND The number excluded at each stage of the screening process is fully presented (e.g. in a flow diagram or table) AND Reasons for exclusion of each article/study considered at full-text are presented (e.g. in an appendix) AND A list of eligible (included) articles/studies is presented as a separate list or in tables (not just included in reference list).
	Green: The total number of articles found and numbers excluded at each stage of the screening process is reported but some aspects missing (e.g. number of unique articles or articles unobtainable) AND Reasons for exclusion of each article/study considered at full-text are presented (e.g. in an appendix) AND A list of eligible (included) articles/studies is presented as a separate list or in tables (not just included in reference list).
	Amber: The total number of articles found and numbers excluded during the screening process is reported (or inferable) but some aspects missing (e.g. number of unique articles or articles unobtainable or reasons for exclusion at full text) AND A list of eligible (included) articles/studies is presented as a separate list or in tables (not just included in reference list).
	Red: No to either or both of the amber criteria above

5.1 Does the review critically appraise each study?	Gold: An effort is made to identify all sources of bias relevant to individual included studies (threats to internal and external validity) AND Each type of bias (threat to internal and external validity) is assessed and explained individually for all included studies AND Results are reported using an a-priori defined (in protocol) critical appraisal sheet. NB. This does not include syntheses in which the design and conduct of each study are stated but validity is not explicitly considered (no critical appraisal), or in which methodological rigour is discussed without transparent and objective assessments for each study.
	Green: An effort is made to identify all sources of bias relevant to individual included studies (threats to internal and external validity) AND Each type of bias or threat to internal and external validity is assessed individually for all included studies and reported on a critical appraisal sheet. NB. This does not include syntheses in which the design and conduct of each study are stated but validity is not explicitly considered (no critical appraisal), or in which methodological rigour is discussed without transparent and objective assessments for each study.
	Amber: Some characteristics of all included studies are explicitly identified as indicators of threats to internal and/or external validity of studies but not reported for individual studies.
	Red: No critical appraisal conducted OR all critical appraisal criteria not applied to all individual included studies. This may include syntheses in which the methods for each study are stated but validity is not explicitly considered, or in which methodological rigour is discussed without transparent and objective assessments for each study.
5.2. During critical appraisal was an effort made to minimise subjectivity?	Gold: An effort is made to minimise subjectivity by predefining a critical appraisal process in a protocol AND At least two people independently critically appraised each study with disagreements and process of resolution reported.
	Green: An effort is made to minimise subjectivity by predefining critical appraisal process in a protocol AND At least two people critically appraised each study but not independently (e.g. second person aware of first person's decision)
	Amber: At least two people critically appraised each study but not independently (e.g. second person aware of first person's decision) or subset of studies was appraised by at least two people independently. Disagreements and process of resolution MIGHT NOT be reported.
	Red: No to Amber above (e.g. Only one person critically appraised each study or number not reported) OR No critical appraisal conducted (i.e. RED for 5.1 above).

6.1. Is the method of data extraction fully documented?	Gold: The authors state in an a-priori protocol the type of data to be extracted AND the methods by which data from each study will be extracted so that the process can be replicated and confirm these methods were ultimately used in their report or reasons for deviation.
	Green: The authors state in the methods (but not in an a-priori protocol) the type of data to be extracted AND the methods by which data from each study were extracted so that the process can be replicated (In some cases methods may have been partially reported in an a-priori protocol but then modified or substantially developed during the review process).
	Amber: The authors state in the methods the type of data to be extracted AND although the review does not provide a fully replicable methodology for data extraction, it is possible to infer the broad method from the reported results (e.g. a table that lists all eligible studies and data extracted might be included).
	Red: No to either part of amber above. It is not clear what data were selected for extraction and/or no consistent approach to data extraction is reported
6.2. Are the extracted data reported for each study?	Gold: All data selected for extraction are provided in a table or spreadsheet as set out in the a-priori protocol. This includes the data used in the synthesis from each primary study (e.g 'raw' outcome metrics: means, variance measures) and meta-data AND calculations or transformation of data by review authors using extracted data (e.g. effect sizes, averaging over variables summarisation of themes, coding, etc.) are reported in full and therefore replicable.
	Green: All data selected for extraction are provided in a post-hoc table or spreadsheet. This includes the data used in the synthesis from each primary study (e.g 'raw' outcome metrics: means and variance measures) and meta-data AND calculations or transformation of data by review authors using extracted data (e.g. effect sizes, averaging over variables summarisation of themes, coding, etc.) are reported in full and therefore replicable.
	Amber: The review provides a table/spreadsheet that includes some of the extracted metrics data for some or all studies (e.g. Table/spreadsheet only lists partial data for each study but omits other information OR Table/spreadsheet lists extracted data, but not for all studies OR A combination of these). Note: It may be unclear if all studies are included since they are not listed anywhere in the article.
	Red: No to amber above. Data extracted are not presented.
6.3. Were extracted data cross checked by more than one reviewer?	Gold: Data were extracted from each study by at least two independent reviewers.
	Green: An explanation was provided of how a sample of extracted data was cross checked between two or more reviewers.

	Amber: A statement that cross-checking between two reviewers was carried out is provided but explanation unclear or incomplete.
	Red: No report of cross checking is provided.
7.1. Is the choice of synthesis approach appropriate?	Gold: The choice of synthesis method (i.e. quantitative or narrative synthesis) is prespecified, described in sufficient detail to be replicable and justified (e.g. in the protocol) on the basis of scoping characteristics of included studies, taking into consideration variability between studies in sample size, study design, context, outcomes measures etc OR Justified post hoc as a deviation from the protocol (but still described in sufficient detail to be replicable) as a result of unexpected outcome (not pre-specified) of critical appraisal and data extraction AND Where quantitative and statistical approach to meta-analysis is not employed when it may have been appropriate, a justification for this should be given (e.g. studies too diverse or data not synthesisable).
	Green: The choice of synthesis method (i.e. quantitative or narrative synthesis) is described in sufficient detail to be replicable and is (or appears) justified on the basis of characteristics of included studies, taking into consideration variability between studies in sample size, study design, context, outcomes etc. AND Where quantitative and statistical approach to meta-analysis is not employed when it may have been appropriate, a justification for this should be given (e.g. studies too diverse or data not synthesisable)
	Amber: No to either or both of the above (e.g. no justification for not undertaking metaanalysis when it may have been appropriate) but none of the listed criteria under Red below.
	Red: No to either or both in green above: AND either quantitative synthesis (e.g. meta-analysis) is undertaken when inappropriate OR vote-counting relied on as an indicator of impact or effectiveness OR narrative synthesis does not include all studies or unclear if it includes all studies.
7.2. Is a statistical estimate of pooled effect (or similar) provided together with measure of variance and heterogeneity among studies?	Gold: Statistical estimates of findings are presented using pre-defined (e.g. in the protocol) meta-analysis method that justifies synthesis approach including study weighting and subgroup analysis AND Consideration is given to study independence (e.g. through sensitivity analysis) and bias (e.g. tests for publication bias).
	Green: Statistical estimates of findings are presented using meta-analysis method that justifies approach (e.g. using study weighting and subgroup analysis) AND Consideration is given to study independence (e.g. through sensitivity analysis) and bias (e.g. tests for publication bias).

	Amber: Statistical estimates of findings presented using defined meta-analysis method but lacks justification of approach and/or consideration of study independence (e.g. through sensitivity analysis) and/or bias (e.g. tests for publication bias).
	Red: No statistical estimate provided either because meta-analysis not conducted or not possible OR Statistical estimate provided but not clear what meta-analysis method was used
7.3. Is variability in the study findings investigated and discussed?	Gold: A strategy for investigating effect modifiers is provided in an a-priori protocol and followed (or variations explained) in the review AND Effect modifiers (e.g. taxa being considered, location, habitat type, study design etc.) were investigated statistically through meta-analysis (alternatively, evidence for heterogeneity between studies is tested and reported as non significant) AND Authors have used results of critical appraisal (not just statistical weighting in metaanalysis) in their quantitative and/or narrative synthesis.
	Green: Effect modifiers (e.g. taxa being considered, location, habitat type, study design etc.) are investigated statistically through meta-analysis (alternatively, evidence for heterogeneity between studies is tested and reported as non significant) AND Authors have used results of critical appraisal in their quantitative and/or narrative synthesis.
	Amber: Effect modifiers (e.g. taxa being considered, location, habitat type, study design etc.) investigated statistically through meta-analysis (alternatively, evidence for heterogeneity between studies is tested and reported as non-significant) but authors have not used results of critical appraisal in their quantitative and/or narrative synthesis. OR Effect modifiers (e.g. taxa being considered, location, habitat type, study design etc.) were investigated descriptively through narrative synthesis.
	Red: Reasons for variability in study findings not investigated. Effect modifiers were not considered (this includes studies that use quantitative synthesis but fail to test for heterogeneity statistically).
8.1. Have the authors considered limitations of the synthesis?	Gold: An explicit section is devoted to the authors' consideration of limitations of their review including limitations of the primary data (available evidence), possible sources of bias in the review process, conduct of the review process and recommendations made for future syntheses and primary research.
	Green: An explicit section or identifiable passage of text is devoted to the authors' consideration of limitations of primary research/data and of conduct of the review process but does not consider all of the following: possible sources of bias in the review process, conduct of the review process and recommendations made for future syntheses and primary research.

	Amber: Some consideration of limitations is evident but not explicitly stated or not focus of specific section OR Consideration of limitations of the primary research included but limitations of the conduct of the review not included.
	Red: No evident consideration of limitations of primary data or review conduct.

Table 12. Critical appraisal of synthesised evidence. A traffic-light schema (see Table A-3.1 for categories) indicates the potential risk of bias in each study. Gold = very low risk of bias; Green = low risk of bias; Amber = some risk of bias; Red = High risk of bias.

Citation	1.1	2.1	3.1.	3.2.	4.1.	4.2.	4.3.	5.1	5.2	6.1.	6.2.	6.3.	7.1.	7.2.	7.3.	8.1.
Bodey, TW, Cleasby, IR, Bell, F, et al. A phylogenetically controlled meta-analysis of biologging device effects on birds: Deleterious effects and a call for more standardized reporting of study data. Methods Ecol Evol. 2018; 9: 946–955. https://doi.org/10.1111/2041-210X.12934																
Brlík, V, Koleček, J, Burgess, M, et al. Weak effects of geolocators on small birds: A meta-analysis controlled for phylogeny and publication bias. J Anim Ecol. 2020; 89: 207–220. https://doi.org/10.1111/1365-2656.12962																
Weiser, E.L., Lanctot, R.B., Brown, S.C. et al. Effects of geolocators on hatching success, return rates, breeding movements, and change in body mass in 16 species of Arctic-breeding shorebirds. Mov Ecol 4, 12 (2016). https://doi.org/10.1186/s40462-016-0077-6																
David Costantini, Anders Pape Møller, A meta-analysis of the effects of geolocator application on birds, Current Zoology, Volume 59, Issue 6, 1 December 2013, Pages 697–706, https://doi.org/10.1093/czoolo/59.6.697																

Cleasby IR, Morrissey BJ, Bolton M, et al. What is our power to detect device effects in animal tracking studies? Methods Ecol Evol. 2021; 12: 1174–1185. https://doi.org/10.1111/2041-210X.13598																
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