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Mass balance approach for calculating discharge from aquaculture production system

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Master science in Aquaculture

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Master thesis

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Abstract

Recirculation aquaculture system (RAS) is widely used in salmon farming because of the high biomass outcome. Besides, it also minimizes the ecological impact through nutrient recycling and by reducing the discharge of waste water into the environment. Atlantic salmon is the dominating species in Norwegian aquaculture, and the sustainability of the salmon farming industry has been questioned. There are some indicators and methods used for measuring sustainability and eco-efficiency of aquaculture productions. For example, the simple fish-in-fish-out-ratio, different kinds of nutrient retention rates, energy retention rate, marine nutrient dependency ratio and forage fish dependency ratio. The energy retention rate has developed as a method to measure the energy efficiency of salmon production.

Therefore, this study is mainly focused on elements (carbon, nitrogen, phosphorous), nutrients (protein, fat, caebohydrate) and energy budget in the overflow of the salmon production system. The retention rates are calculated by using the typical salmon feed composition and typical salmon composition. In the end, a salmon mass balance model was made to better understand the efficiency of the salmon farming industry.

Based on the typical salmon feed composition and typical salmon composition, the result showed that the retention rate of C, N and P were 45%, 36% and 16%, respectively. For protein, fat and caebohydrate it was 40%, 93% and 8%, respectively. And for energy, it was 60%. In addition, the dry matter retention rate was 38%.

Abbreviations

C: carbon

Carb: caebohydrate

DW: dry weight

EWOS, BioMar and Skretting: the three largest Norwegian feed companies

FCR: feed conversion rate

N: nitrogen

P: phosphrous

Prot: protein

RAS: recirculation aquaculture system

TAN: total ammonia nitrogen

TC: total carbon

TN: total nitrogen

TP: total phosphrous

WW: wet weight

1. Introduction

1.1 Aquaculture production status

Aquaculture is a fast-growing food Industry. The average annual growth rate of world aquaculture production from 2001 to 2015 was 5.9% (Zhou, 2017). It is reported that the world population is expected to pass 10 billion by 2062. With the growing population, there is need of an increase in fish production (Clarke and Bostock, 2017, Martins et al., 2010). Presently, more than 50% of edible fish are produced by aquaculture (Ytrestøyl et al., 2015).

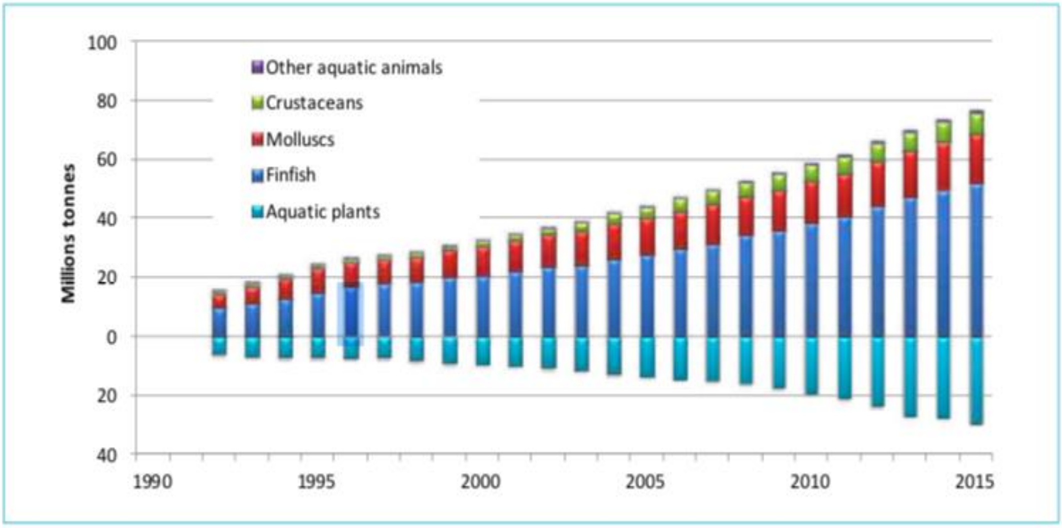


Figure 1：World aquaculture production of farmed aquatic animals and plants (1990-2015) (Zhou, 2017).

Atlantic salmon is the dominating species in Norwegian aquaculture and 1.2 million tons of salmon were produced in 2017, accounting for 94.5% of the total Norwegian aquaculture production (Statistisk sentralbyrå). However, the sustainability of the salmon farming industry has been questioned, partly due to discharge from fish farms, disrupting the local ecosystem (Ytrestøyl et al., 2011).

All food production industry has environmental impact, and the salmon production industry is no exception. Among other things, they depend on non-renewable energy, such as fossil fuel (Tyedmers, 2000), as well as non-renewable sources of phosphorous (Scholz et al., 2013). Moreover, for salmon production, the salmon feed is more or less made from other fish resource, such as pelagic fish and fish oil. Besides, it leads to water pollution by nutrients and phosphates (Torstensen et al., 2008).

There are several indicators and methods used to measuring the sustainability and eco-efficiency of the aquaculture production, such as the simple fish-in-fish-out-ratio, different kinds of nutrients retention rate, marine nutrient dependency ratio and forage fish dependency ratio. All of these methods have their own advantages and disadvantages. No simple methods have been developed to measure the sustainability of the salmon farming (Ytrestøyl et al., 2011). Therefore, developing a model to evaluate if the salmon production is sustainable is needed (Ytrestøyl et al., 2014).

This study will calculate the elements (C, N and P), nutrients (protein, fat and caebohydrates), energy retention rate and oxygen requirement for salmon to make a salmon mass-balance model. The first goal is to use the representative nutrients concentration in feed and salmon to make a resource budget for salmon farming. The difference between what is contained in feed and what is retained in fish is what is released into the water. These released nutrients will pollute the water, and possibly upset the surrounding ecosystem. Thus, water treatment is needed for RAS systems. Particles are mainly removed by filtration methods. For TAN removal, biofilter is always used. Aeration is need for keeping gas (CO_2 and O_2) balance. Moreover, pH value and other water properties are considered in the RAS system.

The conclusion in this study can be useful when trying to make a strategic decision about future salmon production. For example, using less non-renewable phosphorus and less wild marine resources in feed.

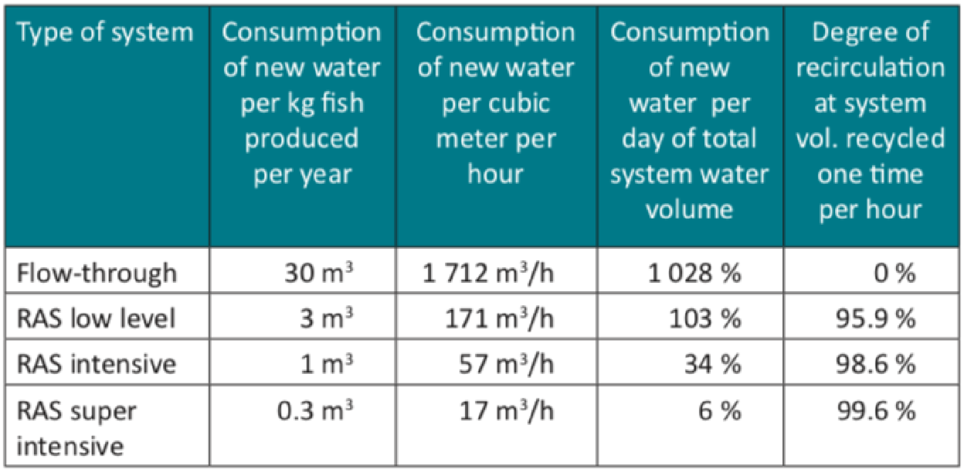
1.2 Aquaculture production system

There are different types of aquaculture production systems in aquatic organism production, from the extensive, semi-intensive and highly intensive pattern. For example, the water-based systems (cages and pens, inshore/offshore), the land-based systems (rained ponds, flow-through systems, raceways), the recirculation aquaculture systems and the integrated farming systems (agriculture and fish dual use aquaculture) (Funge-Smith and Phillips, 2001).

⑴ **Recirculation aquaculture system (RAS)**

RAS systems, were first introduced in the late 1980's and have been used more and more worldwide during the last 20 years in intensive aquaculture farming since it has multiple advantages (Martins et al., 2010). It cultures fish in high density in order to get high biomass outcome. In addition, it minimizes the ecological impact because it reuses more than 95% of total water after the water is continuously treated (Blidariu et al., 2011, Martins et al., 2010). The table below shows the water recirculation rate of different systems:

Table 1：Different degree of recirculation at different intensities (Bregnballe, 2010).



Type of system	Consumption of new water per kg fish produced per year	Consumption of new water per cubic meter per hour	Consumption of new water per day of total system water volume	Degree of recirculation at system vol. recycled one time per hour
Flow-through	30 m^3	1 712 m^3/h	1 028 %	0 %
RAS low level	3 m^3	171 m^3/h	103 %	95.9 %
RAS intensive	1 m^3	57 m^3/h	34 %	98.6 %
RAS super intensive	0.3 m^3	17 m^3/h	6 %	99.6 %

RAS systems include much equipment to treat water continuously, such as aerator, different kinds of filters, various disinfection equipment, automatic PH regulators, heating and cooling equipment, denitrification, automatic feed machines etc, depending on the specific requirements (Bregnballe, 2010).

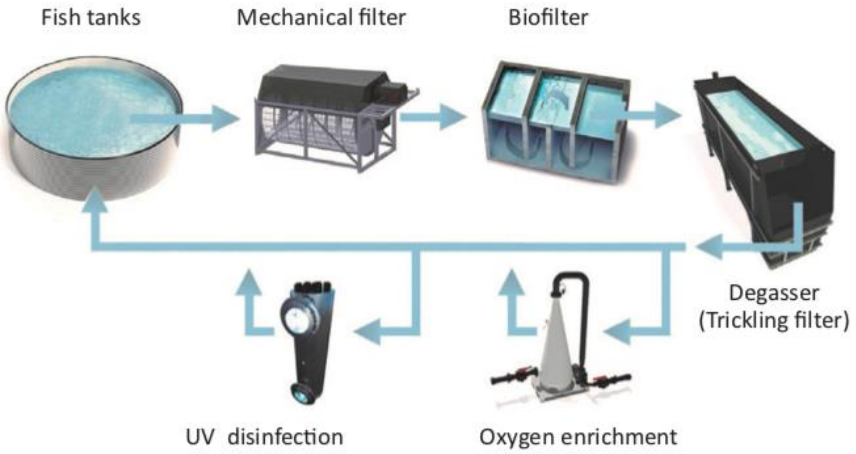


Figure 2：Principle drawing of a recirculation system (Bregnballe, 2010).

RAS systems enable farmers to fully control most of the parameters in the production, such as temperature, oxygen levels, daylight time, PH, salinity, and water flow, which will give stable and optimal conditions for fish (Bregnballe, 2010, Liu et al., 2016). So a skilled farmer can take good care of the fishes by operating the production system (Bregnballe, 2010). Note that parasites and obligate pathogens are not controlled by this system, and continue to pose a problem in fish farming (Bregnballe, 2010, Liu et al., 2016).

RAS systems have been used for more than 10 different species (Martins et al., 2010).

⑵ **Ponds production system**

Convectional ponds system is an extensive culture system, which is an inefficient way to culture aquatic organisms. The reason is the low capacity, high land requirement and low biomass outcome. In addition, the water limit will be a big problem in most places (Funge-Smith and Phillips, 2001). Nowadays, the pond culture system includes the extensive, semi-intensive and intensive culture system and it is used around the world for culturing many species, such as the carp, tilapia, catfish, eel, trout, goldfish, salmonids, milkfish and sea bass (Baluyut, 1989). Pond aquaculture production trends are making the pond production more intensive and integrating with other agriculture systems (Funge-Smith and Phillips, 2001).

Tidwell (2012) stated that the majority of fish and crustaceans cultured for food are produced in the ponds. China is the largest aquaculture products producer in the world, in which 70.4% of the freshwater aquaculture were raised in ponds.

⑶ Cage production system

The cage production system cultures the fish in a fixed or floating enclosed net supported by a framework made of wood or metal. It can be built in sheltered, shallow lakes, bays and rivers. The yield of cage culture is generally high. There are about 10 fish species that are commercially cultured in the cages, such as tilapias, carps, milkfish, snakeheads, catfish, salmonids, sea bass, mullet, and snapper. Comparing with the pond production systems, it is invented more recently (Baluyut, 1989).

The cage production system has spread fast throughout the world. The reason is that the cage production system is a flexible, easy-to-move production system. Besides, it can be built in many types of open water, it has the high biomass outcome and has fewer harvest difficulties (Baluyut, 1989).

⑷ Flow-through systems

The flow-through system is an artificial channel for culturing the aquatic organism and it is widely used worldwide (True et al., 2004). It is a type of intensive culture system when the fish are stocked in high density in long and narrow ponds or tanks. In this system, the quantity of continuous water flowing through, controls the biomass outcome, not the size of the water area (Varadi, 1984).

The flow-through system is a typical production system for rainbow trout culture (Varadi, 1984). Many other species are also cultured in this system, such as tilapia, shrimp, trout and salmonid (Otoshi et al., 2003, d'Orbcastel et al., 2009, Ayer and Tyedmers, 2009).

2. RAS status in the world

The RAS system is seen as a very eco-friendly production system. which has been used widely around world in the recent 20 years (Martins et al., 2010). The reason is that it minimizes the ecological impact and gains high biomass. In addition, it requires less space and land (Ytrestøyl et al., 2015).

In Europe, there were more than 18 European countries with applied RAS technology before 2010 (Martins et al., 2010). Table 2 shows the grow-out production (MT/year) in RAS from 1986 to 2009 in some European countries.

Table 2：The grow-out production (MT/year) in RAS from 1986 to 2009 in European countries (Martins et al., 2010).

	1986	1990	2003	2004	2005	2006	2007	2008	2009
Belgium					10				
Bulgaria					5				20
Czech Republic									235
Denmark					2000				12000
Estonia								40	
Finland					130				
France					70				506
Germany			509	688	657		1257		
Hungary					650				24.5
Ireland									50
Lithuania							15		
Netherlands	300	950			9500		9635		9680
Poland					180				
Norway									20
Portugal							100	110	112
Spain					580				
Sweden					490				
United Kingdom									100

Norway has developed the RAS systems faster than other counties and has developed the RAS system as the standard method for smolt and post-smolt production. In 2014, they produced 42% of aquaculture products in Europe by mass. There were 34 RAS hatcheries and 5 under construction before December 2015. Typical unit capacity of current projects is 12–20 million smolts per year (Clarke and Bostock, 2017).

China is the largest aquaculture products producer in the world which produced 62% of the of the world's aquatic animals in quantity respect both in 2014 and 2015 (Ryder, 2018, Subasinghe and Report, 2017). There are currently more than 50 RAS manufacturing enterprises in China. However, many companies in China are still at adaption stage of this technology since the late beginning of RAS system in China (large-scale application of the RAS began in 2006) (Ying et al., 2015).

Egypt's aquaculture production is by far the largest of any African country (about 64% share of total production in 2011). However, the RAS system contribution in Egypt is lower than 5%, mostly still on experimental period (Rothuis et al., 2013).

The US is a big market of farmed Atlantic salmon. It is expected that they produced more than 350,000MT in 2014. The US started applying RAS for commercial production around 1974 and have shown steady growth since late 1980s (Liu et al., 2016).

3. The pathway of nutrient and element

Tracing the nutrient flows can give a better understanding about how nutrients allocated in the production process. Furthermore, it can provide information about the environmental impact of the aquaculture production and efficiency of the resource utilization (Ytrestøyl et al., 2015).

In salmon production systems, the nutrients flowing begin with the fish feed, which usually contains protein, fat, caebohydrate, phosphorus, minerals and moisture. The ingested compounds are digested, absorbed, metabolized and retained in fish. Besides retention, a small part of them are excreted into the water as feces, urine or through the gills (Liu et al., 2016, Bureau and Hua, 2010). The figure below shows a simple nutrient or elemental partitioning scheme (budget) for fish.

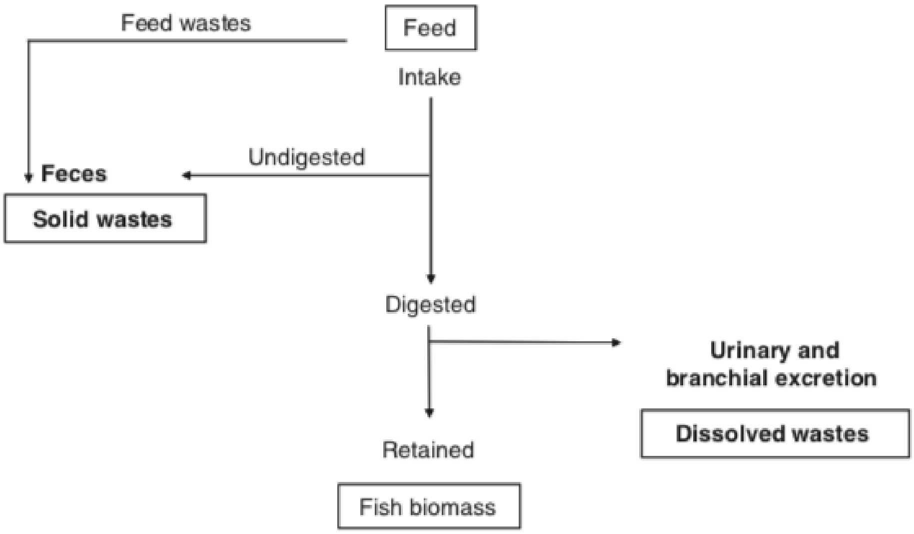


Figure 3：Simple nutrient pathway of fish (Bureau and Hua, 2010).

4. Resource budget for salmon

The resource budget shows the flow of the major elements (C, N and P) and nutrients (protein, fat and carbihydrte) from feed to the salmon in salmon production system (RAS system) (Ytrestøyl et al., 2014).

4.1 Typical salmon feed composition

4.1.1 Typical dry matter concentration in salmon feed

The average salmon feed dry weight is 946g/kg feed (Table 3). This value is based on the different number of dry weight in literature. Ytrestøyl et al. (2014) concluded the average dry matter content of feed ingredients was 938g/kg feed in 2012. It is similar to the average value calculated here.

Table 3: Typical dry matter content of salmon feed.

	DW (g/kg feed)	Reference
	932.0	Espe et al. (2012)
	938.0	Ytrestøyl et al. (2015)
	936.0	Pratoomyot et al. (2010)
	980.0	Wang et al. (2013)
	954.7	Emery et al. (2014)
	955.0	Sajjadi and Carter (2004)
	953.3	Bendiksen et al. (2003)
	931.0	Sørensen et al. (2016)
	960.0	Wang et al. (2012)
	936.0	Silva et al. (2019)
	940.0	Belghit et al. (2018)
Average :	946.0	

Standard deviation: 14.56

4.1.2 Typical C, N and P concentration in feed

Based on the values in the literature, the average content of TC, TP, TN in salmon feed (DW) is typically around 49.31%, 7.61% and 1.26%, respectively (Table 4). However, the values vary depending on the literature, typically lying in the following range TC (44.32-56.50%), TP (0.64-1.62%) and TN (4.66-9.2%). The variation comes from the use of different feed, in the different life stages of the fish. Fry feed is relatively lower carbon content and higher nitrogen and phosphrous contents.

Table 4: Typical C, N, P content in salmon feed.

C (% DW)	N (% DW)	P (% DW)	Reference
50.9-54.3	5.39-6.2	0.64-1	Wang et al. (2013)
56.50	8.0	1.33	Wang et al. (2012)
44.32 ± 0.294	9.2 ± 0.211	1.62± 0.056	Chatvijitkul et al. (2018)
47.43	7.25	1.36	Chatvijitkul et al. (2018)
46.46 ± 1.445%	7.67± 0.432%	1.43± 0.153%	Chatvijitkul et al. (2018)
	7.08	1.26	Hillestad et al. (1998)
	6.24		Hillestad et al. (1998)
	4.656-5.648		Karalazos et al. (2011)
	5.5-5.6		Pratoomyot et al. (2010)
	15.8-17.1		Espe et al. (2012)
	5.6-5.728		Codabaccus et al. (2012)
	9.02		Espe et al. (2012) Sørensen et al. (2017)
	6.76	1.41	Davidson et al. (2016)
	6.77	1.30	Davidson et al. (2016)
Average : **49.31**	**7.61**	**1.26**	
Stand deviation: 6.0	**0. 9**	**0. 1**	

Table 5 shows the C, N and P content of the other fish species.The average C, N and P content is 42.21%, 6.12% and 1.25%, respectivey.

Table 5: Typical C, N, P content in other fish feed.

Species	C (% DW)	N (% DW)	P (% DW)	Reference
Channel catfish	40.07 ± 1.32	5.78 ± 1.04	1.21 ± 0.34	Chatvijitkul et al. (2017)
Tilapia	39.16 ± 1.73	4.60 ± 1.34	1.16 ± 0.30	Chatvijitkul et al. (2017)
Atlantic salmon	46.67 ± 3.30	7.66 ± 0.80	1.44 ± 0.45	Chatvijitkul et al. (2017)
Rainbow trout	43.25 ± 2.61	6.88 ± 0.48	1.34 ± 0.11	Chatvijitkul et al. (2017)
Whiteleg shrimp	39.27 ± 1.34	5.33 ± 1.10	1.12 ± 0.31	Chatvijitkul et al. (2017)
Trout		7.0	1.2	Koçer et al. (2013)
Grass carp	40.51 ± 0.17	4.48 ± 0.11	1.08 ± 0.08	Guo et al. (2018)
Common carp	45.40 ± 0.32	5.12 ± 0.22	1.25 ± 0.12	Guo et al. (2018)
Tilapia	43.38 ± 0.334	8.79 ± 0.191	1.67± 0.139	Chatvijitkul et al. (2018)
Meagre		6.90-6.94		Chatzifotis et al. (2010)
Nile tilapia		4.80	1.00	White et al. (2013)
Average	42.21	6.12	1.25	
Standard deviation	2.69	1.34	0.18	

Different feed composition has been showed in figure 4. Comparing with other fish species feed, salmon feed has higher values of TC and TN (Figure 5).

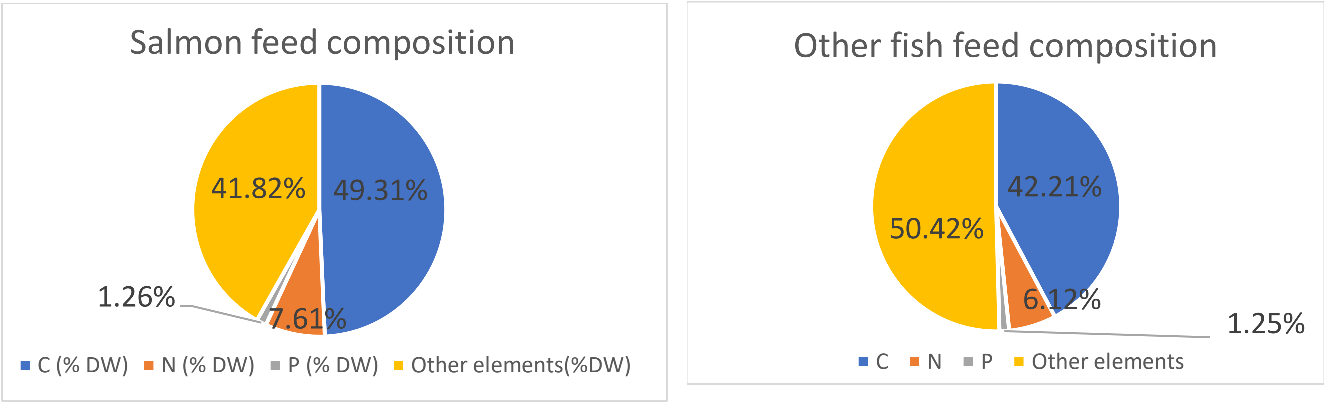


Figure 4：Average salmon feed composition (left) and average composition of other fish feed (right).

Salmon have the higher average C and N concentration than other fish species. The average P content is similar in these species (Figure 5)

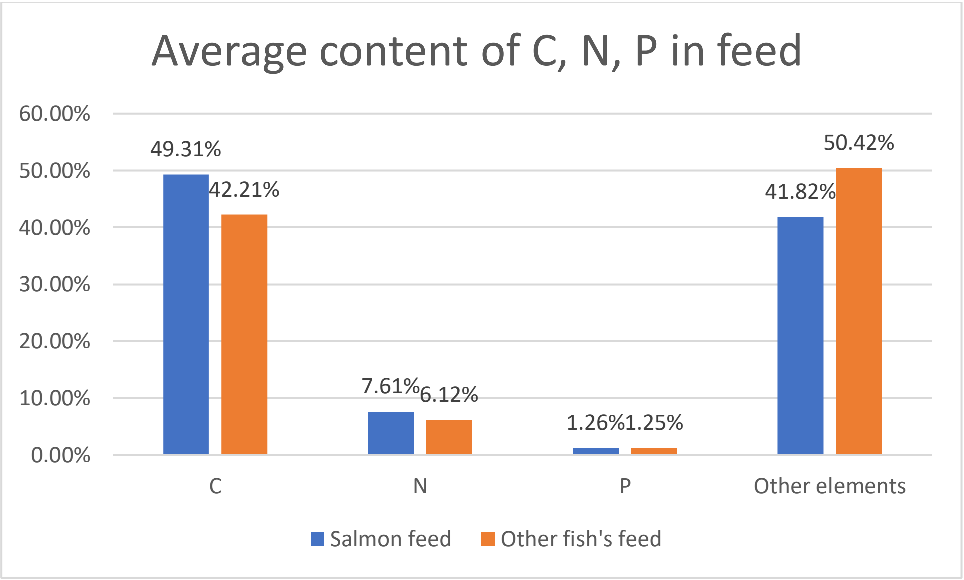


Figure 5：Average content of C, N, P in the feed.

4.1.3 Typical protein, fat and carbohydrate concentration in salmon feed

Protein, fat and caebohydrate are the three essential nutrients that provide the fish with caloric energy. These energy are used to activity and bilogical process. The average content of fat, protein and carbohydrate are 21.5%, 43.8% and 11.1% of feed (WW), respectively (Table 6). However, it chages with the salmon life stages. For fat, it ranges from 17%-30%, the older salmon require more fat content feed. For protein it lies on the range 35 - 55% of the total feed (WW). For carbohydrate, the content is beteen 10 -12% (Table 6).

Table 6: Typical protein, fat and carbohydrates composition in salmon feed.

	Fat	Protein	Carbonhydrate	Reference
	18	47	11	Belghit et al. (2018)
	19	46	10	
	17	46	10	
	22	44	12	
	20	44	12	
	20.7	50.2	*	Bendiksen et al. (2003)
	21.4	50.4	*	
	23.51	35.32	*	Codabaccus et al. (2012)
	23.36	35.51	*	
	23.82	35	*	
	23.74	35.87	*	
	27	42.2	*	Davidson et al. (2016)
	26	42.3	*	
	17	55	10	FAO 1, 2
	20	50	10	
	24	48.1	12	
	30	44	12	
	24	45	12	
Average	21.5	43.8	11.1	
Stand deviation	2.9	5.4	0.9	

Figure 6 shows the typical salmon body composition (Protein, fat and carbohydrate). Protein account for 43.8% of total feed weight, which is the major nutrient in the salmon feed.

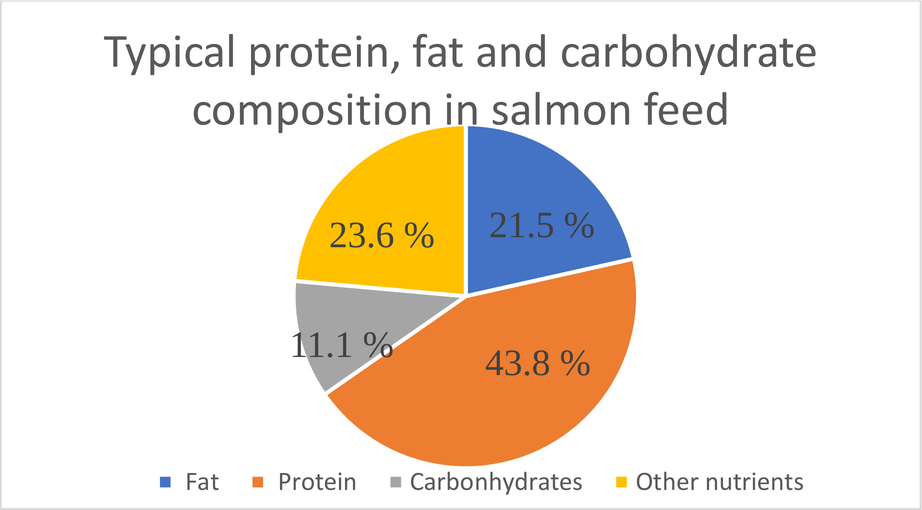


Figure 6：Salmon feed composition (protein, fat and carbohydrates).

4.1.4 Typical energy content of salmon feed

The average content of protein, fat and carbohydrates in salmon feed are 43.8%, 23.4% and 11.1% of the wet weight (Table 6). It is meaning that the average content of them are 438g, 234g and 111g in 1kg fish feed. Then the energy of 1kg salmon feed can be calculated (Table 7).

Table 7: Typical energy content in salmon feed.

	Concertation in feed (g/kg feed)	Energy content (KJ/g)	Energy (MJ/kg feed)	Reference
Protein	438	23.7	9.8	Einen and Roem (1997) Concentration is from table 6
Fat	234	39.5	8.7	
Carbohydrate	111	17.2	1.8	
Total	783	*	20.4	

4.2 Typical farmed salmon composition

4.2.1 Typical salmon dry matter concentration

The salmon whole body composition is required to calculate the nutrients (protein, fat and carbohydrate) retenion rate or elements (C, N and P) retention rate. Many factors will influence the fish body composition, such as the different feed composition, fish size and different life stages of the fish (Reid et al., 2013).

The average salmon dry weight is around 363g/kg salmon from different literature (Table 8). It is quite close to the concluded dry matter value of 340g/kg salmon (Wang et al., 2012).

Table 8: Typical dry weight of salmon.

	DW (of 1kg salmon)	Reference
	360	Chatvijitkul et al. (2017)
	412	Ytrestøyl et al. (2015)
	360	Wang et al. (2013)
	335	Wang et al. (2012)
	316	Lerfall et al. (2016)
	311	Lerfall et al. (2016)
	350	Hemre and Sandnes (1999)
	417	Ytrestøyl et al. (2011)
	412	Ytrestøyl et al. (2014)
Average	363	
Standard deviation	41	

4.2.2 Typical C, N and P concentration in salmon and other fishes

The average content of TC, TP, TN in salmon (DW) is around 58.3%, 7.2% and 0.53%, respectively. The composition varies with the different kinds of feed and different life stages of the fish. The literature puts it in the following range TC (54-63.5%), TP (6.2-8.8%), TN (0.49-1.11%) (Table 9).

Table 9: Typical C, N, P content in salmon.

	C (% DW)	N (% DW)	P (% DW)	reference
	57.4-63.5	6.2-8.8	0.49-0.89	Wang et al. (2013)
	60,6	8.22	1,11	Chatvijitkul et al. (2017)
	54			Strain and Hargrave (2005)
		6.48		Ytrestøyl et al. (2011)
		6.80		Ytrestøyl et al. (2014)
			0.40	Shearer et al. (1994)
			0.48	Shearer et al. (1994)
			0.52	Shearer et al. (1994)
			0.47	Lyle and Elliott (1998)
			0.47	Lyle and Elliott (1998)
			0.45	Lyle and Elliott (1998)
			0.39	Talbot et al. (1986)
			0.58	Talbot et al. (1986)
			0.45	Talbot et al. (1986)
			0.37	Ebel et al. (2015)
			0.54	Ebel et al. (2015)
			0.63	Ebel et al. (2015)
Average	58.3	7.17	0.53	
Standard deviation	3.77	0.75	0.18	

Table 10 shows the C, N and P content in other fish species. The concentration of elemtns various among different species. Catfish has very high C content, which is around 61%. The P content of tilapia is very high, reaching 3.02% of dry weight. Nitrogen content is relatively salmilar among them.

Table 10: Typical C, N, P content in other fish.

Species	C (% DW)	N (% DW)	P (% DW)	reference
Grass carp	47.52 ± 2.57	9.40 ± 0.73	2.01 ± 0.08	Guo et al. (2018)
Common carp	47.11 ± 1.78	9.39 ± 0.63	1.87 ± 0.16	Guo et al. (2018)
Tilapia	50.03 ± 1.47	8.11 ± 0.47	3.17 ± 0.19	Guo et al. (2018)
Channel catfish	61	9.67	2.51	Chatvijitkul et al. (2017)
Tilapia	44.3	8.49	3.02	Chatvijitkul et al. (2017)
Rainbow trout	46.81	7.87	1.06	Chatvijitkul et al. (2017)
Whiteleg shrim	39.24	9.90	1,10	Chatvijitkul et al. (2017)
Average	49.37	7.84	1.73	
Standard deviation	6.8	0.77	0.93	

Figuew 7 shows the average body composition of salmon and other fish species. Altantic salmon has the highest C proportion of the dry weight comparing with all other fish species.

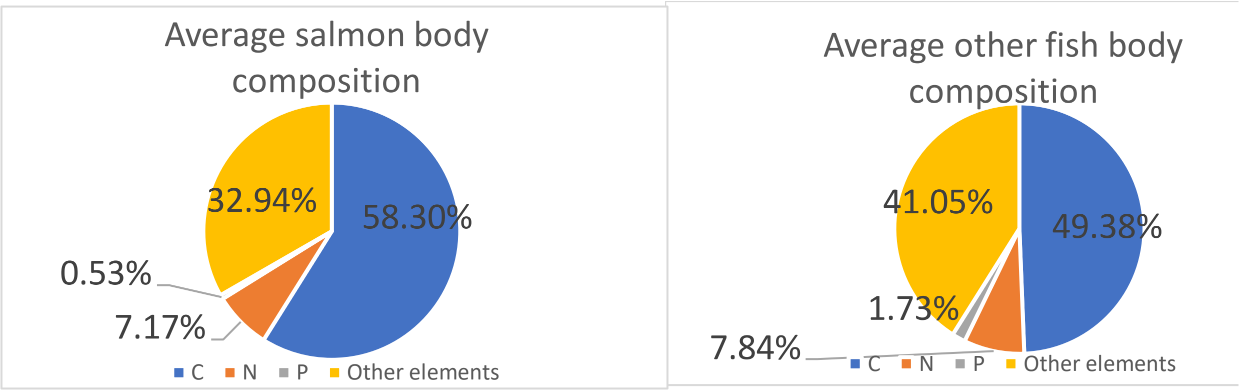


Figure 7：Average salmon body composition (left) and other fish species' body composition (right).

Comparing with the other fish species, salmon has higher values of TC, lower values of TP and similar values of TN (Figure 8).

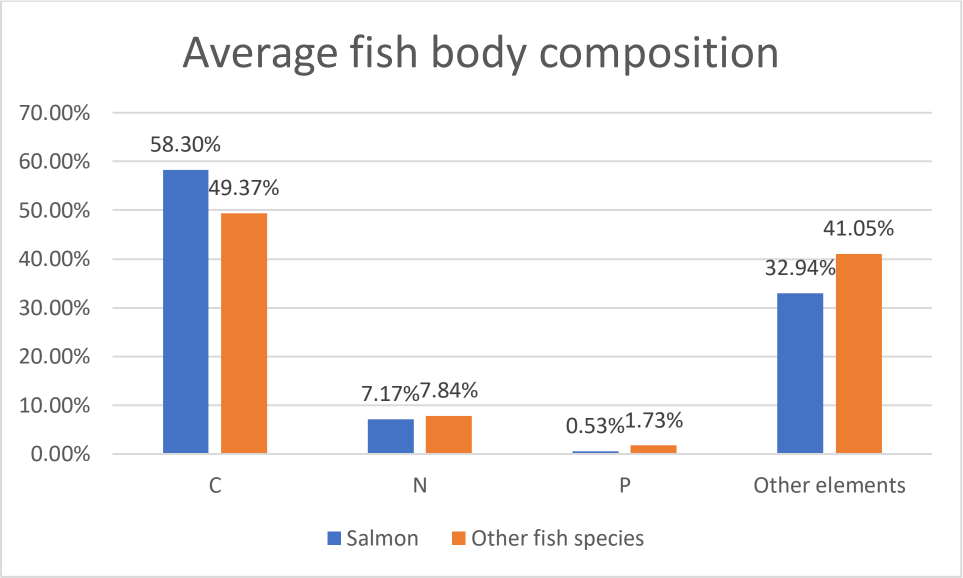


Figure 8：Average content of carbon, nitrogen, phosphorus in fish.

4.2.3 Typical protein, fat and carbohydrate concentration in salmon

In salmon, the average protein, fat and carbohydrate content is 17.5%, 19.9% and 0.88%, respectively (Table 11). Ytrestøyl et al. (2014) concluded the content of protein are 17.5% and 18% in 2010 and 2012, the fat content are 22% and 21% in these two years, which is quite similar to the values found in the literature.

Table 11: Typical protein, fat and carbohydrates composition in salmon.

	Protein (% WW)	Fat (% WW)	Carbonhydrate (% WW)	Reference
	18	16.7		Einen and Roem (1997)
	18.2	17.3		Einen and Roem (1997)
			0·1–2·4	Berg and Bremset (1998)
			<0.5	Wik et al. (2009)
	16.9	22.4		Ytrestøyl et al. (2011)
	17.5	21.3		Ytrestøyl et al. (2014)
	17	22		Ytrestøyl et al. (2014)
Average	17.5	19.9	<0.875	
Stand deviation	0.5	2.4	0.38	

4.2.4 Typical energy content of salmon

The average protein, fat and carbohydrates content in salmon (WW) are 17.5 %, 19.9% and 0.875%, respectively (Table 11). It means the Protein, fat and carbohydrate content in 1 kg salmon are 175g, 199g and 8.75g, respectively. The result of the salmon energy content is 12.2 MJ/Kg.

Table 12: Typical energy content in salmon.

	Concertation in feed (g/kg salmon)	Energy content (KJ/g)	Energy (MJ/kg feed)	Reference
Protein	175	23.7	4.1	Concentration is from Table 11 Einen and Roem (1997)
Fat	199	39.5	7.9	Concentration is from Table 11 Einen and Roem (1997)
Carbohydrate	8.75	17.2	0.2	Concentration is from Table 11 Einen and Roem (1997)
Total	382.75	*	12.2	Concentration is from Table 11 Einen and Roem (1997)

4.3 Retention of element, nutrients and energy in farmed salmon—based on the calculation

Nutrients retention rate is always used to estimate the efficiency of the food production system. The rate means the proportion of the nutrients and energy that is retained in the animal product (Ytrestøyl et al., 2015). The amount (%) of elements, nutrients and energy retained in salmon from feed can be calculated by equation below (Ytrestøyl et al., 2014).

Equation 1: Elements/Nutrients/ energy retention (%)

Elements/Nutrients/ energy retention (%) = (Amount of elements or nutrients or energy retained in salmon) / (Amount of elements or nutrients or energy in feed) *100

The calculation is based on the typical salmon feed composition and typical salmon composition. The retention rate for salmon farming production is shown in table 13. Assuming the FCR is 1.

Table 13: Retention (%) of elements, nutrients and energy in salmon production.

	g/kg feed intake (WW)	g/kg salmon (WW)	Retention in salmon (%)	Reference
Dry matter	946	364.0	38	Concentrations are from Table 3 and 8
Carbon	466.5	212,2	45	Concentrations are from Table 4 and 9
Nitrogen	72.0	26.1	36	Concentrations are from Table 4 and 9
Phosphorus	11.9	1.9	16	Concentrations are from Table 4 and 9
Protein	438.2	175	40	Concentrations are from Table 6 and 11
Fat	226.6	199.0	93	Concentrations are from Table 6 and 11
Carbohydrate	111	8.8	8	Concentrations are from Table 6 and 11
Energy	20.3	12.2	60	Concentrations are from Table 7 and 12

4.4 The retention of nutrients in the literature

Previous research and reports have given some values for different nutrients and element retention rate. The table 14 below shows the retention rate in different literature. The main source is the Nofima reports about the Norwegian farmed salmon production in 2009, 2010, 2012 and 2013.

In the literature, the C, N and P retention rate in salmon farming production are ranged 38-50%, 36.5-47.1% and 20.42-38.59%, respectively. For nutrients, fat retention is highest, from 50.86-64.11%. Protein retention rate is lower, between 23.85-38%. Sun et al. (2016) concluded that the retention rate is influenced by the feed rate and feeding frequency.

However, there is no available values about carbohydrate retention rate in these literatures. The reason is partly because of the lack of the data from analyses (Ytrestøyl et al., 2011).

Table 14: The retention of nutrients for salmon –based on literature values.

	Retained in fish (%)	Reference
C	38	Wang et al. (2013)
	30	Wang et al. (2012)
	50	Yogev et al. (2017)
N	36.50 ± 1.94 to 47.08 ± 5.23	Sun et al. (2016)
	43	Wang et al. (2013)
	38	Wang et al. (2012)
P	20.42 ± 8.05 to 38.59 ± 2.80	Sun et al. (2016)
	24	Wang et al. (2013)
	30	Wang et al. (2012)
	27	Ytrestøyl et al. (2011)
	30	Ytrestøyl et al. (2014)
	27	Ytrestøyl et al. (2014)
	29	Ytrestøyl et al. (2015)
	37	Mente et al. (2006)
Protein	23.85 ± 0.34 to 32.03 ± 0.78	Sun et al. (2016)
	38	Ytrestøyl et al. (2015)
	33	Ytrestøyl et al. (2014)
	34	Ytrestøyl et al. (2014)
Fat	50.86 ± 1.13 to 64.11 ± 2.55	Sun et al. (2016)
	52	Ytrestøyl et al. (2011)
	51	Ytrestøyl et al. (2014)
	51	Ytrestøyl et al. (2015)
Energy	40	Ytrestøyl et al. (2015)
	45	Ytrestøyl et al. (2014)
	37	Ytrestøyl et al. (2014)
	72.40 ± 0.45 to 82.69 ± 0.62	Sun et al. (2016)
Dry matter	43.93	Ytrestøyl et al. (2015)
	44.65	Ytrestøyl et al. (2011)

4.5 Oxygen requirement for feed oxidation

One can find what is respired or excreted from the fish by taking the difference between what fish digest and what is retained in the fish body (Reid et al., 2013). Once the respiratory quotients and the concentration of fat, protein and carbohydrates is known, the oxygen requirement can be calculated.

Oxygen requirement can also be calculated by respiratory quotient (RQ) which is the sum of the oxygen needed per CO2 produced by metabolism of nutrients. The RQ for protein, fat and carbohydrate are 0.95, 0.7 and 1, respectively (Reid et al., 2013). The average carbon content in protein, fat and carbohydrate are 51%, 75,7% and 40.7%, respectively (Table 15).

Table 15: Carbon content in protein, fat and carbohydrates.

	C content (% nutrients)	Reference
Protein	53	Chatvijitkul et al. (2017)
	50	Craig et al. (2017)
	50	Strain and Hargrave (2005)
Average C content in protein	51	*
Fat	77.2	Chatvijitkul et al. (2017)
	70	Strain and Hargrave (2005)
	80	Reid et al. (2013)
Average C content in fat	75.7	*
Carbohydrates	40	Chatvijitkul et al. (2017)
	40	Strain and Hargrave (2005)
	42	Reid et al. (2013)
Average C content in carbohydrates	40.7	*

The oxygen demand for salmon is 533.7g/kg feed based on the calculation (table 16).

Table 16: Oxygen demand for fish.

	Protein	Fat	Carbohydrate	Total	Reference
Content in feed (g/Kg feed)	438	215	111	764	Content from table 6
Retained in fish (g/Kg feed)	175	199	8.8	*	Table 13
Contnt used for Respiration/excretion (g/Kg feed)	263.1	16	102.1	369.5	Reid et al. (2013)
C content in nutrients (%)	51	75.7	40.7	*	Table 15
respirated C contrnt in nutrients (mol)	11.2	1.0	3.5	15.7	C: 12g/mol
RQ	0.95	0.7	1	*	Reid et al. (2013)
Oxygen reqirement (g/kg feed)	376.6	46.1	111.0	533.7	Reid et al. (2013)

5. Discussion

5.1 Retention rate of different substrates

Previous research gives similar values for the retention rates of P, N, C and dry matter as the ones given in this thesis Table 14.

However, the calculated fat retention rate of 93% is much higher than the literature values. The reason is partly because some fat is produced from non-fat precursors (Ytrestøyl et al., 2011). Fat is not only ingested from feed but can also be synthesized from carbohydrates (ter Horst and Serlie, 2017). However, the calculations in this thesis are based on the assumption that all the fat gain in salmon is from the salmon feed.

The previous studies put the energy retetion rate in a wide range: 37%, 40%, 45% and 72.40 ± 0.45 to 82.69 ± 0.62% (Ying et al., 2015, Ytrestøyl et al., 2014, Ytrestøyl et al., 2011, Sun et al., 2016). Sun et al. (2016) stated that different feeding rate and feeding frequency will lead to different energy retention rate, with higher feeding frequencies giving a higher energy retention rate. Besides, the different energy content in feed and fish culture density might also influence the energy retention rate, causing some of these variations.

The literature does not include the retention rate of carbohydrate in the overview of the nutrients flow. Part of the reason is the lack of data (Ytrestøyl et al., 2014). The value of the carbohydrate retention rate given in this thesis is most likely highly innacurate as well. This is due to the fact that carbohydrates are quicly metabolized, leaving very little in the fish body. The calculations are based on an equation that does not account for metabolism of carbohydrates. Hence, the real value is most likely higher than the calculated one.

The calculated energy content of salmon feed (20.8 MJ/Kg) is very similar to the energy content in many other literature so it is most likely right. The calcuted salmon energy content (12.2 MJ/Kg) in this study is similar to the value that Ytrestøyl et al. (2014) gave (12.6 MJ/Kg). Jonsson and Jonsson (2003) concluded that the energy content of the salmon will change with differen life stages because of the different body forms. In addition, he sataed sexs of salmon will also leads to the different energy content.

The calculated oxygen demand is higher than the literature value of 455.29±86.24 g/ kg growth (Reid et al., 2013). A possible reason for this is that different feed composition will lead to different oxygen requirement. The feed that the calculations are based on, might differ from the feed used by Reid et al. (2013), leading to a higher oxygen demand.

5.2 Water treatment in RAS system

The elements (C, N and P) and nutrients (protein, fat and carbohydrate) that are not retained in the fish, will be released into the water. This will influence the water quality in the tank. As such, water treatmet will be very important in order to keep the water conditions optimal.

5.2.1 Particle removal

The calculations show that the dry matter retention rate is 38%. This means that 62% is released into the water. Solids (practicles and suspended solids) including feces, fine feed, uneaten feed and sloughed biofilm, should be removed from the culture system as soon as possible, otherwise the water quality in the culture tank will deteriorate quickly (Badiola et al., 2012). A lot of methods are used to remove the solids in water, such as the gravitational method, by filtration and by screening process (Piedrahita et al., 1996).

For example, drum filters are widely used in aquaculture, where the solids are filtered through a micro-screen (Dolan et al., 2013). A foam filter can also be used to remove the small particles (Cripps and Bergheim, 2000). It is based on the difference in the affnities of components in a gas interface of a foam.The design of a foam fractionator aims to maximize air surface area and dwell time. The bubble should be as small as possible as they have a relatively larger surface area and they raise slower through the water column. For certain organic compounds, such as protein, fat, carbohydrate and amino acids, foam filtration can remove them (Lockwood et al., 1997).

5.2.2 TAN removal

The retention rate of N was calculated to be 36%, meaning that 64% of the nitrogen in the feed is released into the water. Biofiltration is commonly used to remove nitrogen in RAS systems. The majority of the biofilters are designed to facilitate the growth of the nitrifying bacteria, which oxidize ammonia to nitrite and nitrate. By doing this, the ammonia levels can be kept low, thus preventing the concentration form reaching a point that would be toxic for the fish (van Rijn and Rivera, 1990).

5.2.3 Aeration, oxygenation and degassing

The calculation showed that the oxygen demand was 533.7g/kg feed. If the oxygen levels get to low, this will reduce fish growth and increase fish mortality (Summerfelt et al., 2001). On the other hand, if the gas content in water is too high (super-saturation), the fish will be likely to suffer from gas bubble disease (Lekang, 2013). To avoid super-saturation of water, and oxygen deficiency, an aerator should be used. In some cases, the water might contain a high concentration of carbon dioxide, which will reduce the pH. These cases require a specially designed aerator for removing the carbon dioxide (Moran, 2010).

5.5.4 pH adjustment

The carbon dioxide from respiration will lower the water pH, which lead to sub-optimal conditions for survival and growth of fish. The pH can be raised by liming materials, such as $CaCO_3$ (Allan and Burnell, 2013).

6. Conclusion and future perspectives

6.1 Typical composition of salmon feed and salmon

Typical dry matter, TC, TN, TP, protein, fat, carbohydrate and energy content in salmon feed and salmon are in the table 17.

The C is the highest content element in both feed and salmon, accounting for almost half of the feed. The P is the lowest content element among these three elements in both feed and salmon.

As for nutrients, protein is the main part of the salmon feed, around 43.8% of the total feed. Followed by fat and carbohydrate. In salmon, the fat content is similar to the protein content (Table 17)

Table 17: The average values of the dry matter, TC, TN, TP, protein, fat, carbohydrate and energy in salmon feed and salmon.

	DW (g/kg)	TC (g/kg)	TN (g/kg)	TP (g/kg)	Protein (g/kg)	Fat (g/kg)	Carbohydrate (g/kg)	Energy (MJ/Kg)
Feed	946.0	466.5	72.0	11.9	438.0	215	111.0	20.8
Salmon	364.0	212.2	26.1	1.9	175.0	199	<8.75	12.2

6.2 Retention rate of elements, nutrients and energy

The retention rate of dry matter, elements (C, N, P), nutrients (protein, fat, carbohydrate) and energy are shown in figure 9.

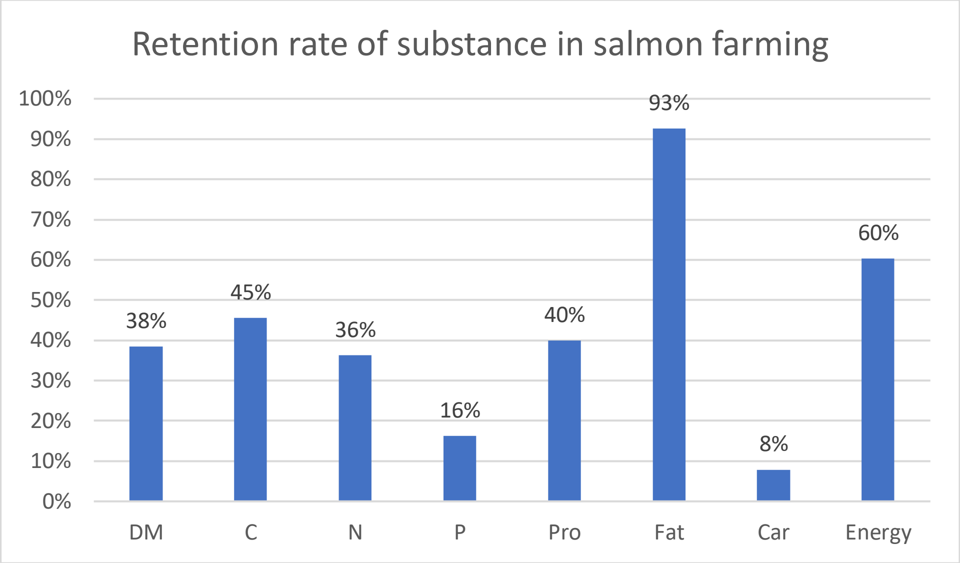


Figure 9：The retention rate of substances in salmon farming.

The fat retention rate is the highest, reaching 93%, while the carbohydrate retention rate is the lowest, around 8%. The dry matter, carbon, nitrogen and protein retention rate are all around 40%.

In addition, the P retention rate is very low compared to the other two elements (C, N), which is only 16%.

The calculated oxygen demand for fish is 533.7g to respirate for 1 kg feed based on the respiratory quotients and the concentration of fat, protein and carbohydrates.

6.3 Necessary water treatment in RAS system

Based on the calculation of elements and nutrients retention rate, the water treatment is necessary in the RAS systems to improve the water quality, such as filter, biofilter, areation, pH adjustment and so on.

In the future, a better understanding of aquaculture feed and water treatment systems is very important for aquaculture industry production. To increase the sustanbility of the aquaculture production, raising the fish feed efficiency and improving water treatment will become more important in RAS system.

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