# Towards a Framework for Agroecological Pig Production: maximizing functional roles for pigs within food and farm systems.

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# Abstract

A theoretical farm design is presented which includes pigs in a number of multi-functional roles, and is built from observations gained during three case studies. The model incorporates pigs as utilizers of waste-food resources, as 'tillers' in integrated pig/crop production, and as species beneficial to agroforestry systems. Two additional historical case studies were conducted in order to construct a theory of how the theoretical farm design might change in response to changes in the intensity of land use and distance from the natural ecology of wild *Sus scrofa*. The selection of case studies grew in response to previous ones, and attention is given to the learning process involved.

# *Preface*

This thesis grew from an interest first acquired during the case study visit that was part of PAE 302 'Agroecology: Action Learning in Food and Farm Systems.' With the case studies, we entered into situations of which we knew very little, and my own experience with pigs and pig production was, at the time, nearly non-existent. The more that was learned, the more challenging it seemed, *to me*, to reconcile pig production with the goal of a multi-functional agriculture that mimicked nature. This main problem guided the course of research and led what, *to me*, are some of the ways in which pigs can be brought back into multi-functional roles within our agroecosystems.

The inclusion of the words "to me" are difficult to justify in an academic text. They imply that reality is subjective, precluding any concrete understanding about the nature of our world; concrete understanding being a goal which has long been the ambition of scientific thought. The suggestion by Wilson and Morren (1990), "that because people approach inquiry into a situation differently, the way in which knowledge is created and the substance of that knowledge is different," has traditionally made our personal *weltenschauungen* an unwanted component of the scientific process.

It is, however, precisely this diversity of *weltenschauungen*, and the associated diversity of knowledge created that that informs our navigation towards workable solutions (Bawden, 1991a; K. Wilson & Morren, 1990). This thesis, then, presents my personal window on pig production, and the process by which that window was positioned through participation within different farm management strategies. Those management strategies are, themselves a result of the diverse *weltenschauungen* of the farmers, and the years (perhaps lifetime) of experience that have informed them.


# *Acknowledgments*

There can be no "sensible way to proceed" then, but to acknowledge all those, past and present, successful in their endeavours and failing in them, recorded and unrecorded, that have endeavoured to understand and/or manage the parts, processes and their own role in the (agro)ecosystems of which they are a part. Their contributions are vast, diverse, and deserving of reflection. We do indeed stand on the shoulder's of giants, even if those giants are humble pig farmers.

Specifically, however, I would like to thank Suzanne Morse and Lizzy Simpson for their insights and suggestions throughout the writing process. I am glad to have crossed paths with two individuals of similar interests and concerns. I thank Neils Andresen for beginning my research with the contribution of his doctoral thesis, "The Foraging Pig."[1] I am, also, and especially indebted to the three farmers that graciously allowed me to disturb them; Heinrich for taking the time to entertain a new and ignorant pig enthusiast, Ole for smiling and shrugging when I allowed the pipes to freeze (repeatedly), and Augustin for tolerating my inefficiency and sloppiness (I think I may have cut a few Corsican pines by mistake). Thank you for your kindness, generosity and patience.

Finally, and by no means jocularly, I would like to extend gratitude to the pig, a species which millenia ago, for better or worse, decided that we were as beneficial to it, as it was to us.


1 (Andresen, 2000)

*For the “Old Grumpy's”*

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# 1. Introduction

Feeding the human species is an increasingly intensive and demanding occupation, and one result of our industrialized agriculture has been, in essence, a decoupling in many facets of food production (Alexandratos & Bruinsma, 2012; Tilman, Balzer, Hill, & Befort, 2011). Food consumption has been decoupled from its production, and species have been decoupled from their ecological context (OECD, 2003; Sæbjørnsen, 2013). In many ways modern pig production has become the defining example of such intensification, with most individuals raised in ways entirely decoupled from their natural behaviours and ecology. Not only are pigs confined at high densities, but feed is grown specifically for them. These feeds are often grown as intensive monocultures on land cleared of forest. The pig's[2] only functional role appears to be that of an economically efficient meat machine, with little regard for their possible multi-functional roles in other aspects of the global agroecosystem.

These broken ecological relationships are at the heart of sustainability issues in modern agriculture and require increasing amounts of human technological intervention in an attempt to "right" the situation or, more often, treat the symptoms. These are usually short lived, unsustainable solutions that ignore the root causes Altieri, 1992, 2000; Wilson & Tisdell, 2001). As we grapple with these issues, there is a growing awareness that ecological relationships and system functionality matter, and an increasing number of examples in which such relationships are slowly being rebuilt (Dobbs & Pretty, 2004; Lovell et al., 2010; Pretty, 2008a).

Of increasing importance, therefore, is the use and inclusion of species in ways that recognize their unique ecological roles and interactions to maximize benefits to the food production system, to the surrounding environment, and to the social systems of which we are all a part. Recently the U.N. commissioned International Assessment of Agricultural Knowledge and Technology for Development (IAASTD) report has referred to this concept as agroecology and has stated its importance in meeting the challenges of global food production. (IAASTD, 2009).

2 The term "pig" will be used in this paper to refer to domestic forms of *Sus scrofa*. Wild forms will be refered to as *Sus scrofa,* though it must be remembered that inbetween exist a myriad number of other stages.

A number of terms have been used to describe agricultural techniques in which complimentary, potentiating interactions between components are created or desired (Pretty, 2008b). Although differing in details, these various points of departure share many key similarities as models of social-cultural-ecological interactions that may provide solutions to some of our vexing food production problems. A central theme in many of them is that agricultural components be multifunctional. Whether living or non-living, parts of the system should provide multiple uses or services to other components. In effect, an attempt is made to (re)build ecosystems containing ecological relationships that are inclusive and complementary of human needs. Although the exact implementation will vary depending on the ecosystem type, topography, and social aspects of a particular location, some guidelines, however, are generally followed. Despite a focus on locally useful species, many common agricultural crops and livestock species are used across situations, which has led to a renewed interesest in traditional agroecosystems in which these species had existed, as well as the ecological role of their wilder ancestors (Altieri, 1995).

Thus the premise of this paper; that our agricultural species, having evolved within a particular ecology, can and should have roles that mimic those of their wilder progenitors. When we, as managers of our agroecosystems fail to find functional roles for our agricultural species a series of deleterious feedbacks occur and those agricultural species fall out of favour, are condemned, and at worst cause the collapse of the agroecosystem itself. In those situations, however, in which we as managers succeed in finding the ecological analogue roles of our agricultural species the agroecosystem gains in resilience and productivity. The result is that those very same species are regarded highly, raised to a level of respect and revered for their contributions and value.

Design and management solutions, widely available to the public[3], have been put forward from the focus point of trees, vegetable crops, grains, water, ruminants, buildings and topography (Fukuoka, 1978; Jacke & Toensmeier, 2005; Mollison, 1988; Savory & Butterfield, 1998; Yeomans, 1978)[4]. Pigs, however, seem especially challenging, and have been dealt with very little in such literature. Their omnivority and destructive rooting behaviour make them difficult to reconcile within our agroecosystems, and there is a thin

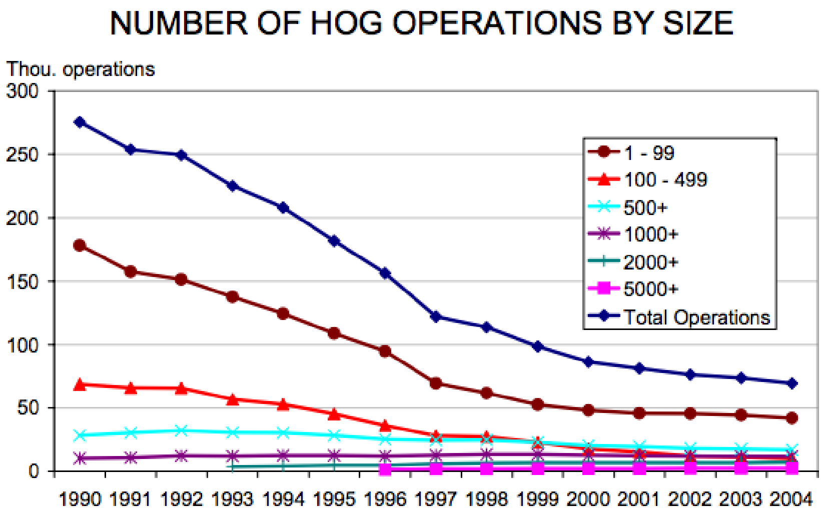
3 A key point. Literature on sustainable solutions is vast and of good quality, yet much of which is in academic texts unavailable to (aspiring) farmers, who are then reliant upon popularized books or extension officers.

4 Among many, many more.

line between an advantageous relationship with pigs and a disadvantageous one. This thesis, then, attempts to find farm-scale solutions to these broader sustainability issues by examining ways in which modern farmers have incorporated pigs into their agroecosystems.

## *1.1 Pig Problems: concentration and competition*

### 1.1.1 Ultra-intensive: pigs in modern agriculture




Today *Sus scrofa domesticus*, has risen to become the world's most produced and consumed livestock species. Global demand for meat, driven by growing affluence, has increased pig meat consumption by 70% since the 1980's, and pig producers have met this demand by increasing production 75% over the same time period. Most of the world's pig meat is produced in China (46%) followed by the E.U. (20%) and the U.S. (10%) (FAO, 2013; OECD, 2003).

At the same time pig farms have become increasingly intensified (Mayda, 2004; OECD, 2003). The economics of production and distribution have favoured a fewer number of large specialized operations at the expense of smaller, often diversified farms (Marquer, 2010; S. Meyer & Steiner, 2005; National Agricultural Statistics Service, 2009; Schneider, 2011). Figures 1 and 2 show changes in numbers of pig operations over the last few decades in the U.S. (Fig. 1) and China (Fig. 2). Starting roughly in the mid-90's the number of small operations in both China and the U.S. begin to decline while the number of larger operations rose. Figure 3 shows, too, that in the E.U. current pig production is dominated by large farms with greater than 400 fattening pigs per farm. These industrialized farms have also become concentrated regionally, with high densities in economically or regulatory favourable districts (Xiaoyan, 2003). Although positive in some ways, the concentrative aspects of industrialization create a number of environmental, epidemiological, and ethical concerns. The economic environment in which current agriculture operates, however, often means that many of these concerns are met with least cost solutions instead of prudent and sustainable ones (OECD, 2003).

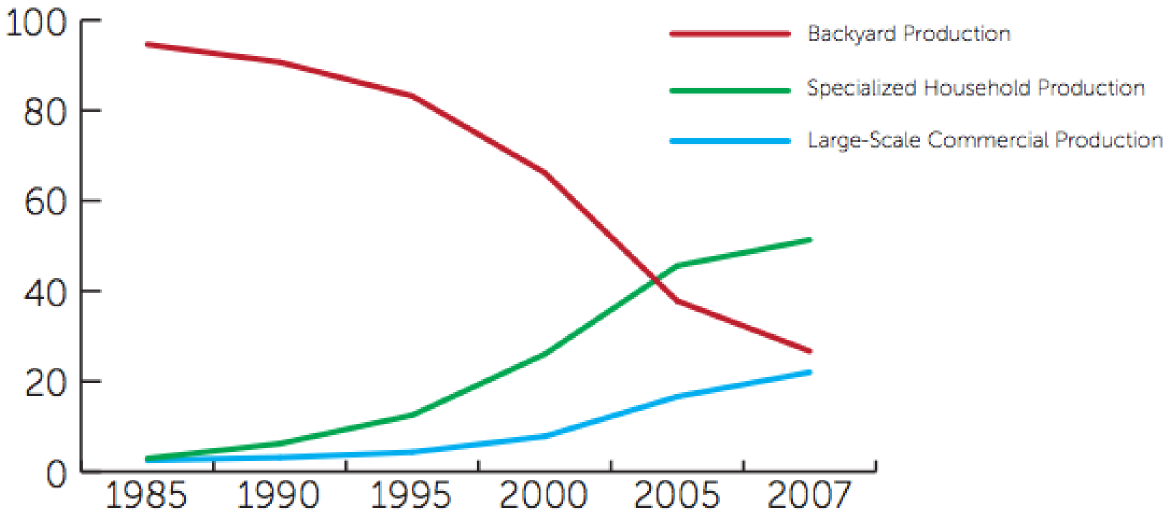



*Fig. 2: Pig Production in China. Backyard Production: <10 pigs. Specialized Household Production 10-500 pigs. Large-scale Commercial Production >500 pigs. Source: Informa Economics and National Grain and Oil Information Center, 2009; (from Schneider, 2011)*

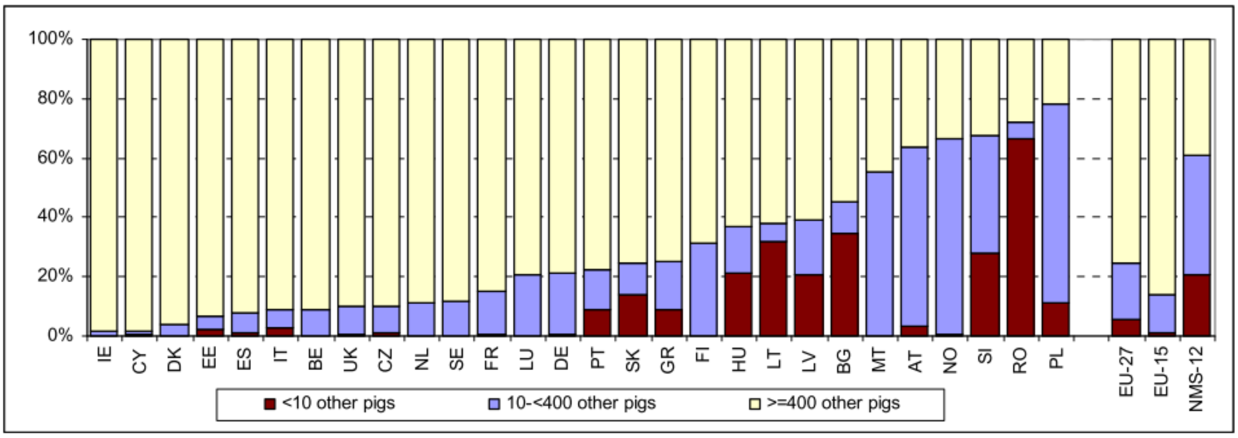



*Fig. 3: Distribution of fattening pigs (other pigs) per farm size other pigs in E.U. and member states. Source: Eurostat 2007, (from Marquer, 2010)*

The concentrated nature of intensive pig production has, for instance, led to waste disposal problems where too little land is available to absorb an excess of nutrients. The specialization and regional density of intensive production further worsens the situation since there are too few crops available locally for which the manure could be used. As pig manure, compared to synthetic fertilizers, is a non-dense source of nutrients, transportation economics have disfavoured the redistribution of manure to distant areas of crop land (Fleming, Babcock, & Wang, 1998). This nutrient excess is then dealt with as waste, with pig slurry being held in lagoons and treated in a variety of ways to remove nitrogen and phosphorus. While this may be more economical than transportation, such methods largely ignore the ecological importance of nutrient cycling (Burton & Turner, 2003). This nutrient excess saturates surrounding soils and eventually enters into water-ways, where it has a number of negative impacts (Holm-Nielsen, Al Seadi, & Oleskowicz-Popiel, 2009; Raven & Gregersen, 2007).[5] The lack of nutrient cycling has also lead to the accumulation of metals, such as copper and arsenic, in areas were pig waste is disposed. These metals are often added to feeds as micro-nutrients or growth stimulators. Their persistence in soils often means they accumulate in crops and pastures fertilized with pig manure, where they can become toxic to livestock (Kerr & McGavin, H.D. (Univ. of Tennessee, 1991; Li & Chen, 2005; Li et al., 2007; F A Nicholson, Chambers, Williams, & Unwin, 1999). Regulation, and compliance of waste disposal varies widely, and contamination of water and soils is a continuing problem (OECD, 2003; Xiaoyan, 2003).

Pig houses are also known sources of infectious disease. The concentration and confinement of large numbers of pigs create conditions favourable to the spread, evolution and emergence of potentially dangerous microbes (Casey, Curriero, Cosgrove, Nachman, & Schwartz, 2013; Saenz, Hethcote, & Gray, 2006; Webster, 1998). While the emergence of human infectious diseases is the most notable, infectious disease among the swine herd itself is also of increasing concern (Lunney, Benfield, & Rowland, 2010; McOrist, Khampee, & Guo, 2011). A common practice in intensive production is the routine administration of low level antibiotics to prevent disease, promote growth, and increase feed conversion ratios. Such prolonged use of non-lethal doses allows microorganisms to adapt, evolve, and emerge as new, antibiotic resistant strains (Gilchrist et al., 2007). Estimates suggest that up to 50% of all antibiotic use in the China is for livestock (Zhu & Juan, 2010), and as much as

5 Although pig slurry can be used for biogas production, and is an attractive solution for the treatment of wastes, initial capital investments are high, and in any event requires the the use of confinement on slatted floors.

70% in the U.S. (Union of Concerned Scientists, 2001).

Ethic concerns abound as well. The conditions in which many pigs are raised are often criticized as cruel and appalling. The reduction of a pig's life experience to its pen, its food and its eventual slaughter are said to be disrespectful of an animals inherent characteristics, behaviour and value as a living species (Fölsch & Hörning, 1996). “*Dignity is essential to life quality. And it is extended to animals. Animal factories interfere with the dignity of pigs” (Naess, 1999).*

### *Life of a Pig*

The United States Environmental Protection Agency's “Ag 101: Pork Production Phases” is especially illuminating of the most common pig production systems in the U.S..

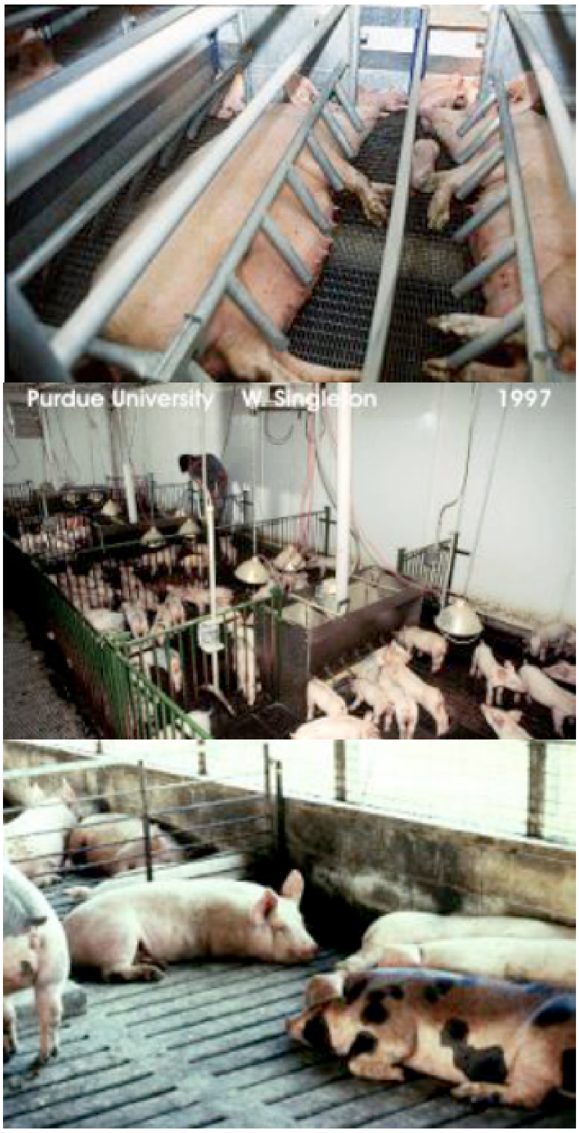



*Fig. 4: Pork production phases from top to bottom: farrowing, nursery, growing/finishing. (U.S. EPA, 2013)*

Production starts 3 to 5 days after the last weaning, when sows begin estrous. This a critical period of time when boars are introduced to the sow pens for breeding. In large facilities sows might be artificially inseminated. If sows are not bred during this period they will come into estrous 21 days later. Since during this time they must be fed and housed, many growers simply send them to slaughter if they miss the first estrous.

Before giving birth sows are moved to farrowing rooms where they are often confined to a crate which restricts their movement and reduces piglet crushing. On either side of the crate is an area in which the piglets can move, sleep and access the sow's teats through the bars. Some more 'natural' farrowing units provide deep straw bedding but this increases both cleaning labour and piglet crushing.

Both the teeth and tails of piglets are clipped to prevent incidents of biting.

At two to three weeks, piglets are weaned and sent to the nursery, where they are kept in a temperature controlled space, since during this period they can easily become too cold. As they grow temperature is lowered to ensure they are not overheated.

The final phase is the growing/finishing period in which pigs are kept inside and allowed to eat as much as they like. Minimum requirements are roughly 8 sq. ft. (~0.74m$^2$)of space per pig. At roughly 6 months of age pigs are sent to be slaughtered (United States Environmental Protection Agency, 2012).

Accompanying pictures (Fig. 4) give perhaps the best evidence of an animal completely removed from its environment. At no time during the production process is the pig exposed to anything beyond the pen in its housing unit. The unnaturalness of the pig's experience is also evident by the necessity of clipping teeth and tails to reduced injury resulting from stress induced biting (Ekkel & Doorn, 1995). The pig is modified for production rather than production being modified for the pig.

Although not covered in the EPA website. The feed sources for most pigs are imported grain and soy, most of which is grown in large monocultures specifically as livestock feed. These areas are themselves removed from normal ecosystem processes and cycles (Tilman, 1999); and their production for use as livestock feed lowers the caloric efficiency of our global agricultural production (Cassidy, West, Gerber, & Foley, 2013).

### 1.1.2 Biosphere II: agroecosystem inefficiency on a small scale

> "Like their readers, many journalists believe that human society may successfully design nature to fit economic aspirations. What Biosphere 2 showed, in a short time, is the lesson that our global human society is learning more slowly with Biosphere 1[6], that humans have to fit their behavior into a closed ecosystem" (Odum, 1996)

From 1991-1993 an enclosed experiment was conducted in order to better understand total ecosystem function and the interactions necessary to sustain a self-contained, artificial biosphere. Named Biopshere II, the project attempted to replicate several natural biomes in a connected facility that was materially closed from the outside

6 Our planet.

world. Since an 8 person 'crew' was to be housed inside for a period of two years an agricultural biome was included to provide for the nutritional needs of the inhabitants. As an enclosed system it was important to develop an agricultural system that was inherently sustainable, non-polluting and system oriented (Nelson & Dempster, 1995). A number of crop species were originally included as well as three livestock species: goats, chickens and pigs. Pygmy varieties were used to allow for higher populations to exist on such a limited area. It was originally planned that the chickens would eat kitchen and other small scraps, that the goats would consume various fodders, and that the pigs would be fed on excess starchy crops. After reducing the numbers of chickens by 50%, both chickens and goats became successful and welcome contributions to the agricultural system, with goats becoming the most successful livestock species overall, contributing the greatest amount of animal fat and protein. Over the course of two years goats contributed nearly 859kg of food, ~842 of which was milk. This amounted to 90.3% of total animal production and contributed 10.5% of total daily protein and 15.6% of daily fat to the diet of the inhabitants. Pigs were the next most produced livestock accounting for 62% of total livestock production, and contributed 3.2% of daily protein and 5.3% of daily fat (Fig. 5). These high numbers, however, were due to the necessity of culling the entire pig population. Due to climatic reasons which reduced amounts of solar radiation during the test period, and a profusion of insect pests lacking adequate population controls, less starchy vegetables were produced than originally anticipated. After a period of poor performance, a decision was made to remove pigs from the system to ensure enough food production for the human inhabitants (Nelson, Silverstone, & Poynter, 1993). While the other agricultural species lived in relative symbiosis with the human inhabitants either by eating what could not be digested by humans (goats) or what was too small to be worth picking through (chickens), the pigs were essentially in direct conflict. By requiring land dedicated specifically for growing their feed stuffs or directly consuming what was otherwise edible to the human inhabitants they ceased to be a species interacting positively with the agroecosystem developed in the Biosphere II program. This, despite the fact that pig meat was the fattiest meat and contributed the second highest amount of fat to a diet in which fat was in short supply (Nelson & Dempster, 1995). In mimicking global ecosystems and agroecosystems on a small scale the facility succeeded also in mimicking a many of our problems with the pig on larger scales.

| BIOSPHERE 2 INTENSIVE AGRICULTURE PRODUCTION FOR 8 BIOSPHERIANS SEPTEMBER 1991 TO SEPTEMBER 1993 | | | | | | | |
|---|---|---|---|---|---|---|---|
| CROP | YIELDS Kg/sq.meter Year 1 | YIELDS Kg/sq.meter Year 2 | TOTAL 2 YR YIELD Kg | g. per person per day | PROTEIN (g.)/ PERSON/ DAY | FAT (g.)/ PERSON/ DAY | Kcal/ PERSON/ DAY |
| ANIMAL PRODUCTS | | | | | | | |
| GOAT MILK | | | 841.84 | 142.37 | 4.58 | 5.59 | 99.05 |
| GOAT MEAT | | | 16.96 | 2.87 | 1.02 | 0.48 | 7.54 |
| PORK | | | 58.74 | 9.93 | 1.70 | 2.06 | 26.11 |
| FISH | | | 10.21 | 1.73 | 0.32 | 0.07 | 2.03 |
| EGGS 257 | | | 14.29 | 2.42 | 0.29 | 0.27 | 3.86 |
| CHICKEN MEAT | | | 8.07 | 1.37 | 0.25 | 0.20 | 2.92 |
| SUBTOTAL | | | | | 8.17 | 8.68 | 141.50 |
| TOTAL PRODUCED | | | | | 53.35 | 38.80 | 1823.41 |

## 1.2 Purpose and Research Questions

Given the problems associated with pigs in modern agriculture, and the opportunity of finding agricultural solutions in mimicking natural ecosystem function, there is much to learn about the ecological roles of wild *Sus scrofa* and the role of the pig in traditional agroecosystems where caloric efficiency was a key aspect. At a larger level, there is much to learn about the process by which we can formulate design solutions themselves.

The main question then is:

1. How can we design, where ecologically appropriate, modern farm systems to incorporate pigs *into* a number of multi-functional roles within agroecosystems.

   (emphasis added to indicate the goal is to find and promote situations where the pig becomes a useful component rather than to design a farm around pig production)

*With a second loop learning question:*

*a[1]. "What can we, as agroecosystem managers, ask about our agricultural species that can lead to more multi-functional inclusions into our agroecosystems?"*

To help answer the main question, two additional questions where framed:

2. How does the agroecological function of the pig change in relation to its ecological context.
3. How are pigs incorporated into modern mixed farms, where pigs are a major livestock species.

*With the second loop learning question:*

*b[2,3]. "Are these appropriate questions to answer question a[1]."*

## 2. Methodology

> "As I need theories about agriculture to inform the actions I need to take to change the situation to hand, so I also need theories to inform the way I go about generating the first set of theories and practices" (Bawden, 1991b).

Given the nature of the main question, and the possibility of falling into the trap of prescriptive solutions that ignore complexity, there was at all times a focus on the process of learning. As Pretty (1995) writes, "technologies are not sustainable; what needs to be made sustainable is the process of innovations itself.[7]" Second loop learning questions, as defined by Argyris (2002), where therefore added to the main research questions in order to ensure a reflective process.

Questions 2 and 3 were chosen as necessary to answer the main question, and their formation was part of the process of answering it. If ecological mimicry truly is a path towards a sustainable agriculture, then it is important to find processes by which we can develop agroecological frameworks for our domestic species.

For instance, when designing an agroecosystem that incorporates a wild fruit-tree species with a number of functional roles, we need only to observe the present day ecological context of that particular tree species in order to develop a framework for how that species should be incorporated into our agroecosystems[8]. Answering questions such as: "Was the species found in wet or dry soils?", "What was the soil type?", When does it flower and fruit?" are relatively easy to answer with direct observation or literature relating direct observation. The answering process is simplified because the species already is in its ecological context with its functional roles defined.

If instead, we wanted to design an agroecosystem to include a domestic species, (e.g. pigs) with a number of functional roles, direct observation of a pig farm would, although important, do us little good on its own. As a domesticated species, it does not, by definition, exist within its wild context. Observing its wild progenitors, although incredible useful, fails to relate any information about the role of human management in the agroecosystem

7 Pretty, 1995; Personal communication with Brunch and Lopez

8 Observation of the wider human context are also obviously important. Questions such as "Is this fruit edible?" or "Is this fruit marketable," however, do not answer "How can the species be fit into the agroecosystem" but rather "If the species should be fit into the agroecosystem"

of which pigs, as a domesticate, are and have been a part. If we were to design an agroecosystem to incorporate pigs based solely on observations of its wild progenitors we would fail to recognize how millenia worth of breeding has changed the pig's possible functional roles. And again, by solely observing a pig farm, we fail to relate that particular agroecosystem within a broader ecological context. We are discounting the myriad agroecosystem adaptations that agroecosystem managers, i.e. farmers, have developed to function within their broader ecological context. We are in essence, just staring at a pig farm.

Question 2 then assumes that agroecosystem managers adapt their practices in relation to their broader ecological context, and that learning how the functional roles of one particular species change as a function of the broader ecological context provides the 'framing' necessary for new agroecosystem designs in which that species is a part. This study, therefore, includes an historical analysis of the pig in changing agroecosystems, which are themselves within broader ecosystems undergoing change. The Middle East and Northwest China from 7,000 BP to 4,000 BP were discovered as suitable examples for historical review since they shared a number of similarities. For example, both were practicing early grain based agriculture, both had pigs as well as ruminants included in their agriculture repertoire, both underwent a similar drying of climate, both were intensifying agriculture, and ultimately both removed pigs from their systems. Their differences, however, are just as important. Being two independently derived birthplaces of agriculture, and being so far removed from each other spatially helps remove the possibility that agroecosystem changes were due to the spread of a social meme. Their historical processes are, therefore, suggested as being fundamental to an understanding of pig agroecology.

Although a historical review over such a long time frame is helpful in defining a general trend, limit, and framework. It does little to reveal individual adaptations at the farm level, and smooths individual variation. By hiding this detail, a purely historical review fails to provide information at a farm-level, at which the main question is positioned. If we are to undertake any meaningful action we must define the scale at which we will undertake such action. Explorations at a similar scale, are therefore appropriate for finding solutions.

Question 3 then assumes that individual adaptation of farm systems, to include pigs in a functional role, is also fundamental to understanding pig agroecology. Three case studies were therefore included to provide some detail to the ways by which modern farm systems incorporate pigs into multi-functional roles at the farm level.

## 2.1 Current Case Studies

The impossibility of accounting for the minute variations at every farm site, limit the usefulness of theoretical model as a design suitable for all agroecosystems. Instead, observations during my case study visits were used to construct a theoretical design that is meant to create and ensure a long-term, ever expanding understanding of a situation. The design, however, does not represent a situation that *is,* as Checkland and Poulter (2006) define a rich picture, but rather one that *could be*. It is intended to serve as a departure point or addition for those interested in including pigs in their agroecosystems. Also, since the *process* of design is as important as the design itself, attention is given to the way in which the case studies evolved.

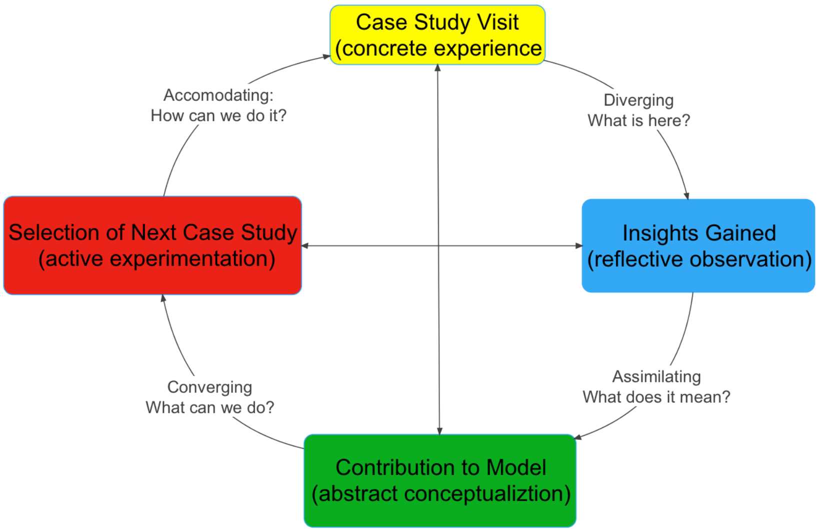


*Fig. 5: Kolb's learning cycle. Used as a model for the expanding case studies.*

The 3 current case studies, therefore, were not chosen beforehand, but chosen based on observations at previous farms. The process was imitative of Kolb's learning cycle  (Fig. 6), in which concrete experience at one farm, led to observations and reflections, that produced the abstract conceptualizations used in building the theoretical design (Fig. 15). Those theoretical designs were 'tested' by choosing the next case study according to its similarity to the abstract conceptualization; and the process repeated (Kolb, 1984). Unfortunately, however, there are time frames and 3 case studies was my personal limit.

Because of the complexity of the systems dealt with, a participant observation strategy was adopted. As Bawden writes:

> “if…one wants to actively explore with rural communities how they might design their own, more sustainable futures, then the method of enquiry needs to be participant-observer and the complexity of the situation must be embraced. There is no other sensible way to proceed” (Bawden, 1991b).

While there may indeed be other sensible ways in which to proceed, participant observation was assumed to allow the most information gathering, and similar methods have yielded valuable insights into pig production methods (Albarella, Manconi, Vigne, & Rowley-Conwy, 2007). The participant observation process was carried out with a list of general farm questions that were answered during my participation. Questions about basic operations included: reproduction, weaning/growing, slaughter, field rotation, manure management, feeding, and other managing movements. Interestingly one of the first insights gained, after visiting Heinrich's farm, had nothing to do with his farm system, but rather with my selection of a relatively short stay and interview with defined questions as my case study procedure. It led me to reform my process of learning by changing the length of stay and interview methodology. Due to the inherent complexity of an agroecosystem, a short stay participation with interviews ignored the necessity of encountering random observations.

> “…there are known knowns; there are things we know that we know. There are known unknowns; that is to say, there are things that we now know we don't know. But there are also unknown unknowns - there are things we do not know we don't know” (Secretary of Defence Donald H. Rumsfeld, 2002).

Although widely mocked[9], Rumsfeld's summation of the types of information that exist is accurate and applicable. Unknown-unknowns are common features of both complex systems and chaotic ones; and important, defined features of managing them. Unknown-unknowns can only become “known knowns” or “known unknowns” if they are met by a random encounter (Bourne & Walker, 2005; A. Meyer, Loch, & Pich, 2002). Facilitating the exposure of oneself to random events, has therefore been proposed as way to not only gain a deeper understanding of ones environment, but to grow in response to it (Taleb, 2010, 2012).

Direct questioning of the farmer, therefore, was relegated to a few daily questions, limited to ensure random information entered the conversation. Much of the questioning wasn't even 'questioning' in the normal sense, but rather small

9 And mired in the emotion of its political context

prompts simply to allow the farmer to talk about his farm. The case study process, therefore, very much resembled the “long interview” strategy used specifically to uncover “unknown unknowns” (Mullins & Jorgensen, 2007). The exact evolution can be traced in figure 6.

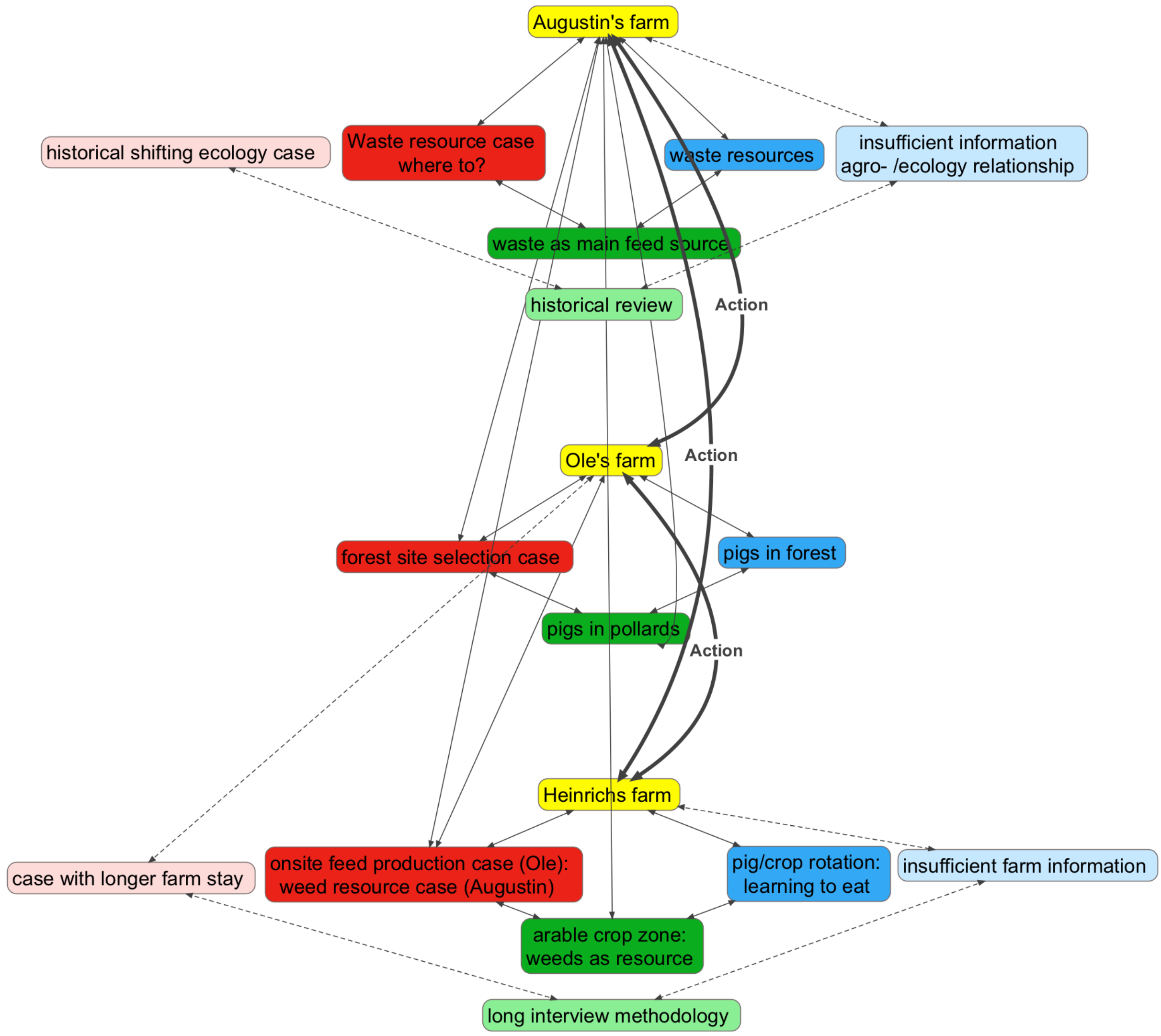



*Fig. 6: Process of expanding case studies, beginning with Heinrich's farm. Colors match those of Kolb's learning cycle presented above. Two processes of second learning are presented as lighter colors and were important in informing the methodology. Thicker lines marked 'Action' mark the eventual sharing of this thesis with the farmers.*

The case studies started with Heinrich's farm where I spent two days in June 2012. Pig tillage in cropping systems was an initial interest, and a fellow student mentioned Heinrich's farm as combining the two[10]. Questions were asked during the

10 In reality the thesis started with the initial farm visit that was part of PAE 302 'Agroecology: Action Learning in Food and Farm Systems.'

course of the work, but it quickly became apparent that in such a short period I would be unable to learn enough about his farm to make valuable insights.

Ole's farm was chosen next because it offered a much longer time period in which to observe farm processes. From October 2012 – March 2013 I lived and worked on Ole's farm. His farm was known from a previous case study of his farm.

Observations and questions raised by observing his pig's escaping into the forest, led me to Augustin's farm. I found his writings about pigs in the forest on the internet and contacted him. I stayed on his farm from March 2013 – May 2013.

Unfortunately I was unable to stay a full season on any of the farms. This obviously limits my understanding of the annual cycle of events, and is especially problematic since most of my time spent observing the farms was during winter months. Direct questioning, therefore, was focused on the summer seasons.

## *2.2 Historical Case*

The second loop learning in Augustin's case (see fig. 6) reflect a problem in the methodology that had concerned me from the beginning and came both to a crisis and resolution at Augustin's farm. That the management decisions for pigs in an agroecosystem are largely a part of the broader environment of which it is a part (both non-human and human), would require an almost infinite number of case studies from which it would be difficult to define broad trends.

Discussions with Augustin about the deeper socio-ecological implications of agriculture, and the history of the pig in a number of contexts, led to the exploration of the limits of pig husbandry in the Middle East, and by way of comparison, northwestern China. Historical review can be used to answer questions about how things change, and combining qualitative methods, i.e. case studies and historical cases, can help add information that support or refute each other's findings (Yin, 2012).

The selection of the Middle East and northwest China was made based on the similarities between the two situations: both were early centres of agricultural domestication, both had long histories with the pig, both underwent similar environmental change, both were neolithic, both eventually abandoned the pig; but despite the similarities, the geographic distance between the two likely limited the spread of social memes between the two that might have influenced management decisions. I suggest, therefore, that similarities between the changes in agroecosystem management where a result of broader changes in the ecology, and can help us with the design of modern agroecosystems.

# 3. Case Studies

## *3.1 Historical Case: pigs in changing agroecosystems 8,000 BP to the present*

### 3.1.1 Domestication: an extensive process

The pig is one of our oldest agricultural species, with a suggested domestication of around 9,000 years BP (Giuffra et al., 2000). Pig domestication is a complex topic, and it is known there were multiple centres of domestication, which gives some indication of the adaptability of the pig to human life-ways (Larson et al., 2005). It is suggested that pigs entered into domestication through a process of habituation, in which they were slowly drawn into closer contact with human settlements, and as an omnivorous scavenger, wild pigs were likely first drawn to human villages in search of various foodstuffs (Zeder, 2012). A common phenomenon even today. This repeated contact changed both the behaviour of the wild pig and how early societies responded to them. Although domestication is often considered a human driven event, it should be remembered that the changing attitudes of the pig to its human neighbours were just as important as our changed attitudes towards these wild visitors (Anderson, 1997). Not only did we resist the urge of an easy kill, we tolerated frequent visits and perhaps promoted them. Likewise the pig, helped no doubt by rich and plentiful village wastes, tolerated ours. Domestication is symbiotic.

'Domestication' as a word, hides the complexity of the event, especially for a species such as the pig, and exact areas of domestication have been difficult to discover. The pig more than any other agricultural species easily reverts to its wild form. Free roaming domestic pigs often return to a life in the wild if abandoned by their human settlement. The release of domestic pigs into new territory and especially islands has been a common practice. The 'domestic' population often does quite well and are able to be culled later

(Larson et al., 2007). Such releases are often associated with ecological disturbance, relating the adaptability of the pig (Cruz, Donlan, Campbell, & Carrion, 2005; Nogueira-Filho, Nogueira, & Fragoso, 2009). Their wildness has been only lightly painted over.

The role of the pig both in island releases and free roaming village situations in one of centralizing distributed food stuff from an extensive area. The pig simply roams and scavengers similar to its wild ancestors, using its exceptional smell to find wide ranging food stuffs. Its omnivority allows it to digest a wide number of items, from herbs to meat, earthworms to tree mast, which are incorporated into the meat and fat of its body. When the pig is culled, those diverse and widely dispersed foodstuffs are effectively 'harvested.'

The ability of the pig to forage in unmanaged environments and return back to the safety of human settlements was likely the first agroecological role the pig inhabited. It is a strategy that requires very little management and one that makes the pig, along with the dog, the only domestic animal associated with hunter-gatherer groups (Guddemi, 1992; Krause-Kyora et al., 2013). Archeological evidence suggests early pig husbandry consisted of this strategy in many parts of the world. If dogs helped with the hunting, pigs must have helped with the gathering.

The terms 'domestic' and 'wild', when applied to pigs, also imposes a false dichotomy to a species so easily inhabiting both worlds. The process of domestication might better be understood as an increasing intensity of interaction between pigs and humans, one that may have taken centuries before the term 'domesticated' might be agreed upon (Albarella, Dobney, & Rowly-Conwy, 2006; Meadow, Hongo, Dobney, & Ervynck, 2001).

Evidence of domestic pigs as the main domesticate at the sedentary site of Hallan Çemi on a tributary of the Tigris reveals their transition semi-wild nature, ranging freely in the local environment yet returning to the village. Grain agriculture did not exist at these sites, instead the productive *Quercus* dominated forests of the region provided a productive forest resource which the inhabitants exploited. Given that pigs are so excellently adapted to such a situation, they would have made perfect free-roaming foragers, and returning to the settlement, would have been easily culled. (Redding & Rosenberg, 1998).

Much has been written about the origins of agriculture, and is well outside the scope of this discussion, but for whatever reason a decreasing reliance on the natural environment and an increasing reliance on human production occurred. The increasing focus and intensification of agriculture likely led to a revaluation of the pigs role. In areas were sedentary human populations grew, and more land was devoted to growing crops, free roaming pigs must have become a liability to the crops and pastures (Redding & Rosenberg, 1998). Free roaming (feral) pigs cause considerable economic losses in modern agriculture, with annual costs associated with crop damages and control ranging from 0.8 to 1.5 billion (Pimental, 2007; Pimentel, Zuniga, & Morrison, 2005). Also with more land devoted to crops and less available for the natural production of dispersed food stuffs, feeding the pigs must have become a more managed practice.

Two areas of interest in regards to the changes in pig agroecological function are the Middle East and northwestern China. Both were regional areas of crop domestication and intensification, and both were areas in which pigs were important livestock species. Climatic changes at the end of the 3rd millennium led both areas to become more arid and marginal, pressuring the agroecological systems of the time to adapt, and eventually abandon the pig as a participant in those systems.

## 3.1.2 Intensification: the changing role of pigs in early sedentary agriculture

***Middle East Pig Prohibition: ecological determinism and religious decree***

While the reasons are unclear, it is generally agreed that Middle Eastern pig prohibition has its roots in ancient Egypt (Murdock, 1959; Zeuner, 1963). A number of theories have been proposed towards an understanding of Middle Eastern pig prohibition, and it remains a complex and contested topic. Early theories rest mostly on religious grounds, in which the practice served merely to strengthen group identity or show religious conviction. Prohibiting the sensual enjoyment of a high fat meat, for instance, would have been especially pious at a time when diets were often limited. Such sacrifices of earthly delights feature prominently in the religions of the middle east and manifest themselves in various ways, from food prohibitions to circumcision rituals. It has also been argued that the prohibitions of pigs served to strengthen in-group/out-group identifications, a nearly universal aspect of all religious belief (Diener et al., 1978). It could be argued, however, that these are more or less arbitrary decrees. Any number of requirements or prohibitions could serve to strengthen group identity, and why prohibit the enjoyment of this particular substance and allow the enjoyment of others (Zeder, 1998)? With the arguments for prohibition based solely upon cultural preferences are relatively weak and unconvincing, a more complete understanding can be gained by considering the functional relationships (or lack there of) of the pig in ancient Middle Eastern agroecosystems.

In pre-dynastic times both wild and domesticated pigs would have found excellent habitat in the seasonally flooded nile delta. Whether Egyptian pigs were domesticated from wild stock found inhabiting these marshes, or wild pigs were a result of feral domestic pigs is unclear; pig domestication is a complex and murky affair. However, it is thought that between roughly 5500-6000 BP, and perhaps as early as 7000 BP domestic pigs were established in Egypt. At this time ecological conditions in the region would have been more favourable to pigs. It is known that prior to ~9000 BP the northern Sahara and surrounding lands were wetter, but slowly began a process of acidification. The drying climate would have put immense pressure on the agricultural system of the time. It is known for example that between 7000 and before 5100 BP areas for free grazing cattle became limited. This was a time too, when the dynastic state of Egypt was beginning to form. Perhaps as a social response to a drying climate and dwindling resources (Lobban, 1994). As Lobban (1994) writes:

> "In the ancient Middle East, as early as 5000 B.C. and certainly before the Egyptian
> Old Kingdom (ca. 3100 B.C.), the areas for free grazing were already starting to become limited (Harris 1985:76). Egyptians had begun to abandon free-range grazing, which was replaced by regular production of animal fodder in the form of Egyptian clover (Trifolium alexandrinum), *berseem* in modern Arabic. Even today, *berseem* remains the most important single crop by cultivated area (Ikram 1980:175). Steadily, the production of livestock fodder-especially for cattle, sheep, goats, and donkeys-became and still is the major emphasis for Nile-valley farmers.
>
> In anthropological studies of the rise of the ancient state, the central role of the domestication of plants and animals is well known. However, it is often assumed that increased human population density directly caused an expansion of agricultural production. It is generally not emphasized that the greatest consumers of agricultural production from antiquity to the present are not people but domestic animals. As a function of this need, the human demand was to bring more land into

> fodder production for their valuable livestock. Just as today, marshes were drained, swamps filled in, and the ecology transformed[11]. One of the earliest animals to face this ecological transformation was the pig."

An increasing focus on strictly herbivorous species would have made reasonable ecological sense in a drying climate. Natural grassland environments are indeed associated with decreased precipitation compared to forested environments, and grazing species are, of course, a fundamental component of them. Just as one can travel spatially through a decreasing precipitation gradient, noting the change from forest to grassland to desert and the associated species of each ecosystem; so too would the inhabitants of ancient Egypt traveled temporally, noting the change in their local ecosystem from wet forest, through grassland to desert and responded with an appropriate change in the species composition of their agroecosystems.

If the escalating marginality of the environment decreased opportunities for free grazing, it is likely to also have limited the availability of foragable feed stuffs for its human inhabitants. As many traditional forms of pig raising involve free ranging of pigs, and with pigs having a diet similar to that of a human, pigs would have become direct competitors with humans. As foraging opportunities dwindled and agriculture encroached on the shrinking moist river valleys, both wild and domestic pigs would likely have been seen as a growing liability. Even today, wild and feral pigs can cause heavy economic losses from crop damages (Pimental, 2007; Pimentel et al., 2005). While losses in modern commodity based agriculture are economical, losses in the primarily subsistence systems of that time would have been an issue of individual and community survival.

Lobban (1994) goes on to suggest that the relative status and respect given to pigs in varying societies is based on the climatic conditions of the regions in which those societies inhabit (Fig. 8). High status is given to pigs in areas where climate is favourable to pig behaviour and ecology such as southeast Asia where the ownership of pigs conveys a high social rank and pigs are in many ways the focus of the society (Sillitoe, 2007). In contrast, societies in hot, dry areas regard the pig as a low value animal and it may even be prohibited. The social status of pigs in differing ecological contexts is largely based on the

11 The statement that the greatest consumers of agricultural production are domesticate animals is questionable. Agricultural production in the Americas, for example, had little emphasis on livestock. Whether land was transformed for the production of human or animal feeds, however, makes little difference. *That* land was transformed for agriculture is the important point, and in this case it was transformed for the more ecologically appropriate grassland-herbivore agroecosystem.

feeding strategies those pigs have within them. In all but the hottest and driest ecosystems listed by Lobban in figure 8, pigs exist as extensive foragers. In southeast Asia pigs are free-roaming with provisions of sweet potatoes more or less serving to keep pigs returning to settlement sites (Sillitoe, 2007). In moist cool Europe too, though not noted by Lobban, pigs traditionally had their place in the forest, free-ranging on nut masts (Ervynck, Lentacker, Müldner, Richards, & Dobney, 2007). Even in hot dry areas pigs were herded to ecologically favourable areas such as marshes and river banks to consume feed in an extensive way. Only in the driest environments, removed from outside sources of feed do pigs have the strongest prohibitions.

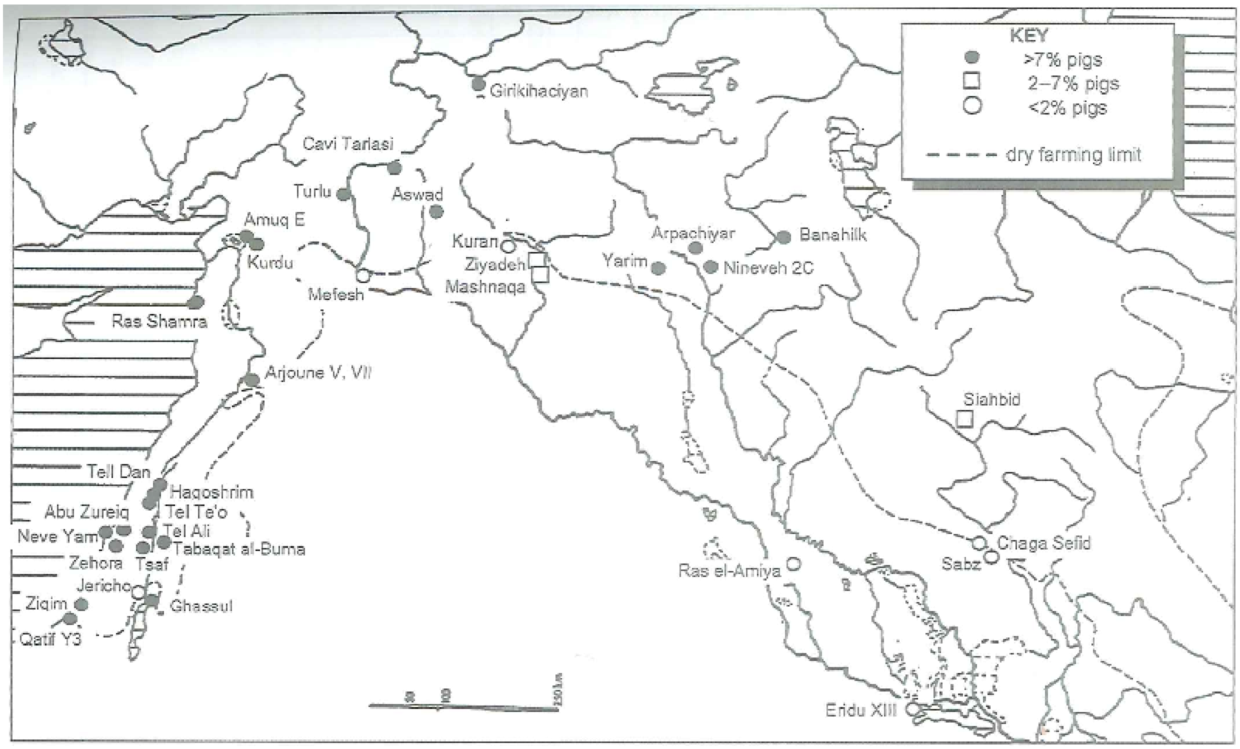
| Ecosystem/Region | Social Status of Pigs | Means of Population Control |
|---|---|---|
| Moist, warm (Melanesia) | very great social rank for large numbers owned | complex taboos; mass periodic slaughter of young and adults; sweet potatoes grown for pig food |
| Moist, cool (China, Europe) | highly valued for meat and other products | few specific taboos; constant harvesting of young and juveniles; pigs eat wastes and grains |
| Hot, wet | some value for scavaging and for food | few taboos for non-Muslims; periodic harvesting of pigs; some are fed, but most are free-foraging |
| Hot, dry (except in marshes and river banks; ancient Nile valley) | limited value for meat and sacrifice | young pigs eaten by lower social strata; some utilitarian value; prohibited for upper classes; pigs were herded |
| Hot, dry (Middle East, at present) | very low status | very strong taboos; pig population at minimum by hunting and confinement; fed wastes and some foods |

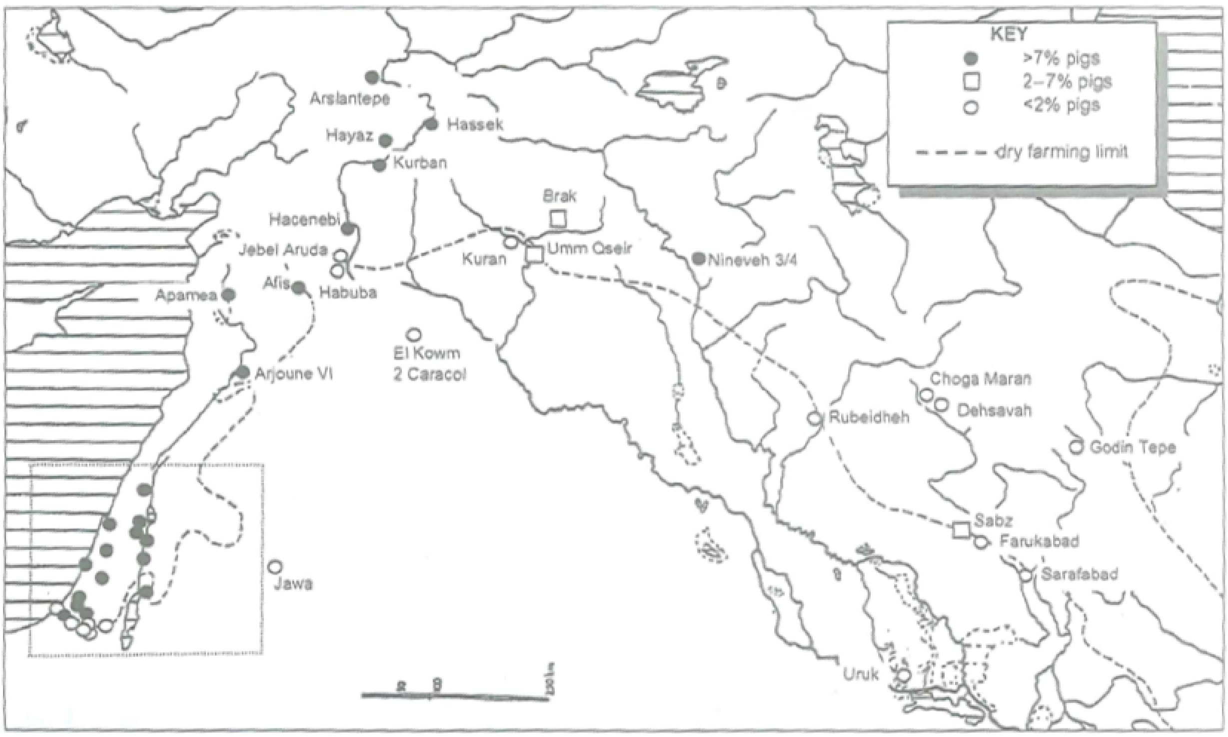
*Table 2: "Correlates of pig ecology and prohibition." (Lobban, 1994)*

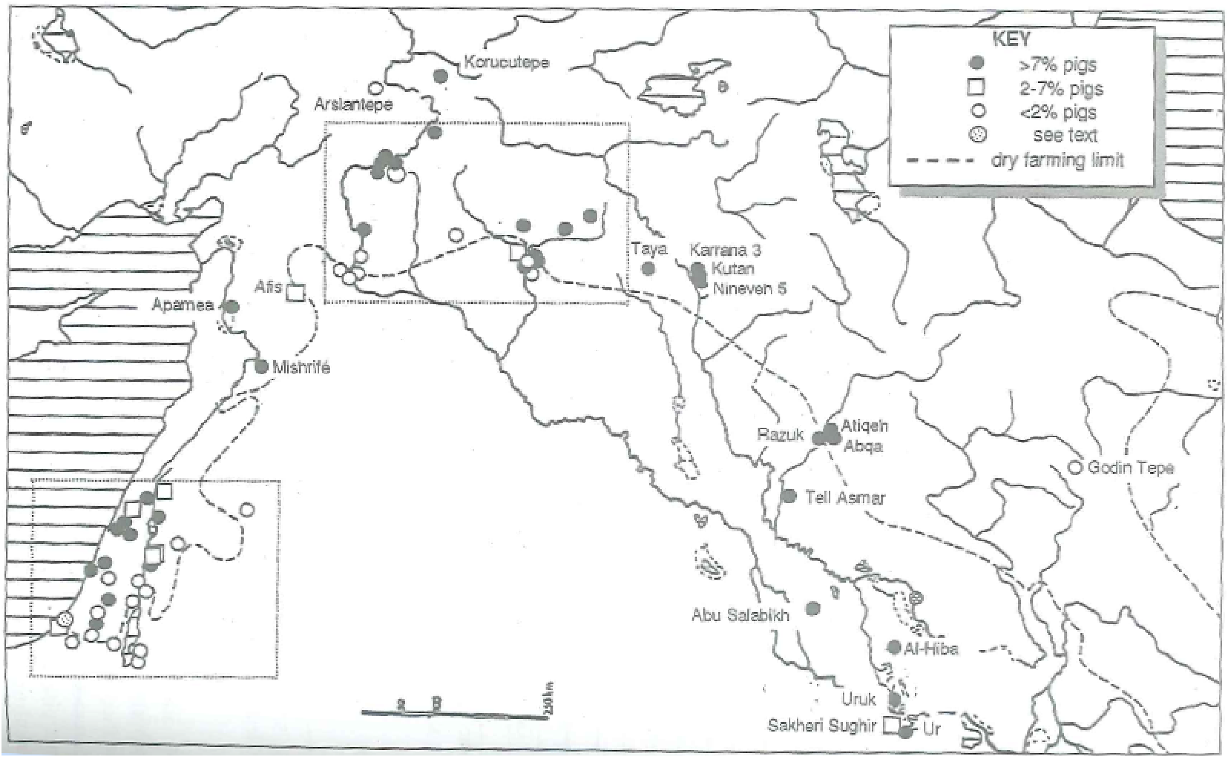
Further evidence of the link between local ecology and the utilization of pigs as a domestic species is given by Grigson (2007), who correlated the archeological abundance of domestic pig remains to the changing limits of dry farming as the ancient Levant dried. From 7,000 BP to 6,000 BP the presence of domestic pigs at contemporary archeological sites, was almost entirely dependent on levels of precipitation at that time. Wet areas were associated with pigs, and dry areas were not. Figure 7 shows settlement sites in the southern Levant around 7,000 BP., with the present day limit to dry farming drawn as a line roughly separating north from south. North of this border precipitation levels are sufficient for the production of grain crops without irrigation, and below this line precipitation levels are too low to support crops without added water. The map shows that sites where pigs make up more that 7% of the faunal assemblages, are generally in the region of high precipitation indicating ecologically favourable conditions for extensive pig husbandry. Figure 8 shows the declining importance of pig husbandry around 6,000 BP as the region dried and aridity encroached. More sites begin showing <2% representation of pigs in the faunal remains, especially near the dry-farming limit. This suggests ecological conditions were no longer favourable to pig husbandry in those areas. The pattern changes, however,  around 5,000 BP. from which time sites in figure 9 are mapped. Pigs again rise in importance with many sites showing >7% pig representation in faunal remains. These sites, however, were becoming large population centres at the time, and known to have practiced intensive and irrigated grain agriculture. It is known that pigs roamed city streets at that time consuming waste, and it is suggested that pigs had found favourable conditions inside the city as an intensive agricultural species (Grigson, 2007).

The presence of pigs at large urban sites suggests that pigs had entered a new agroecological niche in which they were no long reliant on the productivity of the local non-human environment. Instead they have moved into a role dependant on the human social system, mainly the urban area and, possibly, provisions from irrigated agriculture. They had moved from a role as a mainly extensive livestock species, to one that was increasingly intensive, often with an emphasis on the management of a concentrated human waste stream.

Although roundly criticized by (Diener et al., 1978), ecologically derived explanations of pig prohibitions based on a competition for human feedstuffs and a lack of functional ecological and agroecological relationships, is supported by a synthesis of evidence from northwest China.


KEY
>7% pigs
2–7% pigs
<2% pigs
dry farming limit
Girikihaciyan
Cavi Tarlasi
Turlu
Aswad
Amuq E
Kurdu
Mefesh
Kuran
Ziyadeh
Mashnaqa
Arpachiyar
Banahilk
Yarim
Nineveh 2C
Ras Shamra
Arjoune V, VII
Siahbid
Tell Dan
Haqoshrim
Abu Zureiq
Tel Te'o
Neve Yam
Tel Ali
Tabaqat al-Buma
Zehora
Tsaf
Jericho
Ghassul
Ziqim
Qatif Y3
Ras el-Amiya
Chaga Sefid
Sabz
Eridu XIII

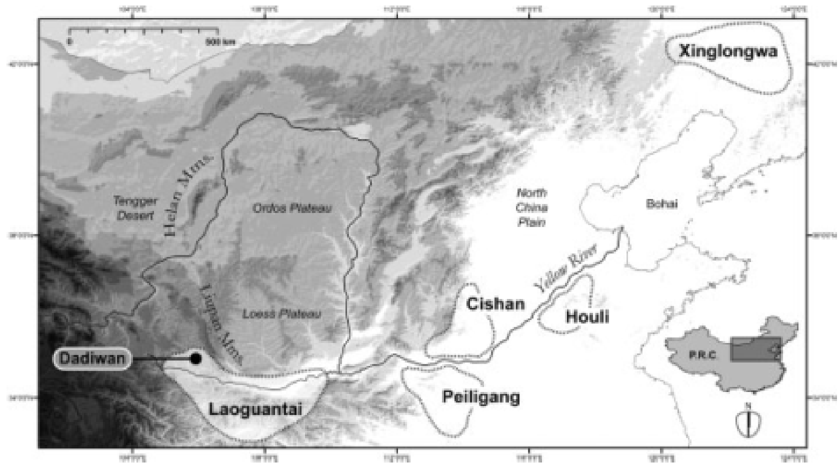

KEY
>7% pigs
2–7% pigs
<2% pigs
dry farming limit
Arslantepe
Hayaz
Hassek
Kurban
Brak
Hacenebi
Jebel Aruda
Kuran
Umm Qseir
Nineveh 3/4
Apamea
Afis
Habuba
El Kowm
2 Caracol
Arjoune VI
Choga Maran
Dehsavah
Rubeidheh
Godin Tepe
Sabz
Farukabad
Sarafabad
Jawa
Uruk



KEY
>7% pigs
2-7% pigs
<2% pigs
see text
dry farming limit
Korucutepe
Arslantepe
Taya
Karrana 3
Kutan
Nineveh 5
Afis
Apamea
Mishrifé
Razuk
Atiqeh
Abqa
Godin Tepe
Tell Asmar
Abu Salabikh
Al-Hiba
Uruk
Sakheri Sughir
Ur
250 km

***Northwest China: an agroecological mirror of Middle Eastern events***

While domestication of pigs in ancient China is also a murky affair, there is evidence that domestic pigs were prevalent in both northern and southern regions by 8,000 BP (Larson et al., 2010). Grain based agriculture was beginning at that time as well, with the wet southern regions cultivating rice (*Oryza sativa*), and the dry northwest regions cultivating broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*) (Barton et al., 2009; Fuller et al., 2009). Around 7,900-7,200 BP societies at the Dadiwan site in the northwest were growing and supplementing their diets as well as those of their hunting dogs with broomcorn millet, and although archeological deposits show the presence of pigs, they were not being fed millet (Barton et al., 2009; Bettinger, Barton, & Morgan, 2010). Though not being fed, these pigs were likely domestic. Evidence of domestication from the nearby site of Xishanping suggest a domestication date of 8,000 to 7,400 BP (Flad, Jing, & Shuicheng, 2007). Further evidence suggests that if the pig was not fully domesticated in the region at this time, it was well along in the process (Wang, Martin, Hu, & Wang, 2012).




Both wild and domestic pigs at that time would have lived in a productive environment. From roughly 8,300-7400 BP climatic conditions were wet in the region, becoming wetter between 7400-6700 BP, then beginning to dry, becoming semi-humid from 6700-6300 BP (An, Feng, & Tang, 2004). Just as in the Middle East, abundant marshes were present and would have offered the pigs a rich and wide variety of food stuffs (Feng, An, Tang, & Jull, 2004). Pollen deposits from both *Quercus sp.* and *Betula sp.* also indicate rich forests of mast producing trees (An et al., 2004). Conditions so favourable to pig ecology likely meant the pig was a successful and important component as an extensive agriculture species at that time.

From 6300-4000 BP, however, conditions in the region became semi-arid. Sediments show that fertile marshland was yielding to dry loess as the region dried. Pollen assemblages also show declining forests and an increasing prevalence of *Poaceae* and *Asteraceae* in general, and a dominance of *Artemsia* (a wind-pollinated, desert Asteraceae) specifically. These drought tolerant species suggest that there was a shift to climates more favourable to millets but less favourable to pigs. Perhaps driven by necessity or more favourable growing conditions, broomcorn millet agriculture began a more intensive phase around 5,900 BP. Human populations also expanded at this time, and it is likely that both the intensification of land use for agriculture and the decreasing productivity of the natural environment led to changes in agroecological strategies for pig husbandry. Indeed, during the same time period not only was millet being fed to humans and hunting dogs, but to pigs as well (An et al., 2004; Barton et al., 2009).

Whether pigs were wild or domestic before this intensification phase is unknown. Such rich conditions previously, may have negated the domestication of pigs in the first place. It is possible that archeological remains of pigs at this time were from completely wild specimens, and that isotopic markers showing grain consumption in pigs around 5,900 BP is the true indication of domestication. Given the complexity and slow transition necessary in the process of domestication, however, it seems likely that pigs were slightly less than wild before this agricultural intensification. Indeed, evidence for domestic pigs starts roughly 2,000 years earlier, and although hunting pigs may have been easy, culling ones that return home every night is even easier. Free-roaming, semi-domesticated pigs are commonly found in semi-agricultural societies, and while millet agriculture existed since ~ 8,000 BP, it was low intensity, with hunting continuing to be a dominate land use strategy (Bettinger et al., 2010). The use of free-roaming village pigs in other hunter/gatherer societies, and the simplicity of such a strategy were probably not overlooked by the early agriculturalists (Krause-Kyora et al., 2013). Especially in habitats ecologically favourable to pigs.

If we assume that pigs were domestic and mainly used as an extensive agricultural species during the most ecologically favourable time period, the intensification of millet agriculture seems also to show an intensification of pig husbandry. Much of the literature on regional societies of this time is difficult to access, and it is unclear what other evidence might suggest an increasing intensification of pig husbandry. The emergence of sty-like architecture, for example, would help clarify if pigs became a liability needing to be contained. Also a clearer understanding of pig domestication in the region would help clarify if archeological remains before the intensification phase were indeed wild or domestic.

In any case, increasing aridity in the region led to a complete abandonment of both the pig and grain agriculture. The period after 4,000 BP is marked by declining human populations and a transition to nomadic pastoralism based on ruminants (Liu & Feng, 2012).

## 3.2 Current Case Studies: multi-functional roles of pigs in modern farm systems

Whether we are prepared or not, the human species is becoming the *de facto* manager of the world's ecological systems. Agriculture, including pasture land, is fast becoming the dominate habitat type on earth. As managers we make choices that reverberate throughout the entire system, and in many ways they are blind. Our adaptation to change is similar to the awkward gait of a drunk. Every step is simply an uncoordinated reaction to the previously uncoordinated one. We judge roughly based on the consequences of the last step, where the next should land, often over or under compensating, and so we stumble into the future. The clarity with which we view our surrounding environment, however, largely defines the extent to which we are successful navigating through it. It gives us clues, through a variety of senses that help us refine the placement of our feet.

This sensory perception of the surrounding environment and the clues it provides is precisely the system evolution has unknowing designed to help a living organism manage the terrain of its environment. Whether the scale is that of a drunk managing his/her way forward, or that of a society managing its response to events, information about the system outside of ones own scale is important. The success of a system, even one on as lowly a scale as pig production, is therefore incumbent upon information from the larger system and the management strategies produced from it.

With modern agriculture, and perhaps especially pig production, trapped almost exclusively in the scale of human economic interactions, it may be valuable to revisit our pig production strategies with an eye on interactions at other scales and with other components. The history of pig husbandry in increasingly marginal environments is reminiscent of our current situation. As we face new urgencies of environmental change and increasing food production demands, overall global food system efficiency may return as a primary focus. The promotion and strengthening of beneficial interactions throughout that system is one way in which system efficiency can be improved.

The following case studies are meant to give a glimpse of some of the agroecological relationships the pig can and perhaps should have as part of our production methods. They are by no means exhaustive, instead, they are meant to exemplify possibilities upon which we might use to frame a more sustainable theory of pig production. The theoretical production system proposed afterward, likewise, is not intended to be exhaustive or prescriptive across all events and circumstances. It is presented only as a tangible model to help guide further inquiry and criticism. It is a synthesis of what I have observed as a researcher and is meant only as one piece of information among many that I hope might help our pig production strategies retain a bit of sobriety.

### 3.2.1 Ole's Farm

The agricultural role of pigs on Ole Johan's farm may be less interesting than the historical roles pigs have had, however a better understanding of pigs in modern agriculture may be more important given the dominance of agriculture in current land use. By E.U. standards, Ole is a medium sized pig producer (Fig. 3), large enough to be commercial but not so large that his farm is a specialized operation. His pigs allow his farm to survive in the economical environment we humans have created. Ole's pig production is a more or less standard model of organic outdoor pasture based pig farming popularized in Denmark. Ole himself is a relatively new pig farmer and also relatively free from economic necessities, and is therefore willing and able to experiment slightly with his pig keeping. I spent almost 5 months working with Ole which provided me with a rich understanding of general outdoor pig production and his system in particular. My description of his farm is by far the most detailed and is a general account of most pasture based pig production systems. During my stay, however, a number of observations were made that moved Ole's production towards trusting the pig's natural instincts, which made Ole's (and my) job easier and allowed the pigs freedom to express their natural behaviours.

### *Agroecosystem Overview*

Ole owns a mixed farm on the side of a rather steep mountain in a high northern latitude. Summers are short and winters are long. As such his farm is not suited to much other than livestock production. He has a little less than 8 hectares of cleared land and a large amount of forested hillside. Ole keeps approximately 130 Tamworth-Durock variety pigs including, 3-6 sows, and 2 boar. He also keeps ~15 cattle and ~30 sheep. He originally split his pig population to consist of the ~135 fattening pigs on roughly 2 hectares on one field, and the sows and boar on roughly 2 hectares on another. This changes, however, on the exact situation. All pigs were kept in one of two style of huts: a smaller one measuring ~1.5m x 2.5m and a larger one measuring ~2.5m x 10m. Depending on the situation, pigs were either given half of a bucket[12], one bucket, or free access to an automatic feeder during the day. Ole uses about 80-90 tons of feed per year, of which roughly 10 tons is produced on the farm.

### Reproduction

Pregnant sows and sows that Ole wanted to become pregnant were kept on 2 hectares along with 2 boar. The extra boar was kept as a spare in case the main boar needed to be killed because of a broken leg, or other illness. They were allowed access to an automated feeder, water and housed in the small style huts. The boars were kept in this field the entire cycle.

Once the sows were pregnant and about to give birth they were moved into the barn where she had an area slightly larger than the size of a small hut (1.5m x 2.5m), and hand fed both water and a bucket of feed each day. Such movement into a segregated area is common practice in pig production and allows closer management of the sow and her piglets. Originally Ole followed this thinking, assuming that the barn would offer better conditions for the pregnant mother and her piglets. Main concerns included the cold and wetness of the field, the aggressiveness of the larger pigs that might want to play with the piglets, and fear that the largest of pigs might step on and squash the piglets.

After a few weeks, when the piglets were deemed healthy enough to contend with

12 Bucket size is roughly 10 litres.

the other pigs (and after being castrated), both the piglets and the mother were allowed near the general population. The piglets were allowed to mix with the other pigs. The mother, however, was kept in her own area with the use of a single electric wire placed at a medium height that kept her in but allowed her piglets to move freely back and forth underneath. Her piglets could then move to the general population to play with the others, and to eat from the automated feeder during the day and return home at night to be with their mother. The mother could in this way be kept from the automated feeder since she no longer needed to nurse her piglets.

### Weaning and Growing

Once the piglets were old enough to leave their mother, which they generally did on their own, their mother was moved to either to a waiting area or back into the field with the boars to be impregnated again. The waiting area consisted of an area fenced off from the general population where the sows had access to water but were put on a restricted diet of half a bucket each day.

One of the larger housing units had a feeder installed on the back wall, and a barrier in the door was made consisting of several boards nailed across at a height that allowed small piglets in to sleep and feed, but blocked out larger pigs. This was done to ensure the smaller pigs always had access to food, as occasionally the larger pigs could block the feeders from the smaller pigs.

The pigs were then allowed freedom to eat, grow, play, root and explore at their leisure, which they often did by testing fences, patience and escaping to play in the forest. The pigs had their choice between the large huts and the small huts, and crowded together inside at night. In addition to body heat, the huts were kept warm with the use of straw in the cold and wet periods of the year. Straw was simply thrown and spread inside the huts. This worked well, and even in the dead of winter, the huts were very warm. Although temperatures were not taken, it was easy to feel the warm air rushing out when the top section of the door was removed to allow easier access, and it was usually necessary to remove ones jacket when spreading hay inside, even when outside temperatures were well below zero. The huts may even occasionally have been too hot, since it was observed that pigs would willingly sleep outside in temperatures as low as -15C. The huts were periodically moved around the field (if they were not frozen fast) to ensure an even spread of manure and rooting/trampling since the fields would later be sown with a crop mixture. The feed for the general population was provided by automatic feeders that were refilled approximately once a week depending on the exact number and general size of pigs in the population. Water was given through a heated dispensing system to ensure that it was unfrozen during all times of the year, though there were often problems with this below -17C.

### Slaughter

Roughly every three weeks the axe fell, and it was our job to round up the fattest pigs and lead them to the feeding area. Once in the feeding area we, with much effort and frustration, corralled them away from the general population and fenced them off from their old home. We led them slowly down the road to the barn where we again corralled them inside. This usually required a significant amount of time and expletives, but once inside there was only the tattooing of ole's farm number on the pigs' hides and the waiting for the truck. Upon arrival the pigs were easily pushed inside the truck and sent to the slaughtery.

Ole's orders were made online and consisted mainly of sausages, bacon, and beef from the occasional bull. He sells directly to restaurants and packages his meats to be sold as is, but his preferred income is by selling prepared burgers and sausages at fairs, music events, and markets. He can get a higher price for his products this way, which is important since he is not as economically competitive as the larger producers. While waiting for the next market or festival, his products are stored nearby in rented freezers.

### Field Rotation

Ole has developed a rotation system that contributes slightly to the pigs feeding requirements and also that of the other livestock. As has been mentioned, the pigs' huts are periodically moved throughout the field to ensure an even spread of manure and rooting. After a season of use by pigs the fields are relatively devoid of vegetation and well fertilized. Ole further prepares the fields by additional plowing and then plants a barley/pea mixture and undersows this mix with a pasture blend. After a season of growth the barley/pea mixture is harvested together as a rough mixture. The undersown pasture mix is allowed to grow and livestock are allowed to graze it for one or several seasons until pigs are rotated back onto the field for the cycle to continue. Ole's barley/pea harvest during my stay was 10 tons of fresh mixture on approximately 4 hectares of land.

At this point it was Ole's original plan to crush the mixture in a mill to help increase the digestibility of the mix, however his mill was broken. The whole grains were instead placed in a large feed bag. A vacuum was used to remove excess air, and the mixture was allowed to ferment for several months. This removed the necessity of drying and storing the mixture, and also increased digestibility. It is known that legumes contain a variety of anti-nutritional factors, and that fermentation can help in the reduction of them (Jezierny, Mosenthin, & Bauer, 2010; Reddy & Pierson, 1994). The mixture was allowed to ferment in the autumn and later was experimentally added to the automated feeders. The breaking of the mill was a fortunate event since it was soon found that the slightly wet grains froze inside the hopper and clogged the feeder. If the mill had worked, and the grains were crushed they would have made a kind of mash that would have frozen even more solidly. Ole also feared that waiting for warmer months might mean that the mixture would begin to grow mold. The grains were still useful, then, as feed given to the animals that were only allowed to be fed from buckets.

Although the failure to crush grains kept the feed from freezing into a solid mash, whole grains were noted in the pigs faeces, meaning they were not properly digested. It was observed that a number of crows came to feed on the passed grains and the comment was made that perhaps chickens could be let loose into the fields as well, to scratch, spread and make use of the undigested grains in the pig manure.

### *Chaos and Pig Ecology*

"Its like a playground for pigs."

Reporters had come on this particular day to write an article on animal friendly production, and to interview Ole, one of the producers that would be offering products at the local market. The barn had been frozen for several days and the decision was made to move the cows outside with the pigs where they could get regular water from the heated dispenser system in the fields. The pigs were enjoying the new company, mostly by harassing the cows. One of the hay bales given to the cows for feed had been knocked on its side, exposing the inside which had not yet frozen. The pigs had, the previous day, excavated the soft pith leaving only the hard outer ring of the hay bale; and they were jumping through it, while the cows watched. "Its like a playground for pigs."

A number of happy accidents and lapses in management during my stay led to a slightly more chaotic farm situation that revealed much about the inherent behaviours in pigs which have so far survived the domestication process. They led to a farming approach that was more or less hands-off, saving us time and the animals some stress.

### Natural birth and nursing

The first occurred with a series of unexpected births within the outside huts. Although moving the pregnant sows inside the barn was thought to help with piglet survival, there was on average no difference in survivorship. This is supported by previous research which showed no difference in mortality between indoor and outdoor raised piglets, if conditions were kept dry (Johnson, Morrow-Tesh, & Mcglone, 2001; A G Kongsted & Larsen, 1999). This makes sense considering the huts are roughly the same size as the sty in the barn, and as long as straw is added, the outside huts are just as warm or warmer. By not moving her we reduced her stress as well as ours. The other sows and boar were not a problem either. The mother was apparently able to communicate in some manner that the hut she had claimed was hers and the others understood and kept away. This did not appear to be aggressive behaviour on the part of the mother. Pigs are a social animals and have a number of sounds associated with particular warnings or 'feelings'(Düpjan, Schön, Puppe, Tuchscherer, & Manteuffel, 2008; Marchant, Whittaker, & Broom, 2001; Puppe & Tuchscherer, 2008). Sometimes even solid eye contact between two pigs can communicate that a particular pig is not in the mood to 'play' or otherwise be disturbed.

The mothers were also apparently able to judge when her piglets were strong enough for more contact with other pigs, and eventually she allowed the others to share her hut where there was room. The huts are quite warm and cozy especially with a number of pigs in them. As mentioned previously, one can feel the warm air rushing out of the huts when the top door panel is removed, and when inside it is possible to wear only a t-shirt even though temperatures outside require several layers. It is likely that the huts are comparable if not warmer than those inside the barn, which is close to the temperature outside anyway. The piglets, then, are just as warm if not warmer outside of the barn in the huts. Such group warming in nests is an important aspect of *Sus scrofa* behaviour (Fedosenko, Zhiryakov, & Sludksy, 1984; Timofeeva, 1975).

At this point, however, it was still thought that segregating the sows and piglets from the fattening pigs was necessary since weaners can be quite playful and rough. Several more fortunate accidents in which sows gave birth in the general population, however, showed that the sows are also able to keep smaller weaners away while her piglets are vulnerable. Interestingly it was observed that the sows chose to give birth in the largest huts, keeping others out only when her piglets were in the most vulnerable stage. Interestingly it has been found that larger huts farrowed larger litters than smaller (McGlone & Hicks, 2000). This indicates that on Ole's farm the sows were choosing huts that were more beneficial to their litters. After a day or two the sows chose a corner and began allowing other pigs in, again creating much warmer conditions. The piglets very quickly assimilated with the rest of the pigs and were able to fend for themselves and for the most part were generally ignored by the rest of the pigs. These are, again, very social animals able to co-exist in all age groups.

Due to failing fences, the sows with piglets were no longer kept separate from each other either. Although this was problematic in terms of feedings, as they sometimes simply sat in front of the automated feeders to the detriment of other pigs, in other ways it appeared beneficial. The nursing sows began sharing nursing duties, and it became hard to distinguish which litters belonged to which sow. Even though this made things slightly difficult when it came time to castrate the piglets (as we often had two sows running after us if the piglets squealed rather than one) it did not appear to be a negative development. Indeed in the wild the sharing of maternal duties is important as it allows the one of the mothers to feed while the other nurses, and then to switch roles (Graves, 1984).

After a series of boar escapes the segregated sow/boar field was abandoned and all pigs were kept in the same field. The boar was seen to be mostly interested in the sows and generally left the younger females alone. The younger females seemed uninterested and were usually slaughtered before becoming sexually active. While this makes it difficult to manage the amount of production, in a production system where there are regular shipments to the slaughter house a constant supply of pigs is needed anyway. At peak times of the year reserve sows could be added or removed as needed, creating slightly less management needs. As long as Ole ensures that no females reach age of heightened sexual activity or are allowed to be pregnant long enough that they cannot be sold for slaughter he can successfully keep all pigs in the same field, without segregating them, moving them to the barn or otherwise disturbing or stressing them. Although these pigs have been domesticated far from their natural appearance they are still able to behave quite appropriately to ensure their young survive.

### Into the Forest

The management requirements of Ole's previous system were one of the main reasons Ole kept his pigs in the field. It is much easier to round up pigs that need to be moved when they are in an open field, though this precludes the use of the field for other agricultural purposes. For example, Ole also raises beef cattle, hay, and the previously mentioned barley/pea mixture. Freeing up agricultural land would help Ole meet even more of his feed demands with the production of on farm feedstuffs. The smaller pigs spend much of their time in the forest anyway, and are continually testing fences in order to get there. While they may be likely to explore anywhere outside of the fences regardless of the presence of forest. The forest is a particularly rich environment, one that the preferred habitat of their wild types.

Ole is now considering putting feeders and huts on the forest edge and allowing his pigs to roam in the forest, an independently derived management theory that mirrors traditional practices of extensive pig husbandry. He has described his new strategy as using the fences to keep the pigs out rather than in. How effective this will be remains to be seen. Piglets and small weaners are already fairly oblivious to the existence of the fence, which is frequently sapped of voltage from overhanging wet branches and mud that has been push by the pigs up to the line. When valuable crops are grown on the fields they may wish to cross them again, this time into the field, and take it upon themselves to harvest Ole's crops. Ole has more substantial fences, however, that he uses to keep the pigs out of his sheep pastures which are very effective. They are high fences constructed of solid poles and chicken wire on one side (the sheep side) and electric wire at pig height on the other. The combination of electricity and an obvious barrier keeps pigs from attempting to find ways through it.

Ole's was the first farm I visited and a major concern of mine at the time was the possibility that pigs would damage trees, either by rooting young ones or stripping the bark off older ones. I did see substantial bark stripping in one area were sows were kept in the forest. In the other areas, even those on the edge of fields containing ~135 pigs with perhaps half of them small enough to enter and the other half occasionally finding a hole, there was no tree damage outside of small trees next to the pig trail which were trampled. This correlates with several inquiries to forest pig farmers in the U.S. and research on combining biomass production with pig production (Horsted, Kongsted, Jørgensen, & Sørensen, 2012) The reason for the damage in the small section of forest which I had observed was due to the sows there being kept on a restricted diet because they had become quite large. In effect they were going hungry and resorting to tree bark. Pigs often increase exploratory behaviour when experiencing food stress (Benjamins & Riseholme, 2002). The similarity of pig and human diets should be considered here. A pig is no more likely than you or I to eat tree bark under normal conditions. In times of stress, however, tree bark becomes a source of nutrition for pigs as well as humans, but certainly not one that is favoured.

### 3.2.2 Augustin's Forest

Augustin's method of pig production was the most traditional form of production in this series of case studies. The scenes from Augustin's farm, (excluding those with electric fences, chainsaws, and vehicles) would likely have been familiar to any medieval swine herder. The ease and simplicity in which his pigs are raised attest to the persistence of pigs in our agroecosystems despite their potential drawbacks. I spent 2 relaxing months with Augustin and can confirm that it is a very enjoyable production method, with morning walks in the forest and long hours spent enjoying high quality cured meats, conversation, home-made wine, good books and of course his pigs' unending and humorous curiosity. It is little wonder that forest swine-herding was once associated with royalty (Ervynck et al., 2007).

#### *Agroecosystem Overview*

Augustin maintains a small farm in the Cévenne region of France. The vast majority of his land holding consists of forested land, making it very different from most concepts of agriculture. Centuries ago, however, the entire landscape must have been denuded of trees. The resulting problems with erosion remedied with the construction of extensive terraces, which are still prominent features of the landscape. The peasants that had previously inhabited what is now Augustin's land had later planted chestnut (*Castanea sativa)* on the terraces, in what must have been an incredibly productive agroforestry system. Still later depopulations, resulting from migrations to urban areas and the plague, left the plantations unmanaged and wild, leaving a forest that today consists largely of this species. Other common species are are holm oak (*Quercus ilex)*, black locust (*Robinia pseudoacacia)*, and especially maritime pine (*Pinus pinaster)*.

*Pinus pinaster* is, outside of Augustin's farm, even more common than *C. sativa*. Planting programs began sometime in the 1800's, coinciding with a population boom created by the new economic value of coal. *P. pinaster* was planted extensively owing to its quick growth and use as support beams in the mines. It has found a welcoming home in the hot, dry Cévenne and has done well on the disturbed, acidified soils that have resulted from the mining activity. It is a species often planted in such conditions (Le Maitre, 1998).

Its success can also be attributed to its association with fire. Like many pines, *P. pinaster* creates conditions which promote fire, yet are resistant to its damage. In essence the pines have evolved a strategy to clear competition and ensure a clean, fertile seedbed for itself at the expense of other tree species (Fernandes & Rigolot, 2007). The resulting cycle of fires has become a mounting concern as *P. pinaster* becomes and increasingly dominant species in the regional forests, and changing climatic conditions create more arid conditions (Pausas & Vallejo, 1999).

In order to reduce the threat of fires, Augustin began manually removing *P. pinaster* from his forest and allowing either *Q. ilex*, *C. sativa*, or other species to recolonize[13]. He soon found, however, that conditions left after the clearing of *P. pinaster* where so favourable to brambles (*Rubus sp.)* and bracken fern (*Pteridium sp.*) that a thick mat of these two species hindered the regrowth of other forest trees, and left a landscape that was difficult and unenjoyable to walk through. The density of bracken litter and root structure is known to

13 Exactly which species depends on the soil type of the area. *C. sativa* does best on acidic soils and *Q. ilex* on the calciferous ones.

hinder the growth of other species (Marrs, 2000). Bracken fern, and the accumulation of understory in general, also have their own fire risks and require management in fire prone areas, sometimes using herbicides such as Round-Up as a control agent (Barkley, Schnepf, & Cohen, 2005). Augustin's days as a swine-herder began when he learned that wild pigs in the area often root for bracken fern rhizomes, and can consume it despite its toxicity (Sandom, Hughes, & Macdonald, 2012). They also root for brambles and other species, leaving conditions suitable for the growth of the new forest (Sandom et al., 2012).

During my stay Augustin's swine herd consisted of 21-23 pigs in total, 4 sows, 3 boar, 7-9 fatteners and 7 piglets. Previously Augustin kept roughly double this amount, but has lessened his workload by keeping less in recent years. He also keeps ~20 sheep and several chickens. His swineherd is a rag-tag bunch ranging from those newly born to 'Old Grumpy' a boar approaching 17 years of age. The pigs on Augustin's farm start life in a wooden pen removed from the other pigs where the pregnant sow gives birth. After a few weeks the sow and her piglets are moved together with the rest of the herd. His herd is kept in one of four fenced areas within the forest. In each of the four areas they have a simple roofed shelter, food troughs and a water dispensing system (similar to the kind Ole uses) positioned near to Augustin's residence and allowing him easy access for feedings. The pigs are given one feeding a day consisting of waste bread from the local supermarket, and once a week they relish fish scraps from the local market. The rest of their time they spend roaming the forest feeding off various foodstuffs, mainly bracken fern, brambles, assorted weeds and especially chestnuts. Augustin's forest is littered with chestnuts and large amounts are produced in the fall off which the pigs are allowed to fatten.

A few days before it came time to slaughter, Augustin simply opened a small section of his fence which allowed the small fatteners through, but blocked the boar and sows. This led them onto a large, cleared field which was fenced. On the other end of the field was a corral of sorts where Augustin positioned his van and began putting food. After a few days the pigs were accustomed to feeding in this area and would readily jump in the back of the van if food was placed. Augustin simply allowed the pigs to jump in and eat while he closed the door.

## Growth and Quality

Augustin's pigs differed from the other pigs studied in that they were Iberian black pigs, a breed used often in Spain, but occurring rarely outside of spain. Iberian black is a traditional breed of southern Europe, with qualities that have been selected by the outdoor, forested, Dehesa style agroecosystems that formerly were prevalent there (Lopez-Bote, 1998). As a result, Augustin's pigs are much closer to wild pigs than the production variety on Ole's and Heinrich's farms. Most notably his pigs have much healthier hips than production varieties and have a lean and agile appearance. Even older individuals can be quite graceful managing the complex and rocky terrain, in contrast to the awkward waddling gait of the Tamworth-Durock crosses. The prevalence of wild boar in the area also raises the likelihood that Augustin's pigs occasionally interbreed with wild boar in the area. One of Augustin's boar was particularly wild in appearance and mannerism and may have been one such cross. His pigs remain extremely friendly, however, and during my stay I never encountered any aggression.

As a result of the breed and a more natural diet, Augustin's pigs have a more natural growth rate. Fatteners take almost a year to reach a desired weight, and even then are still much smaller than the Tamworth-Duroc, which is twice as large in only 6 months. The resulting meat, however, is absolutely exquisite. A fatty, melting and delicious meat that Augustin has been offered top dollar for at restaurants in Paris. With such small numbers of pigs, however, Augustin is unable to meet the regular requirements of those restaurants and instead keeps his sales between friends, an odd wedding, and also cures his meats to be sold as the demand arises. Such cured meats can keep for several years, and among connoisseurs become even better with age.

## Rooting in the Forest

The low density of pigs Augustin keeps means that they do not have as heavy an impact on his land as on the farms of Ole and Heinrich. Rooting occurs as singular excavations roughly 50cm in diameter and <15cm deep. Occasionally rooting excavations occur together over an area (so that single excavations have no vegetation between them) when this happens it is rare that the area affected is larger than 2m in diameter. Rooting occurs sporadically in both space and time and allows for the establishment of seedlings. In addition to the clearing of vegetation mentioned earlier, rooting was observed to create beneficial conditions for seedlings in 3 ways:

1. Loose, aerated soils
2. Increased water absorption from rooting and the creation of wallowing holes
3. Increased nutrients from the collection of detritus and manuring

First, the excavations create areas of loosened soils. The dry soils often lacked sufficient humus accumulation to keep them aerated and were often quite hard. By rooting, the pigs created what was in effect a basin filled with loose soils where seedlings could gain a foothold. Secondly, the basin shaped excavation and the aerated soils helped to both trap and absorb precipitation. This was especially important on the steep hillsides since it was observed that after a heavy rain non-excavated soils were only moist in the top few centimetres, whereas the basins created by pig rooting either had standing water in them or had already absorbed the water deeply into the ground. Also important were the wallowing areas created by the pigs. Patches of the forest high in clay content were selected by the pigs and excavated into wallows as large as 2 meters in diameter. These pig-made wallows were the only source of persistent standing water on the hillside, and must be acting in a very similar fashion to man-made swales and percolation basins created to promote water infiltration in dry, steep areas (Yuen, Anda, Mathew, & Ho, 2001). The name given to the local area means 'Drunken Rock' referring to the numerous springs that existed before mining activity disrupted much of the water system. Augustin has anecdotally recounted the return of one spring since his management. A statement that makes sense considering the increased absorption rates created by the rooting of pigs on his land. The third benefit also relates to the basin like shape of pig excavations and its importance in collecting and holding detritus that is blown or washed down the slopes. The basins are often places with an increased humus accumulation owing to detritus being trapped and decomposed in the moist conditions.

There is, however, a fine line between the positive and negative effects of pig rooting and pigs are well known as damagers of forested and other ecosystems. The lack of forest detritus is probably due to the rooting of the pigs in the first place. It is known that the mixing and manuring of forest soils that occurs from pig rooting hastens the nutrient cycling of forest debris, quickly composting much of what would otherwise lay as dry material (Jezierski & Myrcha, 1975). Studies in the Smokey Mountains of the U.S.A. for instance have noted decreased ground vegetation and soil litter associated with wild pig rooting (Singer, Swank, & Clebsch, 1984). This increased decomposition can be good or bad for trees, depending on the species. It is quite easy to see the landscape changes marked by Augustin's fence lines, and the absence of flammable ground debris, is one of Augustin's fire reduction goals. It is interesting then, that even though the action of the pigs increases decomposition of the leaf litter and reduces ground debris, it also creates pockets of moist nutrient rich soil which are known to be important for seedling establishment (Boerner, Brinkman, & Brinkman, 1996; Jones & Moral, 2005). Also, as shown by previous research and my stay and Augustin's, trees do not become resistant to damage from pigs until they are a few years in age (depending on the species) but are very rarely selectively damaged (Benjamins & Riseholme, 2002; Ickes & Dewalt, 2001; Kongsted, Sørensen, Jørgensen, & Horsted, 2012). Augustin manages this by rotating his swineherd between the 4 aforementioned areas in order to allow new seedlings to establish themselves and reach a resistant size. He also protects prized individuals and his own plantings with a sturdy wire fence, or moves his electric fence to exclude a strip of tree he wishes to grow.

It is important to stress that it is not the interaction between the pigs and forest that creates the desired effects on Augustin's land. Instead it is the interaction between the pigs, the forest, and Augustin himself which allows the forest to develop as it does. Pigs by themselves are known to reduce diversity and numbers of large seeded plants which they prefer to eat (Ickes & Dewalt, 2001; Siemann, Carrillo, Gabler, Zipp, & Rogers, 2009). If left to themselves Augustin's pigs may very well have similar effects. The destructive tendencies of the pigs, however, are balanced by Augustin's creative and protective tendencies. By clearing the land and reducing competition between plants species, the pigs allow space for Augustin to repopulate his forest with species valuable to himself and his wider farm system. Augustin's primary interest is not pigs but the planting of useful tree species. His forestry goal is to establish what several writer's have referred to as a 'food forest' or a forest in which the component species are primarily species of edible value to humans, though may take on other roles such as timber, nectar sources or purveyors of other useful products (Jacke & Toensmeier, 2005). The diversity of fruit and nut trees on his land has, for example, increased the amount of high quality food stuffs for himself, his pigs, and his chickens. The various 'bee trees' have helped fill the nectar starvation periods of mid-summer and early spring, especially useful to his bee-keeping neighbours. And the death of a *C. sativa* provides him with high quality building and fencing material. Although it is difficult to quantify the total resource value of Augustin's farm versus the surrounding woodland, it is probable that the habitat he and his pigs have created is significantly more valuable than the surrounding bracken/pine dominated ecosystem which offered little in the way of food, quality lumber, or flowering plants.

### Waste Utilization

Although Augustin's farm was chosen as a case study in order to better understand the integration of pigs into forested ecosystems, I had not expected to see Augustin's system provide such a wonderful example of common sense integration with the broader local food system. The use of waste food highlighted an agroecological role that is one of the pig's oldest and most important. Twice weekly Augustin collects waste bread bound for the rubbish heap from a super-market in the nearest city. He also collects fish remains and unsold portions from the local fish mongers once weekly after the local street market closes. With addition of the forest, these three sources provide nearly 100% of the pig's feed[14].

It is here that the pig's greatest potential liability, its ability to digest human food stuffs, becomes its most valuable asset. The ability to consume human food wastes and surpluses has been one of the pig's oldest and best recognized agroecological role. Even before domestication, pigs regularly fed on human middens; this continued contact being important for their eventual integration in human life-ways.

14 Augustin buys only a mixture of maize and sunflower seed that is meant for the chickens but that the younger pigs have developed a taste for and sometimes sneak through fences to steal.

### 3.2.3 Heinrich's Pig and Vegetable Farm

Unfortunately, time constraints limited my visit to Heinrich's farm to one intense day of exploration. Because of this, the detailed workings of Heinrich's farm are left undescribed. His farm, however, generally follows the production methodology of standard outdoor production. Many of the details are similar to Ole's original farm management before its decent into chaos. Differences arise mainly in Heinrich's production of organic vegetables and the resulting rotational scheme his pigs are incorporated into.

#### *Agroecosystem Overview*

Heinrich's farm is a mixed farm producing vegetables, pigs, beef-cattle as well as keeping and training horses. His main income, however, is from organic vegetable and pig production. Heinrich's farm was chosen as a case study because of his integration of marketable vegetable crops and pig production. His farm is slightly larger than Ole's, containing approximately 24-17 breeding sows, and a larger number of fattening pigs (although exact counts were not made). Both sows and fattening pigs are kept outside in the fields using electric fences. Hog densities are kept below minimum organic regulations. Sows and fattening pigs are kept in separate fields, with the fattening pigs kept on fields that are later used for vegetable production.

Conditions for the fattening pigs in the fields were generally the same as Oles. Fields were fenced and contained large style housing units and automated feeders. The huts and the feeders were positioned in ways that allowed easy access and required the pigs to cross the field. Their positions were also changed occasionally to ensure an even spread of rooting/manuring. The position of the fences, as well, were moved throughout production since the fields were quite large. Fencing the entire field and allowing the pigs to roam would have meant pig densities were too low to have desired rooting/manuring effects.

One significant difference between the two farms was that Heinrich chose not to castrate his male pigs. When asked about boar taint he said it wasn't very apparent until the animal was older, and since most of his animals were slaughtered around the 6 month mark, the animals didn't develop a noticeable taint.

## Rotation

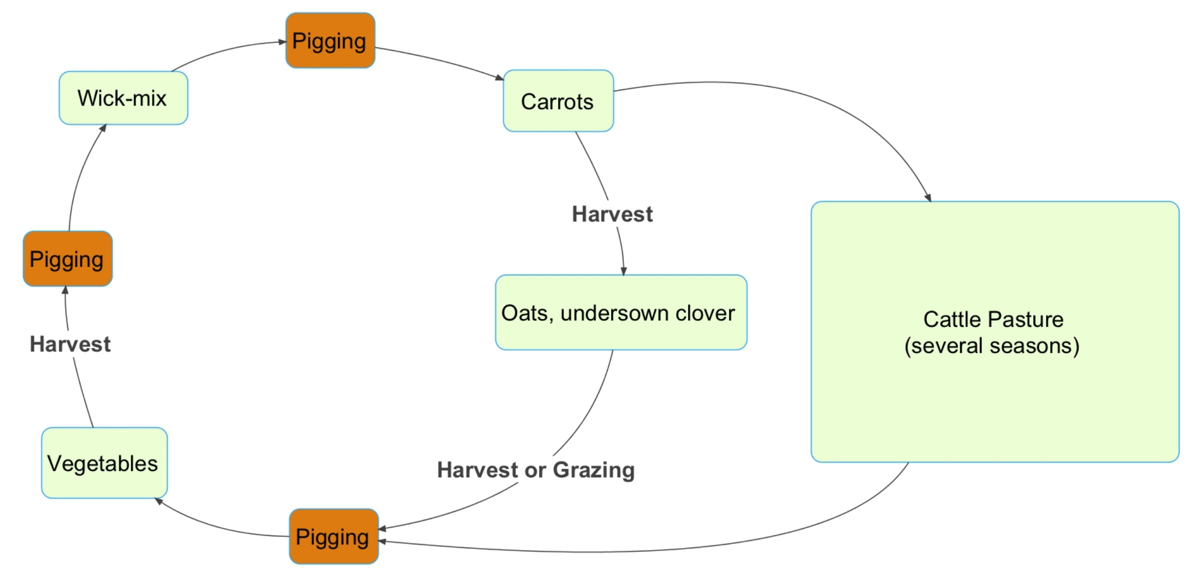



*Fig. 11: Heinrich's vegetable/pig rotation scheme for a particular field. Occasionally the entire cycle is put into cattle pasture for several years.*

Heinrich's vegetable production focuses mainly on broccoli, cauliflower, and carrots. Their production is rotated through a series of fields to ensure the same field is not used subsequently for the same crop or for crops that share a common pest. He also rotates his fields so that neighbouring fields do not contain crops with a common pest. Added to the rotation are oats, wick-mix[15], cattle pasture and of course pigs. The pigs usually both precede and follow a vegetable crop. The preceding 'pigging' prepares soil by rooting/manuring as well as removing weeds. The following 'pigging' serves the same functions and also clears vegetable stalks which might harbour disease and pests. The rotation is generally described in figure 11, though is modified occasionally. The weather during a particular season may, for example, make a field too wet for a particular use. He and his neighbour also communicate their plans so that susceptible crops are not planted in neighbouring fields. They may even switch fields to benefit both of them with an added rotation.

Occasionally the entire inner-rotation is put to pasture for a few years. These few years as pasture are important for long term fertility of his soils, and also allow Heinrich to include cattle and horses into his farm system, increasing the diversity of products.

15 A mixture of peas and grains which, when mature, the pigs are allowed to fatten on.

### Weeds

After pigging an area, the fields are prepared as they regularly would be without pigs. This includes all conventional plowing and seeding operations. In addition fields must sometimes be levelled again if pigs have created large or numerous wallowing areas. These fields are, however, nearly completely free of weeds from the presence of pigs, especially couch grass (*Elymus repens*) which is a major concern in the area. Since it is not feasible to have pigs on all areas before they are plowed and sown, areas dense with couch grass are tilled with a goosefoot style plow. Since using this instrument requires the soil to be disturbed to a depth of 27cm and entirely mixed when separating out couch grass roots, soil structure is badly damaged especially in such wet conditions. Fuel consumption is also high when moving such large quantities of soil. The result is that couch grass roots are separated from the soil and left to freeze or dry, however, in wet conditions the roots have a tendency to survive and continue growing. The differences in his neighbours fields are illustrative of the impact pigs have in removing weeds. Though neighbouring fields may have followed similar preparation (excluding pigs of course) Heinrich's fields are almost completely free of it, while in his neighbours individuals are clearly visible.

Along with couch grass, four other species were main weeds in Heinrich's farm: creeping thistle (*Cirsium arvense*), lamb's quarter (C*henopodium album)* in vegetables and dock (*Rumex crispus, R. obtusifolius.)* in the pastures. *Rumex sp.* was especially prevalent in pastures and of a quantity significant enough that management options were considered. Both topping of seeding individuals and manual weeding were seen as options but the later prohibitively expensive in labour. Although all the aforementioned species are edible to humans, and therefore pigs (Dogan, Baslar, Ay, & Mert, 2004; Guil, Rodríguez-García, & Torija, 1997; Luczaj, 2010; Trichopoulou et al., 2000; Tukan, Takruri, & al-Eisawi, 1998), In the case of *Rumex sp.* Heinrich observed that the pigs eat around it, and that only at higher stocking densities would the pigs actually remove it.

# 4. Discussion of Cases: bringing pigs back into an agroecosystem

## 4.1 Current Case Study Insights

### 4.1.1 Biomass/Pollards: preserving and promoting agroforestry systems

The Horsted et al. (2012) study of combined woody biomass and pig production outlines a number of benefits from such a combined system. They included decreased nutrient leaching from the uptake of nutrients from *Salix sp.* and *Miscanthus sp.* root systems, higher land use returns, the provision of shade from the hot sun, the slowing of cold winds, as well as creating an environment simulating *Sus scrofa*'s natural forested habitat.

The study notes some drawbacks, however, mainly that pigs should not be held on the paddocks during the spring when the energy crops are establishing themselves. While a production system using rotations could create a manageable system, a large amount of land is still out of production for at least a few months during every Salix planting/harvest cycle (Kongsted et al., 2012). This raises the possibility that pig production could be combined with pollards, an ancient practice usually associated with lumber/biomass or herbivore production, in which established trees have their branches lopped at a certain height and allowed to regrow branches (Read, 2006). An established pollard field would not need to be devoid of pigs for any part of its production cycle, since the trunk and root system are already large and able to withstand pigs. Any dead or dieing trees could also be replaced with an individual planting protected by a sturdy wire fence.

Pollarded areas are considered a cultural heritage landscape, identified with a unique ecosystem and biodiversity compared to the surrounding forests (Bergmeier, Petermann, & Schröder, 2010; Clemetsen & van Laar, 2000; Fay, 2002). In Norway pollarding has usually been associated with herbivore production, where herbivores are allowed to graze between pollards, and the pollards themselves are cut every 2 to 5 years in a rotation system to provide leafy fodder (Austad & Hauge, 2007). It is a labour intensive activity and has fallen out of favour with the increased use of mechanical hay bailers. A few remnant stands exist in Norway and in some areas government subsidies are given to keep them maintained. Other parts of Europe have at one time or another used pollarding to keep herbivores, grow timber used for the production of charcoal, or to produce high quality lumber shaped from an early age to provide particular shapes. In spain for example many oak pollarded areas were created to produce curved lumber for the ship building industry (Read, 2006). Such land uses could also be employed in combination with the land use requirements of pigs.

Although it may be that current subsidization of agriculture by cheap fossil fuels makes using such pollards for fodder uneconomical, other land use benefits are apparent. In areas of steep land where fields cannot be mowed mechanically, or perhaps should not be planted in fields at all, tree pollarding becomes an attractive possibility to provide a land use without unmanageable levels of erosion. This, for instance, is the reason some pollarded areas have survived in Norway, they represent the only viable land use option. Even accounting for the high disturbance force of pigs and the resulting instability of soils, a series of pollard rows along a contour, in combination with strips of native forest and swales, could effectively mitigate the erosion effects of pigs as long as pig densities were properly adjusted. The increasing biomass industry also makes pollarding an attractive option. Again, however, mechanical harvesting of pollards is not yet possible in the same way that mechanical harvesting of even stands of willow is. Still the aforementioned situations allow avenues of opportunity for such diverse multifunctional systems to become economically viable. The production of custom shaped niche lumber is one option that could be very economically valuable as such lumber is still used in the construction of personal sailing ships and post and beam architecture.

The variety of tree species which can be pollarded is outside the scope of this thesis, except to mention that many proposed biomass species such as *Salix sp.* are pollardable, as well as a number of mast producing species that, if allowed to set seed, could provide either a harvestable crop of nuts for human consumption, sale or pannage for the fattening of pigs. Pigs raised or finished on such high quality feeds are given top prices on the market. Many masting species such as *Quercus sp.*, *Juglans sp.*, and *Castanea sp.* are also choice lumbers, as are many fruit producing trees. The straight or customized lumber from these species could add considerable income to a pig production system, while also up-taking nutrients, providing shade and landscape aesthetics both to humans as well as the ever curious and explorative pig.

One possible problem from a pollarded system is the higher diversity of vertebrate species such pollarded trees are known to have. Old individuals provide a number of habitat opportunities in their numerous nooks and hollows (Ranius, Niklasson, & Berg, 2009). This would likely cause more interest to the pigs which may damage the trees seeking these potential food items. The large pollarded oak plantations in southern Spain referred to as Dehesa, however, stand as one example that pollarded systems with pigs can work without tree damage. These systems are wonderful examples of complex diverse agricultural mimics of natural ecosystems. They provide a number of marketable products from several livestock species each of which inhabit a unique agricultural niche (Joffre, Rambal, & Ratte, 1999; Olea & Miguel-ayanz, 2006; Rodríguez-Estévez, García, Peña, & Gómez, 2009; Trujillo, Mata, & Hovi, 2000). A similar system was a common part of the agricultural repertoire in other parts of Europe during the middle ages. An analysis of texts and images dating from the period have shown a system in the UK that consisted of open oak/beech woodland and pigs. Interestingly noted was the complementarity of grass (a high fibre source), and nuts (a high fat/protein source) in the diets of pigs (Jørgensen, 2013). These examples show that such systems can and do work, and should be reconsidered/rediscovered as viable forms of multifunctional pig production.

### 4.1.2 Waste Resources: limiting competition for grain/legume supplies

The use of pigs to consume human garbage is perhaps also the simplest form of pig production. As has been discussed, in many societies pigs are simply left to roam free in the villages and surrounding wild-lands in search of food. They readily eat any human food wastes, as well as less savoury items such as human and animals faeces. This helps to recycle otherwise wasted calories and serves a valuable hygienic role. The consumption of village waste is known to be important in preventing certain human parasites (Nemeth, 1987); and the combination of pigs and cattle has been shown to reduce helminth loads in heifers since the re-digestion of cattle dung by pigs helps break the parasite's life cycle (Roepstorff, Monrad, Sehested, & Nansen, 2005).

Pigs have long played an important role in the consumption of human food surpluses. Before the advent of modern storage methods a variety of human foodstuffs had a relatively short time in which they could be consumed by humans. Pigs lengthen this window by converting rotting food to meat and fat that can be harvested later. Pigs have, therefore, been associated with wealth and status, relating the amount of food grown/harvested to an individual's or community's power and influence (Macintyre, 1984; Roscoe, 1989; Thurnwald, 1934). The 'piggy-bank' shows a contemporary understanding of the pig as a storage vessel, able to consume otherwise useless food and, over time, grow to become a useful food item. These savings are especially important in societies where food comes all at once, resulting in feast and famine cycles, or in other situations of food stress (Watson, 1998). During the Second World War, for example, government programs in the U.K. actively promoted that kitchen waste be collected and utilized for pig feed to help with the war effort (Fig. 12).

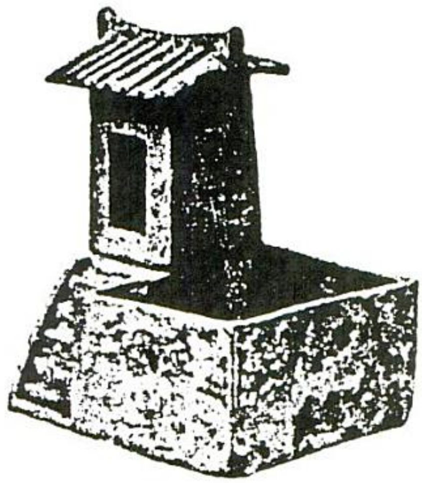

*Fig. 12: Second World War era poster urging the collection and use of kitchen scraps for feeding pigs (William Brown Co. ltd., n.d.).*

This is important to reconsider, given the growing human population and the efficiencies our agricultural systems will need in order to cope. Feeding pigs human food supplies often leads to food shortages and exacerbates food inequality. The poor are particularly susceptible to the rises in cereal prices caused by feeding livestock (Wiggins & Levy, 2008). There are also basic land base problems. Since caloric energy is lost at each of the trophic levels, pig production increases the amount of land needed to feed the same number of people (Cassidy et al., 2013; Pimentel & Pimentel, 2003).

The threat of disease is, however, an important consideration when feeding food waste to pigs. In recent years the feeding of food wastes to pigs has declined in Europe because of regulations formalized after the outbreak of foot and mouth disease (FMD) in 2001 (Department for Food Environment and Rural Affairs, 2001). The threat of

*Salmonella*, *Listeria*, and *Taenisis* are also associated with feeding food wastes to pigs. Any successful production method must pay careful attention to epidemiological aspects. In countries where food waste to pigs is used, regulations usually specify thorough heating for a minimum of 30 minutes at 100C. Considering, that the recent outbreak of FMD originated on a farm operation disregarding regulations (Westendorf & Myer, 2004); current bans seem hasty and knee-jerk.

The epidemiological issues associated with pigs are paradoxical, as pigs can serve both to prevent or spread human diseases. Disease (or rather the threat of it) has, for example, led to the abandonment of a form of human waste management utilizing pigs to directly consume human faeces. These pig-latrine systems were once used in parts of India, south-east Asia, Korea and China. Although our modern sensibilities revolt at such a use, there is considerable evidence that such systems were highly regarded elements of ancient Asian agroecosystems. Instead of generating disgust, such systems were revered and commemorated with figurines buried with high ranking persons (Fig. 13) (Kim et al., 1994). Such idolization may in part be due to a certain belief structure, one which holds that all things have a place. Indeed Needham (Needham, 1956) remarks on the Neo-Confucian virtue of "sincerity" that it:



> "is achieved when every organism fulfills with absolute precision whatever its function may be in the higher organism of which it forms a part."

The pig-latrine certainly contributed to the function of the overall agroecosystem. While the production of meat from otherwise wasted resources is the most obvious benefit (Nelson, 1994), the pig-latrine is also often referred to as a fertilizer factory, creating compost high in phosphorus and amenable to the soils. Most information about pig-latrine systems comes from Jeju-do island in South Korea where its use survived until the green revolution. Previously the latrines themselves were built above an enclosed pit where the pigs had access. Human waste fell directly from the latrine into the pit, and other kitchen wastes were thrown over the sides. Agricultural residues such as stalks were added to provide a carbon source, and the rooting and trampling of the pig served to mix and aerate the components so that a high quality compost was created (Nemeth, 1987). Perhaps the most interesting and unanticipated aspect of pig-latrine systems is the lowering of overall parasitic load compared to other systems of nutrient recycling waste management. Re-digestion by the pig serves to kill several human parasites and additional composting further reduces pathogen loads (Nemeth, 1987). One notable exception, however, is the tape-worm *Taenisis* which was found to infect a large number of Jeju-do islanders. Such high rates, however, were probably due to the islander's practice of eating raw pork. Thorough cooking quickly kills the parasite, and if precautions towards cooking were taken such infections would presumably have fallen quite drastically.

While our modern sensibilities recoil at the thought of pigs consuming human waste, western society is not wholly free from it. New York city also at one time employed herds of swine to roam its streets and consume kitchen as well as the large quantities of human and animal faeces (Alonso & Recarte, n.d.). Obviously such a system would be foolhardy in modern society, yet it remains a part of the history of domestic pig ecology and is worth considering in areas were the threat of disease from open wastes is greater than the possibility of transmission through pigs. Disregarding human faecal waste, it seems especially worth regarding the value of pigs in re-incorporating kitchen wastes into the system. The presence of pigs turns what was waste into a resource. Such is the case for the Zabbaleen of Egypt where Christian based society has for centuries fed off the scraps of the greater metropolis. Though they have often been regarded unfavourably and given a low cultural status, their contribution to the functioning of the local food system became apparent when a coordinated strike stopped collection and food wastes accumulated in the city (Fahmi & Sutton, 2006).

It must be remembered that successful interactions are not always morally appealing and acceptability as defined by society is rather malleable, especially in times of stress, as in the case of Britain during the second world war. If we discount these two extremes, faecal wastes and mixed kitchen wastes, it is more or less acceptable and common sense that pigs should be given unsold, out of date, or otherwise fairly acceptable food that will otherwise be wasted. This has certainly always been an important role for pigs and one that has almost entirely died out. A few producer successfully navigate the various barriers and integrate their pigs into the wider local food system. Little more is needed than a keen eye, sense of resourcefulness, and social relationships with the wider food community. Augustin, for example maintains a number of friendships while out on his weekly trips, and he has come to be relied upon to collect and remove the bread and fish resources others are unable or unwilling to utilize.

### 4.1.3 Pig Tillage: working with animal behaviour

Pigs like to root. They love it. It is, if you will, the essence of being a pig. Pigs are, therefore, commonly associated with nose rings designed precisely to deter a their natural behaviour by causing pain. From an animal welfare point of view this practice is questionable if not unethical. From an environmental view it often makes sense. Rooting upturns soil, increases erosion, and often destroys the seed bank under the soil. Agroecologically, however, it makes little sense to work against a natural behaviour and is simply another example of the human propensity to fit a species to our uses, instead of our uses to a species.

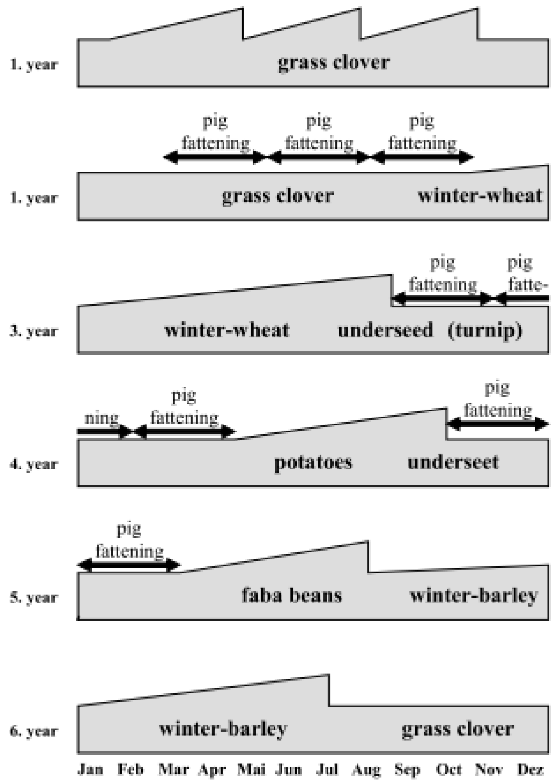



*Fig. 14: Possible crop rotation schemes as part of an outdoor pig production system. (Quintern, 2005)*

As mentioned pigs are excellent scavengers of food stuffs. As such, they are sometimes, as in Heinrich's case, used to 'graze' through fields after harvest in order to clear crop residues, and help reduce weeds that have accumulated and may exist in the next crop. This may be especially beneficial where previous crop residue have allelopathics effects on the following crops, or where vegetatively reproducing weeds such as *Elmyrus* or *Cirsium* are present. Research has shown that pigs can more thoroughly harvest a field of *Helianthus tuberosus* than can be done by mechanical harvesters. *H. tuberosus* is a vegetatively reproducing plant similar to *Elmyrus* and *Cirsium* in its ability to regrow from root segments.

Perhaps the most ambitious incorporation of pigs into the agroecocystem is the use of their rooting behaviour to substitute for mechanical tilling of the soil. Successful tillage is more likely to occur where pigs have a food source, and therefore a reason to root. Any intercropping strategy developed would do well to include species with somewhat deep rooting behaviour. Grain for example has shown best results after the field has been previously plowed to a depth of 28cm (Børresen & Njøs, 1994). For fields to be planted with grain, the previous crop should then contain species rooting to that depth. Daikon radishes and mangle beet come to mind as deep rooting vegetable crops easy to grow and nutritious to pigs. Also of consideration are carrot, parsnip, or other myriad root crops. Depending on which 'tillage crops' are chosen a number of additional benefits might also be achieved. Perhaps some of the greatest benefits could could come from the inclusion of wild 'weed' species. Wild carrot for example, a deep rooting cold hardy species, is a member of the Apiaceae a genus known to attract a number of beneficial insects (Bugg, 1992). Chicory (*Cichorium intybus),* another wild plant, has been used to take up nitrogen that would otherwise leach below the level of a grain crops with which it is interplanted, thereby preventing nitrogen loss and contributing to a more environmentally sound farming operation (Thorup-Kristensen, 2006). Interestingly *C. intybus* is also known to reduce parasite loads in sheep (Deane, Warren, Findlay, Dagleish, & Cork, 2002), and is used by humans for various health promoting purposes (Jeambey, Johns, Talhouk, & Batal, 2009; Mulabagal, Wang, Ngouajio, & Nair, 2009). It is probable then that chicory has similar benefits for pigs. Other research has that feeding chicory to intact males can reduce boar taint (Hansen et al., 2007). There are a number of example species including deep rooting leguminous species from warmer environments that would both promote tillage, serve as a source of protein to the pig, and ultimately add nitrogen to the system. Since the list of possible plant species is long it would be wise to focus on plants found in the local environment. These 'weeds' would be by definition extremely successful in the environments where they occur. Usually, though not always, they have small highly dispersable seeds making them easily broadcast-able in the farmer's field and amongst other agriculturally valuable species. They often grow quite rapidly, perhaps with a high rate of vegetative reproduction, which would make them more resistant to damage (Howe & Smallwood, 1982; Westoby, Leishman, & Lord, 1996). Such plants are highly competitive against our relatively fragile agricultural crops, and substantial time and energy has is devoted to keeping them under control. Focusing on deep rooters means that the nutritional sources would be found at a different soil profile than that of the crop's, reducing competition (Berendse, 1982). This would mean the utilization of otherwise leached nutrients, as is the case with chicory, bringing those nutrients back into circulation.

If interplanted, such species may also compete for light, and a selection of shade tolerant or shade requiring species would help ensure their survival beneath the crop canopy and help limit competition between the two. Such a selection would also ensure that little light was available for non-desirable plant species (Holt, 1995). Much of the time an unplanted piece of land is valued only in terms of the agricultural yield it can supply without considering the important ecological services it provides. It may aid in preventing nutrient runoff and leaching thereby recycling nutrients otherwise lost. It may contain species whose rooting behaviour brings up deep minerals which accumulate in subsoils. It may provide a home for predators of crop pests (Heimpel & Jervis, 2005), and contribute pollination services via its insect populations (De Marco & Coelho, 2004; Ricketts et al., 2008). These variables add considerable complexity to simple yield*price calculations but should be considered when allocating space for tillage promoting species. A well researched selection could add these and other ecological services to the agroecosystem (Olson & Wäckers, 2006), *and* promote tillage that would reduce the need for fossil fuels, an expenditure that will certainly only rise in the future.

### 4.1.4 Learning to Eat: using animal knowledge in agroecosystems

Animal food choices are not entirely genetic, and like humans, food stuffs are both preferred or avoided depending on learned behaviours when young (Bennett, Galef, & Laland, 2005; Isbell, 1991). In traditional Jeju island pig latrine systems it was known that non-accustomed pigs would avoid faeces, but if it was given as a food item when the pigs were young they would begin to accept human faeces as standard fair (Kim et al., 1994). The loss of dietary diversity in many species of domesticates, including humans, is probably exceedingly common and should come as no surprise, especially for animals rumoured to be as intelligent and social as the pig. A large part of intelligence is the ability to learn from ones's surroundings, especially at a young age, those skills necessary to survive in one's environment. If sows are kept on simple diets given to them from the hopper then the young will also learn that food largely comes from a hopper and may not associate weeds such as dock as a worthy food source. What may contribute substantially to a particular agroecosystem is the education of its livestock in what is and what is not worth eating. *Rumex sp.* are especially interesting in this regard since they are implicated in early sedentary yet pre-agricultural societies, occasionally being excavated in greater quantity that wild cereals (Savard, Nesbitt, & Jones, 2006).

There is a growing interest in training livestock to eat various pasture 'weeds' (Burritt, 2011; Frost et al., 2012; Peterson, Brownlee, & Kelley, 2013; Popay & Field, 1996; Voth, 2010). These species usually contain higher protein levels than grass, as well as contain a number of secondary metabolites that help maintain the health of the herd and allow individual animals options to choose biochemicals they might need (Deane et al., 2002; Harrington, Thatcher, & Kemp, 2006; Provenza, Villalba, Dziba, Atwood, & Banner, 2003). They also may play a role in moderating pasture productivity since the increased species diversity helps ensure that in any given year conditions that may be unfavourable to one species are favourable to another (Clark, 2001; Tilman & Downing, 1994; Tilman, Reich, & Knops, 2006). Despite these advantages they have been ignored and unwanted in pastures, being actively removed by chemical spraying, or tillage (Bellm, 2004; Sellers, Ferrell, Mullahey, & Brecke, 2006). Both of which increase costs and environmental impacts of livestock husbandry. Presumably this dislike is because livestock owners have never noted the consumption of these species by their herds, and for good reason; the livestock have never consumed them. The situation is similar to that of the human species. Though we are surrounded by a plethora of species that are both edible and healthful our main crop plants are relegated to a handful of species recognizable at the local supermarket. Even when presented with new species we know are edible we tend to select familiar items (Bäckström, Pirttilä-Backman, & Tuorila, 2004)(Pliner & Hobden, 1992). The issue in both livestock and humans is one of knowledge and learning. Though we do not recognize knowledge in our livestock species, perhaps because we don't want to acknowledge that what we eat can be knowledgable, it is known that observations by the young of the rest of the herd is important in learning the edibility of the surrounding environment. Feeding experiments carried out and promoted by ranchers in the western U.S. have been especially informative concerning the feeding habits of livestock and teaching them what can be eaten.

The knowledge of livestock in our agricultural systems is a subject rarely discussed. Though there is increasing concern about our own species understanding of agroecosystems, and the usefulness of species to be included in them, little has been discussed concerning the livestock's own understanding of the agroecosystem in which they inhabit. It must be remembered that they are domesticated species. Many varieties of which have been bred in conditions completely removed from the environments in which they will eventually inhabit. They have, in effect, (and if I may), lost the traditional knowledge of their ancestors. The observations of edibility that were previously passed down through the generations of a herd no longer exist. We as managers of agroecosystems must recognize this if we are to increase the mimicry of our agroecosystems to the wilder ecologies. It is interesting, then, that 'Old Grumpy' was left in Augustin's herd. Since the herd is left to roam the forest habitat clearing weeds, Old Grumpy's ~17 years of experience might be of unique importance in transmitting knowledge about the edibility of that forest to the rest of the herd, and therefore the functioning of that herd within their agroecosystem.

The knowledge base of the livestock themselves adds yet another dimension to agroecosystem function and mirrors a number of issues related to the loss of traditional knowledge by our own species. We and our pigs are both intelligent species, and knowledge of our environment has been an important aspect of our ancestor's survival. We are both a wide ranging species able to learn and adapt to a variety of habitats and situations. As we move spatially through our environments, the ability to learn and adapt to changes is central to our species' success. Similarly as we move temporally through our environment we are faced with changes that require an adaptive understanding. We are entering into an uncertain agricultural future, and the pig's knowledge of the agroecosystem in which it inhabits may be of increasing (and returned) importance to the functioning of our agroecosystems. Likewise, as managers of these agroecosystems our own knowledge of the pig's knowledge is crucial. These two scales of learning may be of vital importance if we are to continue this 9,000 year agricultural symbiosis with the pig.

## 4.2 *Historical case*

### 4.2.1 An agroecological tipping point

While clear evidence of domesticated foraging pigs before the intensification phase in northwest China, and sty based production after it would strengthen similarities between the Middle East and northwestern China, it is clear that changing ecological conditions had a major impact on management decisions regarding pig husbandry. Both situations suggest a changing agroecological role of pigs, from one closely linked to production in the local ecosystem to one closely linked to production in the human social system.

Although it is not clear from the evidence, the possibility of social strain resulting from unequal food distribution might be expected. The continued use of agricultural production for the feeding of livestock is highly inefficient. The possibility that pigs were used as a way to store surplus, as they have been used in some societies, seems unlikely given the ease of storing grain in arid conditions. The use of pigs simply as a protein source also seems unlikely given the availability of ruminants that would have contributed more efficiently to food production strategies[16]. The high fat content of pig meat may have been one reason they continued to be kept, however fat from other animals sources was also available and though diets would have been lean, they would have been survivable.

As increasingly concentrated centres of humans population, however, these early sedentary sites would likely have been filled with the wastes of society. Spoiled grain, kitchen scraps, slaughtery remains, and perhaps human and animal faeces were likely the one product widely available and of no use to anyone, except the pig.

Isotopic evidence in northwest China showing an increasingly grain based diet, does not necessarily show that pigs were exclusively being fed produced grain. Nor does it specify if grain was fresh or spoiled. It may be that the isotopic evidence doesn't even show the consumption of grain at all, but rather an increase in the consumption of human and animal wastes that themselves were increasingly grain based.

The possibility that isotopic markers are indicative of an increase in human and animal faeces is particularly compelling given that coprophagia is a common among wild

16 See table 1, pg. 9

pigs, and the wide spread use of pig-privy style human waste management systems in later Chinese history. Similar systems are also found in Korea and India.

If pigs were indeed being feeding on urban wastes in these cases, then although there was a changing agroecological role for the pig as society itself changed, it was still one which contributed to the overall caloric efficiency of the system. Before, pigs roamed freely within the local environment to find foodstuffs that would otherwise not be gathered, and later pigs roamed the villages to find foodstuffs that would otherwise not be used. Efficiency is a prized strategy, and one important in selection processes. Centuries later in Han dynasty China, pig-latrine systems elevated the pig to a privileged status in society. Despite feeding on such a lowly foodstuff, the respect still given to the pig indicates a respect given to overall system function, efficiency and harmony; an important concept in the belief systems of that time.[17]

Also possible, however, is that even in these societies where efficiency in food utilization and caloric stress were present, human managers still chose to feed pigs valuable human food-stuffs. A situation exactly parallel to our own management decisions for pigs today. If this was the case than surely we would also expect to see parallel problems. Namely highly stratified societies between those that have and those that don't, and ones increasingly strained and vulnerable to shocks that would necessitate social responses.

It is interesting, then, that in both the Middle East and northwestern China pigs were eventually abandoned. In the Middle East abandonment came in the form of strict religious decrees against utilization of the pig in any way, while in northwestern China the entire sedentary agricultural experiment was abandoned in favour of nomadic pastoralism. Regardless of whether pigs were used as efficient waste utilizers, or inefficient grain eaters, increasing aridity must have crossed not only an ecological tipping point, but its associated agroecological one. Not only did the local ecology transition from one favourable to extensive pig production, to one favourable to grains/intensive pig production, but eventually crossed a threshold that forced a social reassessment of whether the pig had any value at all.

In the case of northwestern China it is probable that the complete abandonment of

17 See page 50

sedentary agriculture indicates that the new ecology of the region was simply unfavourable to millet based agriculture as an agroecological strategy. What became more efficient and tenable on the new arid grasslands, was instead ruminant based production on widely dispersed pasture grounds which necessitated a nomadic lifestyle.

Aridity in the middle east, though forcing some settlement sites to pursue nomadic pastoralism, did not cause a wholesale abandonment of sedentary grain based agriculture in all cases. Pig remains did, however, disappear from most settlements known to lie in particularly arid zones. Pigs remained in more humid settlements indicating that pig production in these areas was still ecologically viable. Most of these high rainfall, ecologically favourable sites were also small, suggesting that pigs may have still inhabited an extensive agricultural role. The pig also remained in the largest of sites even inside the arid zones, where they are known to have roamed city streets. This may demonstrate that although pigs were outside of their zone as an extensive agricultural species they remained as an intensive one finding a new home within the human social environment. The ultimate prohibitions of pigs in these societies then is slightly less clear, but two possible scenarios may have arisen from social inequality and disease.

The possibility that outbreaks of disease associated with pigs feeding on waste in densely populated urban areas shouldn't be ignored. As seen by recent Foot and Mouth Disease (FMD) outbreaks, mishandled food-waste as pig feed is a problem even for modern, technologically advanced societies. The probability that disease outbreaks also occurred in ancient societies, and the increased threat to livelihoods, would have made any association with disease a powerful one. Early observers may have noted a link between disease and pigs, and with a society increasingly focused on cattle, diseases such as FMD to which both pigs and cattle are highly susceptible would have been a particularly devastating. Perhaps even considered a sign from God.

Also to be considered are the aforementioned social inequalities that may have resulted from inefficient agricultural practices. Just as in our own society, the temptation to feed pigs valuable grain supplies would have put pressure on local production. A decreasing agricultural land base from a drying environment and a growing population would have put increasing strain agricultural systems. Grain-fed pigs, as a kind of system freeloader, would have exacerbate social inequalities and injustices between those who could afford to feed grain to pigs and those who could not afford to eat. Inefficiencies manifest themselves in many ways, and societal disruption is least among them. The growing populations in these early urban societies required an increased focus on governance to maintain equilibrium. Prohibiting the pig to maintain social stability would have been a very ethical decision indeed, requiring compliance at all levels of social stratification, especially among the wealthy and powerful which had the ability to feed grain to pigs in the first place. Such a decree would be most efficacious if delivered from the highest level of all. Ceasing a behaviour beneficial to yourself solely for the benefit of others is an important part of maintaining functional systems, and the definition of piety. To submit oneself for the benefit the larger whole would have been to submit to God[18].

## *4.3 Towards a framework of outdoor pig production*

Building ideas into tangible visions is important for providing the framework and inspiration for change. Although it is impossible to fit one model to all situations, providing a best practice framework and examples can be important in both communicating ideas and providing the basis for which others can cooperate. With such models in mind we are able to modify them according to the situations at hand without losing focus on key components. This thesis, therefore, presents a theoretical model of pig production based on important functional roles of the pig found during the case visits, backed by historical accounts of pigs in agroecosystems and the ecology of wild *Sus scrofa.* It is an attempt to find farm scale solutions to broader sustainability issues in ways that are beneficial and, therefore, attractive to farmers. Such scale-level benefits are important in attracting actors that, while benefiting themselves, contribute to larger sustainability goals (Atlani, 2013).

The three farm visits highlighted four main agroecological roles for the pig that could be integrated into an outdoor production design. Each farm highlighted one or several of the following, but no farm exhibited all. The historical cases highlighted in what ways those functional roles might change in relation to the broader environmental (human and non-human) context.

18 Of further interest is the discussion proposed by Zeder (1998) in which pigs allowed urban inhabitants, through sty based production, to limit their reliance on a state imposed economy. Although grain, and cattle may have been controlled by elites, pigs would have given urban inhabitants some measure of self-sufficiency. This autonomy compelled the state to enforce restrictions. Considering recent litigation against small scale farmers in the U.S. this argument is particularly worrisome (Center for Food Safety, 2012)

- **Economic.**
  - Defined as the farms ability to generate profits from its pig production that make it competitive in today's market society.
- **Utilization of waste resources.**
  - Defined as the farm's ability to use foodstuffs from the wider food system that would otherwise be considered waste and disposed of.
- **The use of forest habitat.**
  - Defined as a production method in which pigs are kept in treed areas for reasons of forest management, animal welfare, and/or farm system function.
- **Pig tillage/manuring for arable crops.**
  - Defined as a production method in which pigs are kept outside on fields with the intention that their rooting and defecation tills and manures soils for a following planted crop.

- **Socio-ecological determinate of agroecosystem management.**
  - Defined as a function by which the broader environmental context defines the relative proportion of emphasis given to the above agroecological roles.

### 4.3.1 Economic

Both Ole's and Heinrich's farms exhibited the importance of the pig as an economical component of the farm. In Ole's case, especially, the presence of pigs and their relatively high profit margin allowed his farm to survive and exist as an agroecosystem. Pig husbandry may not have been as necessary for the survival of Heinrich's farm since he had a profitable vegetable production operation. The numbers of pigs produced and sold on Heinrich's farm, however, certainly added to his farm's profitability. Also the savings provided in the preparation of soil by manuring and removing weeds for following crops should not be lost from the discussion.

Augustin's agroecosystem was not counted as being particularly profitable, nor was that his goal to the same extent as the other cases. It should be remembered, however, that the high quality of meat produced on Augustin's farm would have fetched the highest price per pig and that his inability to meet a regular delivery schedule was the main factor preventing his entry into the market system. This meant that Augustin kept his products within a small circle of buyers, and also allowed his pig herds to be kept at sizes appropriate for his system. The added value and storability of the cured meats he created allowed him to keep a product available until demand arose.

The economical component of agroecosystems has become an increasingly important aspect of system function. For any agroecosystem to continue existing there must be a suitable profit from sales to compensate for (at the minimum) labour and taxes. There is also, in most cases, initial capital investment in infrastructure and equipment that also must be payed for. The quest for profit is a balancing act, and is the main driver for agroecosystems towards unsustainability. It is, however, a necessity in our increasingly human dominated world. One which we should pursue with great care.

#### *Design implications*

In order to survive the farm either needs to have high amounts of production or a high quality product (ideally both). Due to supply and demand, however, it is impossible to achieve both for any period of time. While ultimately it depends on the broader social context, the model will assume a middle ground.

### 4.3.2 Utilization of waste resources

The utilization of food waste was unique to Augustin's farm. Although Ole said he occasionally used food from Bama-Gruppen[19] none was utilized during my 5 month stay, indicating that usage was very slight. Heinrich's system, too, involved a minor usage of residual crop waste from the vegetable fields, though he stated it was mainly entertainment. In contrast, Augustin's trips to secure food waste were twice weekly, in the case of waste bread, and once weekly in the case of fish scraps from the market. His trips helped remove approximately a van full of bread and half a large trash can seafood from being wasted on the local landfill each week. Pigs have a long history of utilizing excess and poor quality food, and is perhaps the main reason they have persisted so long in our agroecosystems. The recent outbreak of FMD has changed regulations in the E.U. regarding the use of food waste in pig feed. Given the history of pigs and their unique omnivority, this seems a hasty measure. Certainly there are ways in which we can use food waste as pig feed safely. Pre-selecting wastes before they mix, as Augustin has done, is obviously effective. Other mixed wastes that may contains products suspected of harbouring disease must be pre-cooked before being fed to pigs. In areas with sufficient sunlight, storage areas

19 A Norwegian distributor of fruits and vegetables (http://www.bama.no/).

for such food built as solar cookers or given focused sunlight as a heat source may be a cost and energy effective way of achieving this.

What should be avoided, however, is our current situation where surpluses are artificially created so they can be fed to pigs. The utilization of land to produce feed for pigs may make sense economically, but compromises the efficiency of our agroecosystems both in terms of land base that maybe be used for human feed, as well as solar energy used per calorie obtained, since feed suitable for humans passes through pigs in the food chain. Our current production techniques in the U.S. began in order to utilize surplus grains, but have morphed into a situation where artificial surpluses are created with economic subsidies that are then fed to livestock (Goodland, 1997; McMichael, Powles, Butler, & Uauy, 2007). It should be recognized that efficiency is a key factor in nature's calculation of continued existence.

#### *Design implications*

Food wastes should ideally be used as the only feed inputs to the system. Since disease is a serious risk, all waste should be thermally treated. To facilitate easy treatment the heating should be done either close to the feeding area, or close to the source of food waste. The feeding area is the place most regularly visited by pigs and is therefore also the place they most willingly go. The combination of both inputs (waste feed) and outputs (slaughter pigs) into one location makes sense, simplifies farm routines and takes advantage of animal behaviour.

### 4.3.3 Pig tillage/manuring for arable crops

Ole's and Heinrich's farms both showcased the pigs unique ability to root and how it may be exploited to prepare fields for following crops. Pig rooting is most often cited as a destructive behaviour that, on large scales, is especially damaging to the environment. Nose rings and sty based production have been the usual means of prevention. Although rooting is unwanted in most ecosystems where a more or less steady state is preferred, in most agroecosystems regular disturbance is a major component of system functioning. Today plowing is accomplished, in the majority of cases, by tractors that utilize fossil fuels and contributed heavily towards the energy consumption on most modern farms. Although pigs do not remove the necessity of plowing in these cases, there are others in which they do, especially at smaller scales[20]. As mentioned previously using pigs to replace even some

20 Personal communications with Sunny Side Farms, Dover Pennsylvania, U.S.A. (http://sunny-side-farm.com/)

of the requirements of plowing is beneficial economically, and can also be more effective than plowing in some ways. In the case of *Elmyrus repens*, for example, pigs will thoroughly consume it whereas plowing can leave pieces that will re-root if soils are wet enough.

The importance of crop and livestock rotation in agroecosystems has been well established, and many rotation plans have become common practice . Pigs, for a number of reasons, are usually left out of rotation discussions, but may in fact be one of the best animals to use in arable systems (Andresen, 2000).

The sections on pig tillage and animal learning offer areas of further research that might lead, not only to a more selective removal of weeds in pastures, but also the possibility that plant species that are not usually considered as feed, and often considered as weeds, could be used as pig fodder. Several weedy species i.e. *Plantago*, *Taraxacum*, *Cichorium* etc. come to mind as species that may be particularly adapted to environments disturbed in such a manner and also offering an edible forage to pigs. *Plantago* in particular has been shown to be an excellent feed source which increases meat quality (Fujii, Kumagai, & Tamura, 2002; Quijada, Bitsch, & Hodgkinson, 2012); and *Cichorium intybus* has been shown to reduce boar taint and also to help uptake leached nutrients (Erick, Ingrid, & Anna, 1996; Hansen et al., 2007). These and other species might be useful precisely owing to their weedy, yet edible nature. It is an area of further research that might be particularly promising, especially as feed prices rise.

The production of pigs on an arable field is also favourable from an animal welfare standpoint. Pigs utilized in this way are allowed to express their inherent behaviours. Other outdoor systems occasionally use nose rings which cause enough pain to dissuade the pig from using its snout to disturb soils. Although it is difficult to justify one ethical standpoint over another, consumers have increasingly shown a willingness to buy products produced with animal welfare concerns in mind.

The disturbances by pig rooting in Augustin's system, while valuable, were not counted here as they differed both in scale and impact. Rooting in his forest was considerably patchy, due to lower numbers of swine and was not intended to be repeated annually in the same area. Rooting in his agroecosystem served to remove weeds so that forests could be established, and while rooting may have continued occasionally in one area, it was not meant to completely reset the landscape in the way desired on Ole's and

Heinrich's farms.

The avoidance of *Rumex sp.* by Heinrich's pigs shows a lack of knowledge concerning its edibility. While it may be argued that they are preferring high quality food from the feeders and avoiding less desirable fair, it was observed that pigs would risk the fence to escape into surrounding cow pastures where they consumed cattle faeces. They also rooted their environment for grass, couch grass, and vegetable stalks. It may be that since *Rumex sp.* grew primarily in pastures, and pigs were only exposed to pastures once every few years, and therefore the pig herd is unable to store a knowledge base about its edibility. The other 'weed' species are remembered, however, since the herd is exposed to them once or twice a year and at least some individuals remember their edibility and transmit this to the rest of the herd through demonstration. On Augustin's farm pigs spend much of their time rooting for weeds within the forest. Although it is unknown role he plays, and individual such as 'Old Grumpy' has certainly built a base of knowledge about Augustin's farm routines and environment during his nearly 2 decade stay there.

#### Design implications

The model should therefore make use of the pig's ability to till and a crop's ability to uptake excess nutrient from the presence of pigs. This is best done through rotation and design should allow for the ease of that rotation. This area should, also, be close to the intensive area for feeding and delivering of pigs to slaughtery. For even pig tillage/manure it must be ensured that pigs move throughout the field. Crops should be selected based on their contribution to the farm system, and they might be vegetable crops for sale, or new 'weedy' crops for pig feed, pasture or a mix. The possibility that pigs might learn the edibility value of different species, indicates that a number 'weedy' species might suitable candidates. It also raises the possibility that highly specialized forms of rotation could be developed to target specific weeds within pastures. Some old members of the herd should be left as sources of knowledge, not separated from the rest of the herd.

### 4.3.4 The use of forest habitat

Also unique to Augustin's farm was the regular and planned use of forested habitat. Although Ole's pigs frequently escaped the fences to inhabit the forest, they were not permanent residents. Keeping pigs in the forest puts them back in the habitat where their wild types are most commonly found. This also frees cleared land for either arable or pasture based agriculture and helps preserve a type of ecosystem that today is in rapid decline. Although forests are the preferred habitat of *Sus scrofa*, and co-evolved together, pigs are not wholly undamaging to forests. Forest composition will change when pigs are kept in substantial numbers, and care should be taken both in the regular rotation of pigs but also in the re-planting of trees that tolerate the presence of pigs in the wake of those that don't. These species might also benefit the pigs with annual feedstuffs. Augustin's system and other surviving systems in which pigs utilize forest resources exemplify the high quality meat that can be produced when trees such as oak and chestnut supply pigs with high quality feed.

The value of the forest need not rest solely on its contribution of high quality pig feed however. Forests are themselves valuable either for lumber, biomass, cultural heritage or aesthetics. The possibility also exists that such a forest might be an open one, such as in the Dehesa systems of spain, where pigs are allowed to forage for acorns during the fall, but sheep or cattle are allowed to graze pasture at other times. Trees also might be pollarded to provide high quality feed for such livestock or perhaps roughage for the pigs themselves. Such pollarded landscapes are endangered cultural heritage sites in Norway and many other parts of Europe. The keeping of pigs amongst them might be a key conservation strategy to protect them. At the least, such pollards or whole trees might be kept simply as biomass to be used to heat residences, or perhaps to pre-cook waste to be used as pig feed when days are too cloudy for solar heat.

Also to be considered is the utilization of pigs in areas in which no forest exists at all. Deforested areas might uniquely benefit from the introduction of pigs and their human care-takers. Although pigs themselves do not replant a forest, their presence might help the forest to regenerate more quickly, by removing weeds likes brambles and fern as in Augustin's case. Their presence in the agroecosystem may also provide incentive for their human caretakers to renew a forest with species that add economic value to pig production, such as Oak and Chestnut. Even though nut producing species may not show harvestable crops for at least a decade, other species planted alongside as part of a mixed forest will much more quickly show benefits, such as screens for sun and wind and root systems that help reduce nutrient leaching.

Lastly, similar to pigs in arable systems, keeping pigs in the forest allows them to express behaviours inherent in their species and is positive from an animal welfare standpoint. Judging from the eagerness of Ole's pigs to test the fences for weaknesses, the forest must be uniquely attractive to the pig; an ancient lure where both their form and behaviours took shape millions of years ago.

#### *Design implications*

The addition of forested land in the model provides a number of multi-functional benefits, and should be considered. Since trees are susceptible to high densities of pigs for extended periods, this area should be only occasionally visited. It should be easily accessible to the pigs but as it is only occasionally visited it should be located on the farm periphery. The probability that the forest will change from the interactions with pigs, replacement trees should be selected both for resistance to pigs as well as contribution to the total farm system. In cases where forest does not already exist, a diversity of acceptable tree species should be made to mimic a natural forest.

### 4.3.5 Socio-ecological determinate of agroecosystem management

What the current case studies hinted at, but failed to provide a theoretical foundation for, was how the broader ecological context determines which of the pig's functional roles agroecosystem managers choose to emphasize. The changes in both the ancient Middle East and China suggest that as the environment becomes more marginal pigs are shifted from an extensive role in which they are left to forage largely within the non-human environment to an intensive role in which their food-stuffs are largely derived from the human environment. While the historical cases where based on climatic changes that, through time, limited the suitability of the broader ecology to an extensive form of pig husbandry the case studies, the case studies also lend evidence of extensive to intensive shift as the broader ecology becomes more marginal.

In Augustin's case, for example, the sheer productivity of the natural environment allowed his pigs to stay in a largely extensive role, although not entirely. Although waste food is an input, much of the weight gains occur within Augustin's farm system, i.e. in the forest during masting season. The number, and nuisance, of wild pigs in the area confirms that the broader ecology in which Augustin lives is an environment favourable to the pig's natural ecology. In addition, the relative freedom Augustin has from economic necessities also means his pigs inhabit a relatively favourable human environment. Neither he nor his pigs are pressed by economic forces that necessitate large numbers or regular slaughter routines.

By way of comparison Heinrich's farm exists in an ecological context that is less favourable to pig ecology. The climatic context limits the productivity of the wild forest lands and centuries of agriculture have intensified the landscape. He also exists within an unfavourable human context in that he is not free of economic forces. His pigs exist solely within the human environment, being fed feed produced and mixed in other parts of the world. Heinrich, however, does inhabit a favourable *agricultural* context and his land is valuable for the production of quality vegetable crops and some barley. As an agroecosystem manager, he has therefore developed a highly integrated rotation scheme which utilizes the behavioural aspects of pigs (rooting) to favour his vegetable production. Likewise, aspects (behaviour?) of his crop production, such as the promotion of weeds, and the production of crop residues, favours his pig production. The vast majority of his pigs' feed, however, comes from outside his farm system, and unfortunately it comes from the human context of direct agricultural production, rather than the human context of waste streams.

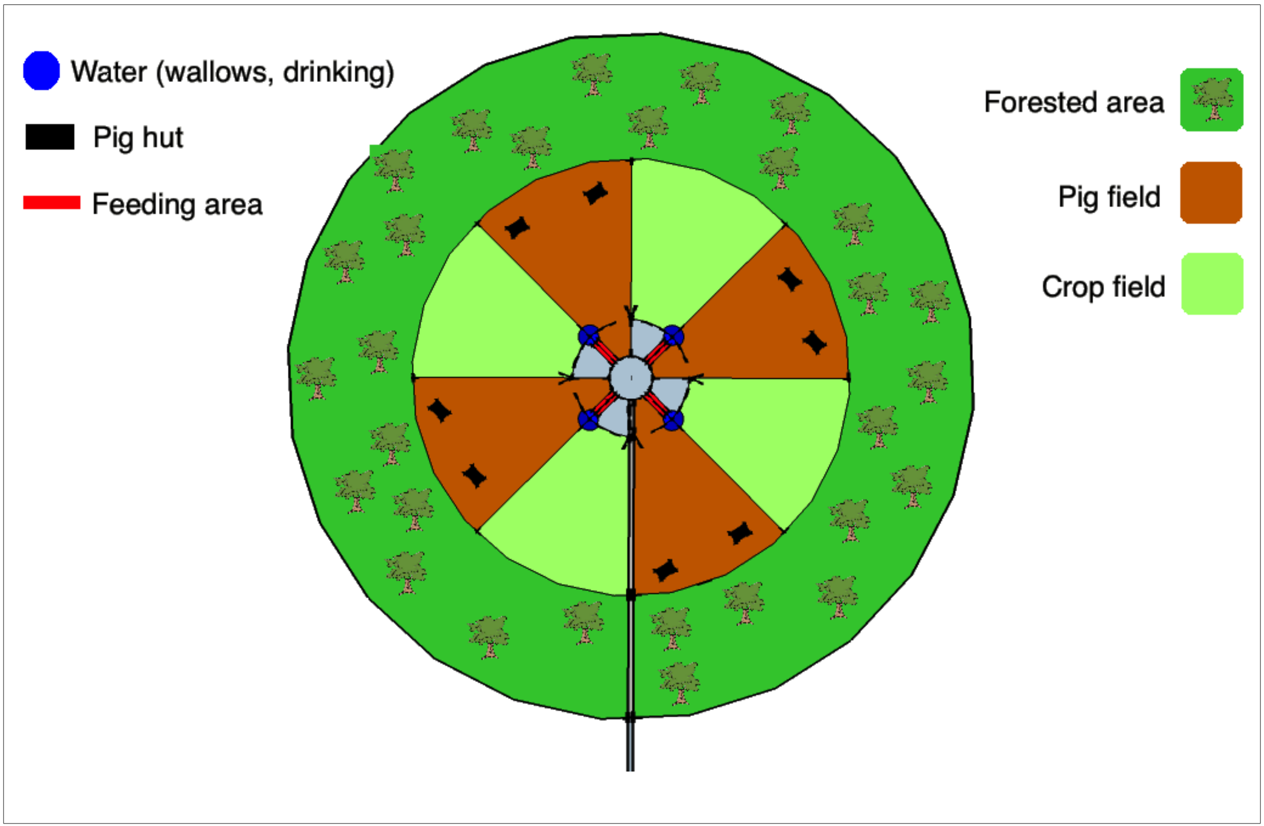
Ole's farm also exists outside of an ecological context favourable to pigs, and his pigs exist solely within the human environment. He is also compelled by economics to produce pigs. His farm differs from Heinrich's, however, in that both climatically and topologically his farm is unfavourable to the production of quality vegetable crops, and has therefore limited his emphasis on developing a highly integrated rotation scheme. His farm, however, is not so far removed from an agriculturally favourable context that rotation does not exist. His pigs are still part of a barley-pea/pasture rotation. Interestingly, that Ole's farm exists at the edges of a context suitable for arable crops, the quality and therefore economic value of those crops is limited. This frees Ole to produce lower quality crops that contribute to his pigs' feed. The contribution, however, is not total and Ole is still reliant on inputs from the broader human context. Again, unfortunately this is by way of transnational feed supplies.

### Design implications

The model, therefore, should not be a static design. Its different components should be stressed or understated as a function of the broader ecological context. More specifically, it should be a function of the marginality and intensity of land use in the broader ecology of which it inhabits. It is also a function of its economic context, which can allow a model which is ecological appropriate within its context to move into an ecologically inappropriate one. A multi-billion dollar pig house on the moon for example.

# 5. Theoretical Model

## 5.1 Baseline model

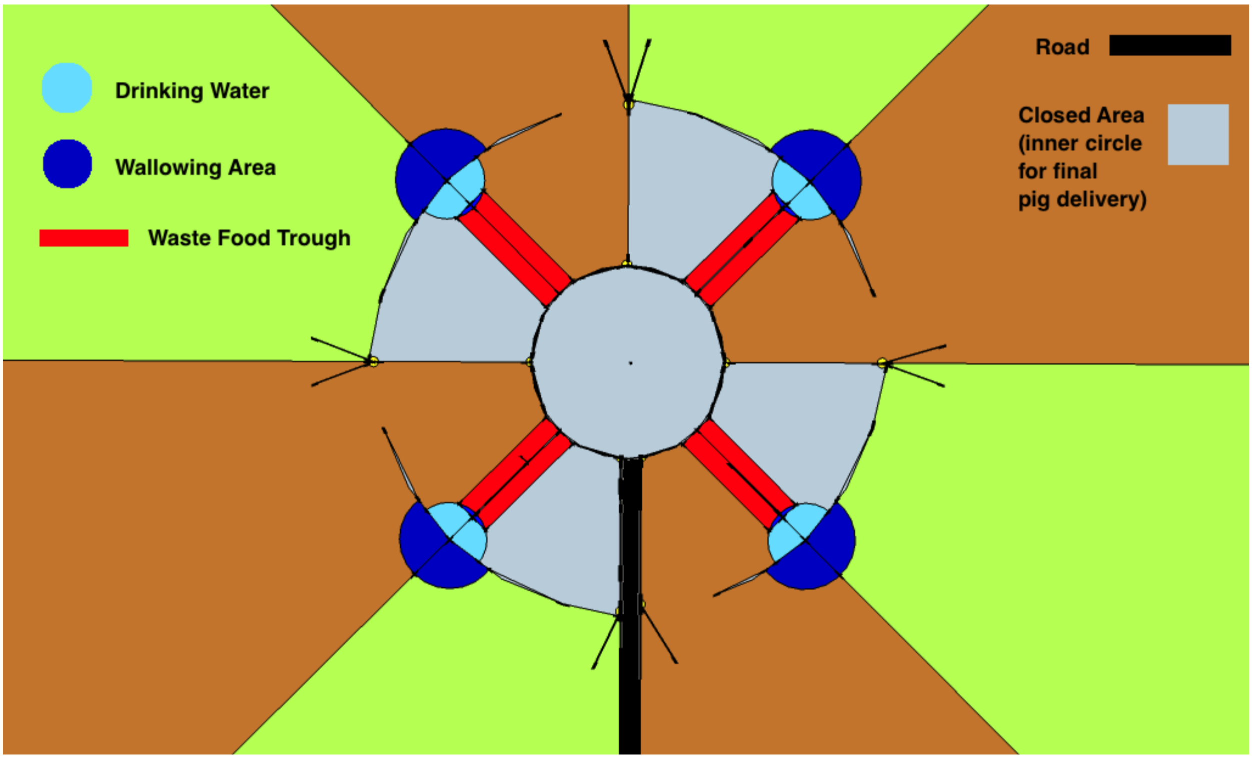



Any resemblance of the production system in figure 15 to a flower is due to the effect of symmetry and zoning which are both important aspects in the partitioning of space and resources. Regardless of any similarity or not, the flower will be used to refer to parts of the production system. Similar to a flower, the production system consists of 3 concentric rings that represent different zone of activity. The most intensive zone is located in the middle and moves to less intensive, more extensive zone in the largest ring. The symmetry of the 'petal' is a result of the equal division of one zone, the arable crop zone, into parts that facilitate the rotations necessary in combined arable crop/pig production. The 'stem' of the system, as in a flower, is the route of access for the inputs and outputs of the system.

Even the most self-sufficient production systems require inputs from the outside environment. Only the entire universe is a truly closed space. Therefore, the 'stem' is simply the road which transports feed in and pigs out. The inner most circle then is both an area of feeding and an area of loading pigs for delivery since it was seen in Ole's and Augustin's farms that a place pigs associate with food is the easiest place to get them to go.

The inner ring, then, consists of a centre spacing where food can be delivered, and alternately, where pigs can be sent to the slaughtery. Gated openings are therefore necessary on the base of each 'petal' to allow movement of the pigs to the truck. As mentioned, this is the most intensive area of the system and would therefore require the most infrastructure and precaution. It is where the larger food system connects to the farm system and is likely the main pathway for the introduction of disease to the farm.

Since it is easiest and most efficient to centralize labour so that a number of operations can be performed from one location (Hosokawa, 1991); water, wallows and feeding are combined in the central ring area. Figure 16 shows one possibility in which food and water and centralized, and gates allow for selection and movement of pigs, either to slaughtery or for rotation through the fields.




The importance of utilizing waste food as the only feed input has been established. The associated necessity of ensuring that such waste is thoroughly processed would necessitate the use and inclusion of a heat treatment device near the entry point. This treatment device can and should utilize renewable energy as much as possible. Since it is relatively easy to capture heat energy from the sun, a solar heating device similar to a large box-cooker style solar oven might be one such solution. It would be relatively easy and cheap to build. Another might be the use of mirrors to concentrate energy onto pipes to produce steam which is then used to heat-treat waste food. Both solar ovens and concentrated solar heaters are used for cooking in areas where other sources of energy are scarce (Beaumont, Eiloart, & Robinson, 1997; Suharta, Abdullah, & Sayigh, 1998). Either of these could be supplemented with wood-heating on cloudy or winter days. In any event, heat treatment of food waste is a legal requirement as long as both food waste and pigs are part of the input/outputs to the wider system. Even if heat is generated from non-renewable resources, impacts should be measured against the impacts of grain/soy production as well as the costs associated with food waste disposal.

When it comes time to slaughter, pigs could simply be pushed down to the feeding area following a habit and route familiar to them each day. Just before the gate to the centre area, selection could be made of individuals that are ready to be slaughtered and those which will continue growing. The small pigs would then be pushed away from the gate and the larger pigs allowed through.

The second zone, or the 'petals' is a slightly less intensive zone but is still one in which pigs spend a majority of their time. It is a cropping area/field where the pigs carry out most of their life. The division of this zone allows for pigs and crops to be rotated and to take advantage of the pig's ability to till, weed, and manure a crop field. Although these fields might consist of marketable vegetables as in Heinrich's system, it is known that pathogens can survive for months in manure applied to a field (Fiona A Nicholson, Groves, & Chambers, 2005). The possibility that some pathogens from food waste might spoil the season's vegetable crop or worse, makes such a use one which should be engaged with caution. It is paramount in such a case that waste foods entering the system are properly treated.

Other uses, however, might include the growth of crop mixes to be used to supplement waste food similar to Ole's fermented mixture, and Heinrich's 'wick-mix.' Hay might also be planted for direct grazing or bailing for ruminant livestock. Given the possibility that knowledge within current pig herds is lacking, the possibility exists that pigs could be highly specialized components of a pasture rotation system in which their presence target specific weeds. Although the model suggests a rotation scheme based on annual crops, longer term pasture rotations might be included similar to those in Heinrich's system. Pigs might then be rotated onto the pasture, not to reset the system, but instead to consume specific weeds. Such specificity would shorten the rotation process since less time would be needed for the regrowth of grass.

Regardless, the importance of this area lies in its ability to utilize the impact of pigs, which can be quite heavy. This is were excess nutrients accumulate and must be used. It is also were soils are disturbed and advantages to this disturbance should be found. Growing vegetables or other crops helps remove nutrients and heavy metals from the system (vegetables) or reduce inputs in the first place (crops for pigs) while also utilizing what would otherwise be wasted land.

Since fields will be used for the items that appeal to pigs, well constructed fences are a must. Since they do not need to be moved, some money and time can be invested. Ole's sheep fences provide on example of a fence that might work and in some areas living fences in combination with wire fences might be an attractive solution. They would also help add diversity to the farm and provide an adequate barrier as long as the farmer is willing to brave the associated viciousness of such species.

Since even tillage and manuring is needed, housing units are concentrated towards the broad end of the flower and moved to ensure even manuring. Daily movements of the pigs to the feeding area would help 'till' the narrow area of the petal. In order to move huts, and for the final tillage seen as necessary at Heinrich's farm, tractor access could be either at the broad end of the petal or from the intensive zone, depending on size and landscape.

Despite the observation that chaos was manageable in Ole's farm, production strategies and market forces might compel the separation of boar and sows. Population increases for slaughter at peak seasons such as Christmas or finishing on seasonal forest resources (see below), may mean it is best to control reproduction. Boar and sow are relatively easy to fence and fencing them within a field ('petal') with the general population would be sufficient. Nursing sows need only be moved to nearby housing units or back with the general population until weaning.

Recently the necessity and ethics of castration has been called into question, and the E.U. has instituted a ban by 2018 (European Union, 2010). Usually castration is performed to remove boar taint, an unpleasant flavour in the meat of Boars, and to help regulate pregnancies. Heinrich's' farm visit showed, however, that castration is unnecessary since taint only becomes apparent in older animals. Regulations forbidding castration will soon come into effect, and as a result ways of managing taint are needed. The inclusion of *Cichorium intybus* into the diet of boar has been shown to reduce taint and may be an appropriate 'weedy' crop to be incorporated into the rotation system. Its high protein content and adaptation to disturbed soils make it an ideal candidate for further research. The added ability of its deep tap-root to uptake nitrogen is an added bonus in pig production, where soil nitrogen concentrations are often high.

Experiences at Ole's showed that the separation of boar was not necessary to prevent pregnancy of females in the herd. This was because the growth rate of his animals was so quick that they were slaughtered either before they were sexually active or before they were visibly pregnant. The high quality of Augustin's animals, however, make slower growth rates attractive. In such cases male animals may need to be separated from female animals in another field to ensure there are no unwanted pregnancies.

The exact strategy then is determined by the breed, and the ability of a well divided farm to accommodate different breeds becomes a possibility. A fast growing modern breed might be kept with both males and females together on one field, while slower growing breeds such as the Iberian might be kept in two other fields (or one if castrated). The fast growing production varieties then would fill one market niche; that of 'cheap' cuts of meat and sausages. While the other slower growing varieties fill a higher quality niche such as cured hams (Talbott et al., 2007). The cured meat on Augustin's farm was particularly important as a way of storing his products until there was demand.

Pigs have historically been a quality food, offering meat traditionally praised for its high fat content. The recent abandonment of high fat meat for leaner cuts has, as well, caused the abandonment of many traditional pig varieties and replaced them with modern varieties producing leaner meat (OECD, 2003; Schneider, 2011). At the same time the cattle industry has fattened its meat by finishing cattle in feedlots where they are fed diets very different from the grass based diets they have evolved to cope with. We have then, at the same time, both neglected the finer quality of fatty pork in favour of leaner varieties, and forced cattle to become a fatty meat they originally were not.

While this is largely a social issue arising from a number of complexities that drive consumer appetites and is outside the scope of this paper, the return of pork to a respected position as a high quality, high fat meat may be the single most advantageous change in helping to reduce the negative impacts of pork production.

The movement of pork from a low quality, mass produced item to a high quality skillfully produced one also helps bring the pig back to its ancestral roots; the forest. Wild *Sus scrofa* are well adapted to forest environments and especially to forests where trees produce a mast of nuts. They are able to consume a large quantity of this mast and store it as body fat (Rodríguez-Estévez et al., 2009). The fatty acid composition of forest nut mass leads to particularly flavourful meat and is an important aspect in the curing of high quality hams (Cava, Ruiz, Ventanas, & Antequera, 1999; Lopez-Bote, 1998). Open forested habitats consisting of nut producing tree species have been a part of both the Dehesa systems of southern spain, as well as the pennage systems of northern Europe (Jørgensen, 2013; Olea & Miguel-ayanz, 2006; Trujillo et al., 2000). The third ring, then, represents the least intensively used area of pig production, the forest area. The use of forests incorporates the extensive role of pigs in concentrating dispersed resources into its body.

The vulnerability of forests to heavy impact may negate their use under the high density of pigs needed for most economically viable production systems. The benefits of forests, however, are both large and multifunctional enough to warrant their use as a seasonal foraging area, particularly for nut masts. Many regions of the world hold a suitable diversity of tree species that a mix of fruit and nut producing species could be included in an open forest type habitat. For example, the Mid-west region of the U.S. is now one of the largest corn producing areas, but historically was an area noted for its forests of nut trees (Nicholis, 2009; Ramankutty & Foley, 1999). The restoration of some of this area from fields that produce corn for pigs to an agricultural matrix that includes nut forests for pigs, would not only increase the quality of pork but also the quality of the regional forests. Similarly, large parts of China have been deforested although a number of *Castanea* species are native to the area (Huang, 1998; Lang & Huang, 1999). Europe too has seen decline in its forest and the near abandonment of pennage systems based on beech/oak forests

(Ervynck et al., 2007; Jørgensen, 2013).

Interestingly, such radial pasture designs have been suggested for both pigs and cattle, since they centralize inputs and therefore labour, and allow easy rotation through pasture or life stages (Figs. 17 -18) (Clark, 2003; Hosokawa, 1991). Radial designs have also been associated with agro-pastoral systems in the Middle East 5,000 BP, and at other sites during the Iron and early Medieval periods (Casana, 2013).

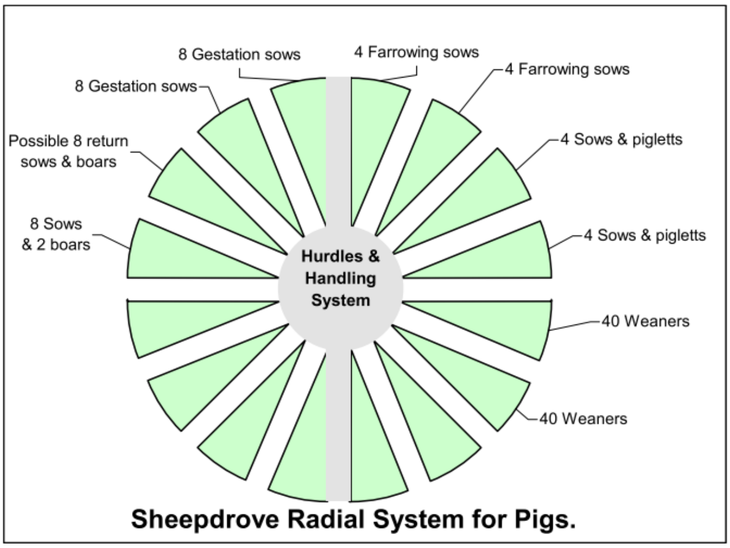



*Fig. 17: Radial production model for pigs (Clark, 2003).*

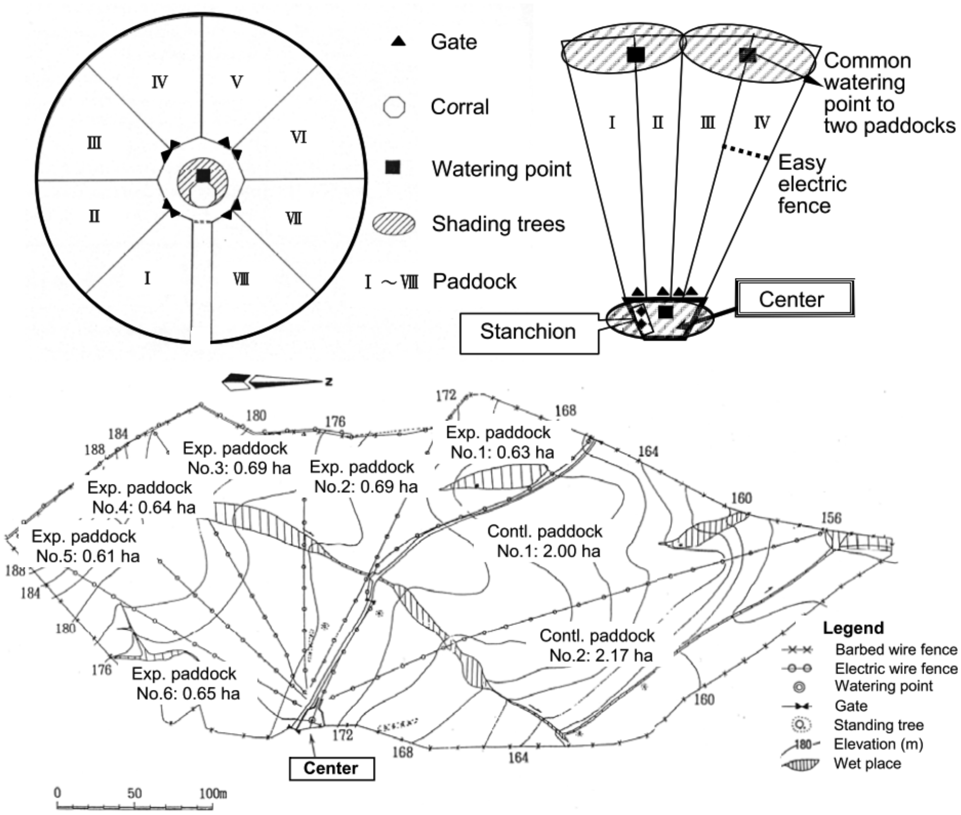



*Fig. 18: Theoretical model of a radial pasture (top left), "Yaeyama" grazing system (top right) and detailed map of Yakumo beef cattle farm utilizing a radial layout. (Hosokawa, 1991)*

Forests are an important and declining habitat type the world over. Their decline is due to a number of reasons, not least of which is clearing for agricultural land (Pagnutti, Bauch, & Anand, 2013). The complexity and long growth period of forested systems has led to their valuation in terms of lumber and as land to be cleared for arable agriculture. Their complexity and perennial nature, however, is also a key feature that makes forests particularly interesting as a sustainable agroecosystem. Increasing attention has been turned towards forests as a way to both mitigate the impacts of arable agriculture and to increase overall productivity (Broom, Galindo, & Murgueitio, 2013; Jose, 2009; Leakey, 2012; Nair & Garrity, 2012).

In areas where no suitable mast tree species can be found, one might reconsider the value of pig production in that area in the first place and instead focus on agroecosystems that are better mimics of the local ecosystem, as both ancient northwest Chinese and Middle Eastern societies did. The adaptation of our agroecosystems to the processes of the naturally evolved local ecosystem is likely a key aspect of sustainability. The economic system, however, is often at odds with this notion and facilitates the inclusion of agricultural practices unsuited to local conditions. If no suitable mast producing tree species are available, there are still other benefits to the agroecosystem from the inclusion of the forested zone. As an additional land base it may simply function to lessen the annual impact of pigs in the arable area, helping to uptake excess nutrients to be incorporated into trees and shrubs. This open forested habitat might then be grazed by ruminants, similar to the pollarded tree systems of old. Such a combination has been shown to be more productive than pasture only systems (Broom et al., 2013).

In any case the forested zone is only visited occasionally by the herd once a year during mast or perhaps throughout the winter in areas where the ground freezes. The high impact of a rather dense herd should be limited to ensure tree recruitment. If huts are retained in the field area pigs will return to them in the evening to sleep, especially in cold conditions. In the spring then, when regrowth is important, pigs could be removed from the forest simply by locking the gate at night.

## 5.2 Function of broader ecology: a changing model

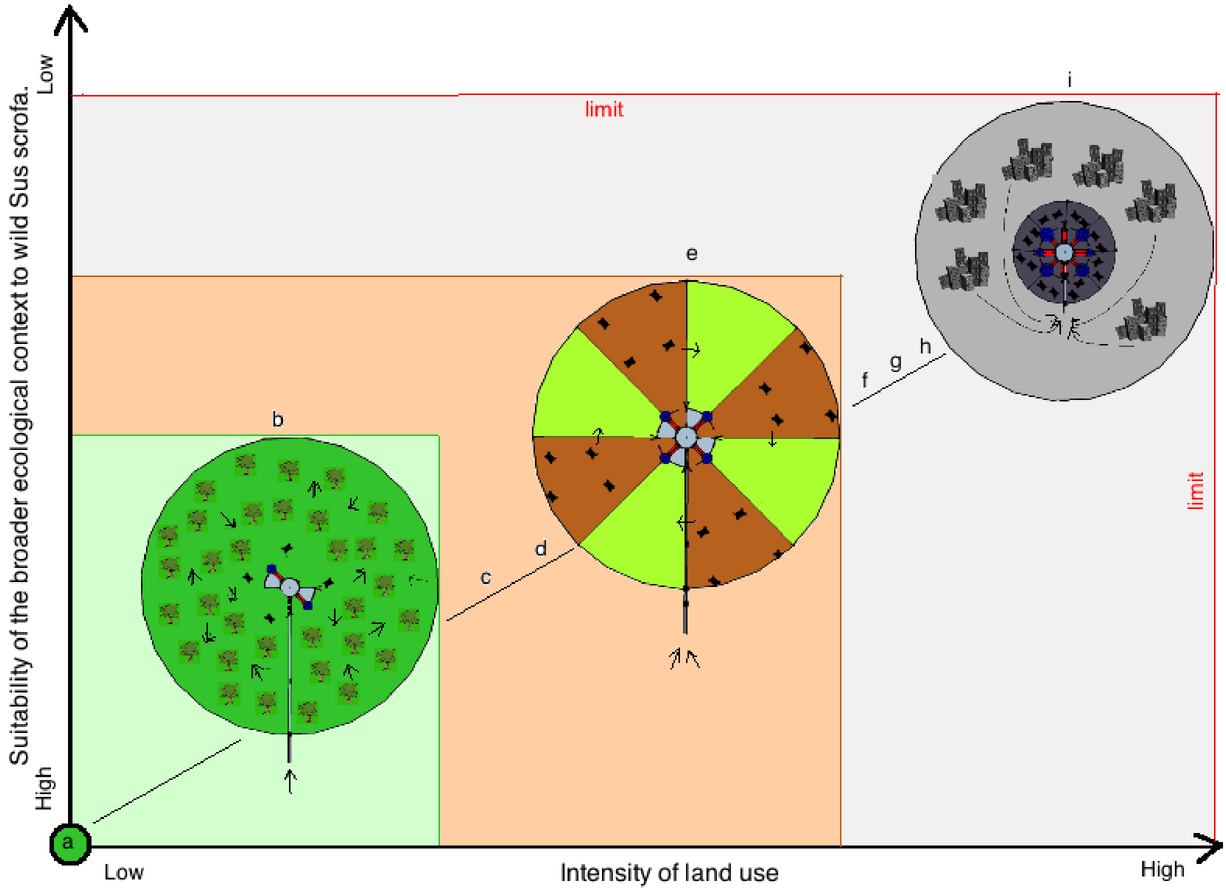



*Fig. 19: Graph representing the changing role of domestic pig in its agroecosystem as a function of land use intensity and suitability of the broader ecological context to that of wild Sus scrofa. The three models presented represent, from left to right: (b) model with extensive husbandry practices emphasized, (e) model with pig/crop rotations emphasized, (i) and model with waste resources emphasized. Small circle at the left (a) represents a truly wild state. Positions: c, d, f, g, h, represent approximate locations of farm types refered to in text below. Arrows within the models represent the flow of feed stuffs. Note that increasing intensity of agroecosystem management allows the domestic pig to inhabit agroecosystems very different from the 'natural' (non-human) ecosystems of wild Sus scrofa. Also of note are the limits imposed by the biology of the pig (horizontal bars) and those imposed by agricultural potential (vertical bars). (Proximity of limits to the intensive model is purely a result of the constraints on page size and not meant to represent impending doom).*

The theoretical model presented above can, on its own, only represent one situation in which the agroecological roles for pigs found during this case study are equally represented. It can not, by virtue of the diversity of the world, be applicable to all situations. It is therefore interesting to explore the ways in which the agroecological roles found during the case study change as a function of the broader ecological context. The above graph (Fig. 19) relates both the intensity of land use and the suitability of the broader ecological landscape to the agroecosystem roles of domestic pigs.

It is appropriate to frame the graph with **intensity of land use** vs. **the suitability of the broader ecological context to wild *Sus scrofa*** since they are closely related. As human land use intensity increases it destroys habitat, not only of *Sus scrofa* but of other species as well[21]. As intensity increases ecological suitability declines. Likewise, as the suitability of the broader ecological context diverges from that of *Sus scrofa*, human managers need to bring domestic pigs in closer contact with human life ways, and therefore closer to agricultural systems. It is those agricultural systems themselves that increase the intensity of land use.

Arrows within the model represent the flow of food, from randomly dispersed within the low intensity model, to cycling in the medium intensity model, and streaming from urban areas in the most intense model. The graph was also designed with an increasing number of pigs in each model rather than shrinking models. The graph could have instead been presented with the same number of pigs present in each model but with decreasing size; more land needed in the low intensity system, and less (or no land) needed in the high intensity system. In fact, the highest intensity model does shrink, since the scale of pig production is represented in a larger urban context.

In environments very close to the ecology of *Sus scrofa* production methods can utilize pig's in an extensive role making use of forest resources, but this can only happen if human land use practices are low in intensity. The left-most model (b), then, might represent a situation very close to Augustin's in which a small amount of waste-foods are input from outside of the farm, but the majority exist as dispersed and randomly occurring food stuffs within the forest.

As land use intensity increases, the role of pigs changes to that of a component in a crop system (e). Likewise, as the broader ecological context diverges from that appropriate to wild *Sus scrofa*, the domestic pigs need to be brought in closer contact with human management. The arrows, therefore, indicate an increasing input of waste-food from the outside environment and a reliance on crop production for feed stuffs. What must be

21 There may, however, be an increase in pig numbers due to human agriculture, but this is due to the wild pigs raiding human crops. In such a case the wild pigs have become part of the human system and no long in completely wild ecological context. It could be argued that they have begun the long process towards domestication that ancient agriculturalists took advantage of.

remembered, however, is that this is a sliding scale with an infinite number of variations. Perhaps the farm is slightly less intensive and pigs are being fed low quality food-stuffs sown after their presence, as in Ole's case (d), or perhaps even less intensive and you arrive at the theoretical model in which forest, pig/arable, and waste feed is balanced (c). On the other hand in a slightly more intensive situation pigs are being fed input feed and instead are used only for rooting and manuring for vegetable crops, most similar to Heinrich's case (f). Increasing the intensity even more from this point and you have a situation very similar to most modern outdoor production systems (g). The pigs are kept as the sole agricultural species, fed an increased number of inputs (ideally waste food, but in reality produced feed) from outside the farm system. And so on.

The right-most model then represents a situation in which pigs inhabit an highly intensive role (i). They are well outside the ecological range of *Sus scrofa* and completely reliant on waste-food from an intensive urban landscape, similar to the situation of the largest urban areas in the Middle East during the driest period. It is also similar to modern indoor production methods where pigs are confined in high numbers and biological limits modified with the use of technology (h). An ideal situation would still, however, utilize waste resources. Further along, we can imagine a number of scenarios in which use of the pig as an agricultural species requires increasing disdain for its biology and manufactured solutions that bring the pig even closer into the human environment, and totally reliant on human technology.

If imagining this situation begins to leave a sickly taste, take heart. The distance of the pig from its basic biology and ecology likely mean that at some limit further inclusion of the pig into agroecosystems is impossible. This is backed by both abandonment of the pig in the ancient Middle East and northwest China. In a modern context we might imagine a situation in which increasingly intense epidemioligical factors make such high concentrations of confined pigs impossible to justify. The possibility also exists that the intensity of land use places such a high value on food that little waste is created, and, as in Biosphere II, competition removes the pig from our agroecosystems[22]. Worryingly, both societies also ran into limits of agricultural production itself, suffered population declines,

22 A third situation (intentionally offered as a footnote) exists in which production becomes so far removed from the pig's basic biology that human society, abhorrent of its practices, itself sets ethical limits to what is tolerable.

and abandoned their settlements; a process imitative of the 'release' Ω phase of Holling and Gunderson's (2002) theories of adaptive cycling, and a progression seen many times throughout history (Gunderson & Holling, 2002; Manning, 2005)

# 6. Conclusion

> "Perhaps another lesson from our Biosphere 2 experience relevant to all life systems, from restoration ecology to maintaining the health of Earth's biosphere, is suggested: that humans who are living with and dependent on crops and ecosystems for their life support are vital for their care" (Allen, Nelson, & Alling, 2003).

Pigs most likely entered our agroecosystem when they were drawn to the middens of our ancient villages. There they found an abundance of food-stuffs that left them less reliant on the vagaries of the outside environment. They remained, however, excellent scavengers able to both find and persist on a variety of foodstuffs. This dual role, the ability to make use of local human wastes as well as range extensively to feed on their own, made them useful and attractive to not only the first sedentary agricultural groups, but hunter-gatherers as well. As the intensity of our agroecosystems grew, the newly domesticated pigs began to compete with us as users of the extensive local environment. Where once they had roamed freely to gather and incorporate dispersed food stuffs into the meat and fat of their bodies, such free roaming began to disturb and conflict with our increasingly intensive land use practices. In rich ecosystems, such as the tropics, pigs were able to remain as extensive agricultural species. The rich environment held an abundance of dispersed food sources, which precluded the need for intensive forms of production. In more marginal ecosystems or ones in which intensive practices were not as hindered, the use of pigs as extensive agricultural species began to decline. As such areas grew to become regional centres of food production they increased in population and size, allowing the pig to change to an intensive agricultural role, feeding on the increased waste produced from those new urban centres. They continued to roam freely in the streets but began to be concentrated and confined. The waste products they were fed cleaned the city and produced valuable food while keeping them out of competition with the human population.

Today pigs inhabit what might be considered an ultra-intensive existence, confined in houses and fed on feed specifically produced for their consumption. They have been bred to grow rapidly despite crippling developmental problems that would occur if they were not quickly slaughtered. They have entered into the 20th century as yet another part of industry; a meat producing machine that must be optimized in ways that make economic profits.

The baseline design proposed was developed with reflection on *Sus scrofa*'s roles as an intensive and extensive agricultural species as well as a species of disturbance in the environments it inhabits. It is also meant to be one that acknowledges our species economic habitat and the necessity of sustained and relatively high production levels. It also, however, acknowledges the unique value of pork as a fatty meat, one that should be relished for its quality and versatility.

Most importantly it is a production system that attempts to reconcile our needs with the needs of our pigs and its wilder ancestors. Not only is it one meant to spare land resources better used to produce food for the earth's human inhabitants it is one meant to spare the pig the indignity and disrespect of being denied its basic evolved impulses and behaviours.

The graph of intensity, by comparison, conveys our role as agroecosystem managers and the broader issues that inform our strategies. It hints at deeper issues facing humanity, mainly finite resources on an finite planet. Its implications are especially worrisome, not only for the future of the pig, but our future as well.

Modern agriculture can be summed up as a disconnect of people and animals from their food; of livestock/poultry from their natural habitat and behaviours; and even from the broader ecological context we, as agroecosystem managers, inhabit. The problems associated with this disconnect are diverse, unsettling and of rising urgency. There are no easy answers, especially for agricultural species with such adaptable and complex histories as the pig and its human caretakers.

With human agroecosystems rapidly becoming the majority habitat type on earth, sustainability issues compel us to find agricultural solutions. A concerted effort then, should be made to better understand our agricultural plants and animals and the ecological niches their wild ancestors inhabited in order to better mimic a functional ecosystem. This must be combined, however, with and equal understanding of how the agroecological roles of those species have changed through time and broader ecological context. Ancient pig prohibitions may well be a response to the difficulty of reconciling the impacts of pig husbandry on local eco-, agroeco- and social systems. A summation of the impacts of modern pig husbandry shows a similar difficulty, and as managers of what will soon become a global agroecosystem we should re-evaluate the value of the pig and their place in our systems.

The persistence and celebration of the pig in other societies, however, points to the usefulness and unique roles pigs have. The extent to which they are positive or negative, then, is a responsibility that rests solely on our shoulders as managers. Indeed the management strategies for all our agricultural species define the success or failure of the endeavour as a whole. If we are to continue this ~10,000 symbiosis with our agricultural species it is a role we should engage with caution, respect and a deeper relationship with systems of which we are a part. As we endeavour to find the pig's beneficial roles within our agroecosystems, we endeavour as well to find our own.

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