Introduction to aquaculture: the global and EU context

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22 April 2018

Abstract

This text is part of unit 1 in a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture' made by the AquasSpace project.The text, expanded by slides, introduces the global and European contexts for aquaculture: why it is needed, the main species that are cultivated and the main technologies used. Expansion of aquaculture in the EU requires more space with appropriate assimilative and carrying capacities; spatial planning is needed to resolve conflicts with other users of marine or land space; and the Ecosystem Approach to Aquaculture is needed to ensure environmental, economic and social sustainability for the industry.

This document may be cited as: Ferreira, J.G. and Tett, P. (2018) Introduction to aquaculture: the global and EU context. AquaSpace project (H2020 no 633476), SAMS, Oban, Scotland, 13 pp.

Contents

1 Introduction & Study Guide

This text was written during the H2020 Aquaspace project (2015-2018, contract no. 633476) for a Masters-level course in 'Planning and Managing the Use of Space for Aquaculture'. The course consists of a number of units; this unit provides an introduction to aquaculture in an European Union (EU) and global context, covering

- Global patterns in fisheries and aquaculture production
- Worldwide consumption and future trends
- The EU situation in perspective (trade, production, regulation)
- Species and technologies
- Carrying capacity and sustainability challenges at a global level
- The relevance of the AquaSpace project

The unit comprises the document you are now reading, a set of slides containing additional information, further reading, viewing, and an exercise. For self-study purposes it may be best to proceed in this way: 1, view the slides; 2, read the rest of this text; 3, view the slides again; 4, follow the suggestions in section 8; 5, answer the self-assessment questions (SAQ) in section 9.

Learning outcomes

Upon completion of this unit, the student will:

(i) understand the worldwide distribution of aquaculture production and consumption;

(ii) be able to identify trends in aquaculture development and trade patterns;

(iii) know the main groups and species cultivated for human consumption;

(iv) know the main types of technologies used for cultivation of aquatic species;

(v) have an overview of the requirements for sustainable aquaculture production and of the need for (Marine) Spatial Planning and the Ecosystem Approach (to Aquaculture).

2 Rationale & Overview

According to FAO (2016), "fisheries and aquaculture remain important sources of food, nutrition, income and livelihoods for hundreds of millions of people around the world. World per capita fish supply reached a new record high of 20 kg in 2014, thanks to vigorous growth in aquaculture, which now provides half of all fish for human consumption . . . ". Figure 1 illustrates the evolution of fisheries and aquaculture over the period 2004-2014, and shows that capture fisheries are flatlining, whereas aquaculture is increasing at about 6% per year.

In mid-2013, aquaculture became the dominant source of aquatic (freshwater and marine) protein, a paradigm shift in production that mirrors the emergence of agriculture in the Neolithic period, ten thousand years ago. Most aquaculture takes place in Asia, whereas the European Union

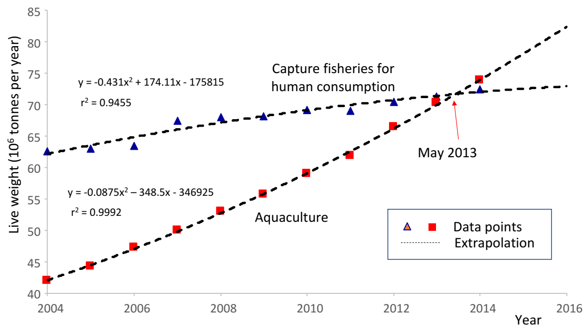

Figure 1: Worldwide trends in capture fisheries and aquaculture, re-worked from FAO (2016) by Lopes et al. (2017).

and the United States import most of the aquatic products that they require. Consumption of fish products in developing countries is growing rapidly as per capita GDP increases and the world population rises towards an expected 9.7 billion in 2050. Total seafood consumption in India and China alone has increased by approximately 20 million tonnes in less than 10 years, and the expected additional consumption by 2025 should increase this number by a further 14 million tonnes (FAO, 2016). This increasing demand creates a critical food security risk for the EU, and a need for a rapid increase in domestic production capacity.

3 Species

3.1 European Union

According to FAO records[1] 116 species of fish, invertebrates and algae were cultivated in salt or fresh water in the European Union in 2013 (Figure 2). The main cultivated fishes are:[2]

Order Cypriniformes - carps and relatives, including the freshwater *Cyprinus carpio*;

Order Perciformes - perch-like fish, including the sea-bass *Dicentrarchus labrax* and the gilthead sea-bream *Sparus aurata*, both of which are better fitted to warmer seas such as the Mediterranean;

Order Salmoniformes - salmonids, mostly cool-water *anadromous* fish, including the Atlantic salmon *salmo salar*, raised in freshwater and grown in salt-water, and the rainbow trout *Oncorhynchus mykiss*, grown in both fresh and salt water.

The main invertebrates cultivated in the EU are marine bivalve molluscs, especially

Order Mytiloida - mussels, including the cool-water blue mussel *Mytilus edulis* and the warm-water Mediterranean mussel *Mytilus galloprovincialis*;

Order Ostreida - oysters, in particular the Pacific oyster *Magallana gigas* formerly called *Crassostrea gigas*.

Order Veneroida - clams - including *Venerupis* (formerly *Ruditapes) philippinarum*, the Manila clam

This list is not exhaustive. Elsewhere in the world, other invertebrates, and seaweeds, make larger contributions than they do to EU production.

[1] FAO Fisheries Global Information System.

[2] We have used WoRMS - World Register of Marine Species for information on Orders and on the names of species.

Species	Scientific name	Production in 2013 (t)	% of total	Cumulative % of total	Environment	Group
Mediterranean mussel	*Mytilis galloprovincialis*	276,817	21.64%	21.64%	Marine	Shellfish
Rainbow trout	*Oncorhynchus mykiss*	178,265	13.93%	35.57%	Brackish and Freshwater	Fish
Blue mussel	*Mytilus edulis*	163,958	12.82%	48.38%	Marine	Shellfish
Atlantic salmon	*Salmo salar*	163,631	12.79%	61.17%	Marine	Fish
Gilthead seabream	*Sparus aurata*	109,030	8.52%	69.70%	Marine	Fish
Pacific cupped oyster	*Crassostrea gigas*	89,328	6.98%	76.68%	Marine	Shellfish
European seabass	*Dicentrarchus labrax*	78,259	6.12%	82.79%	Marine	Fish
Common carp	*Cyprinus carpio*	69,560	5.44%	88.23%	Freshwater	Fish
Brown seaweeds	*Phaeophyceae*	40,042	3.13%	91.36%	Marine	Algae
Japanese carpet shell	*Ruditapes philippinarum*	31,933	2.50%	93.86%	Marine	Shellfish
Turbot	*Psetta maxima*	9,833	0.77%	94.63%	Marine	Fish
Marine fishes nei	*Osteichthyes*	7,451	0.58%	95.21%	Marine	Fish
North African catfish	*Clarias gariepinus*	4,643	0.36%	95.57%	Freshwater	Fish
Bighead carp	*Hypophthalmichthys nobilis*	4,190	0.33%	95.90%	Freshwater	Fish
Grooved carpet shell	*Ruditapes decussatus*	4,129	0.32%	96.22%	Brackish and Marine	Shellfish
European eel	*Anguilla anguilla*	4,017	0.31%	96.53%	Brackish and freshwater	Eel
Chars nei	*Salvelinus spp*	3,931	0.31%	96.84%	Freshwater	Fish
Silver carp	*Hypophthalmichthys molitrix*	3,786	0.30%	97.14%	Freshwater	Fish
Sea trout	*Salmo trutta*	3,454	0.27%	97.41%	Freshwater and Marine	Fish
Atlantic bluefin tuna	*Thunnus thynnus*	2,345	0.18%	97.59%	Marine	Fish
Other (n = 96)		30,816	2.41%	100.00%	All	All
Total		1,279,417				
		By groups				
Fish		661,365				
Shellfish		573,353				
Algae		40,393				
Eels		4,017				
Other		288				

Figure 2: List of top 20 species, plus aggregates for others, cultivated in the EU28 in 2013. Data from FAO FGIS, analysed by O'Hagan et al. (2017)

3.2 Salmonids in non-EU Europe

Almost all the marine cultivation of (Atlantic) salmon in the EU takes place in the Britain and Ireland, totalling in 2013 about 173 thousand tonnes production. This, however, is dwarfed by Norwegian production, 1,168 thousand tonnes in the same year, 81% of the European total (table 1).

Table 1: Salmonid production in Europe during 2013. BW = brackish water; FW = freshwater; M = marine; 'salmon' is *Salmo salar*; 'trout' is *Oncorhynchus mykiss*, rainbow trout; 'sea trout' is *Salmo trutta*. Subtotals shown for most important producers. Percentages relate to Europe totals. The Faroe Islands, Iceland and Norway are not part of the EU28. Data from FGIS.

where	Europe	EU28	%
salmon (M,BW)	1,442,300	172,659	12%
.. Norway	1,168,324		81%
.. UK		163,512	11%
.. Faroes	75,821		5%
trout (FW)	183,747	154,551	84%
.. Italy		35,059	19%
.. France		30,818	17%
trout (BW/M)	101,144	29,607	29%
.. Norway	71,449		71%
.. Denmark		13840	14%
sea trout (FW,M)	2,742	2,522	92%
all	1,730,091	359,475	21%
	world		
all	3,187,262		

Norway also dominates marine production of rainbow trout; only in freshwater production does the EU28 prevail. Adding Norwegian and Faroes production of salmonids, and other non-EU European aquaculture, to the EU28 total of 1.3 Mt, more than doubles that total to 2.7 Mt.

3.3 Rest of the World

Although European (as opposed to EU28) salmonid production is about half of the global total for these fish, in all other respects European aquacultural output is small compared with the world total of 97 million tonnes in 2013; a comparison of the data in Figure 2 with that for China (Table 2) is instructive. Apart from total amounts, a particular difference is that aquatic plants, mainly seaweeds, constitute 0.04 Mt in Europe, 13.5 Mt in China and about 26 Mt in Asia as a whole.

4 Technologies

Farming fish in freshwater is a long-established technology. In China and Europe the practice of keeping carp in ponds, often enriched with vegetable matter, dates back several thousand years. Starting in the 19th Century, biologists learned how to breed salmonids, initially for restocking rivers. The farming of salmon in sea-cages has its origins in the rearing of young salmon in freshwater hatcheries in order to restock the capture and recreational fisheries in rivers.The development of aquacultural technology has accelerated during the last half century, in three main fields:

recruitment - the source of the farmed

Table 2: Aquaculture production in China during 2013. BW = brackish water; FW = freshwater; M = marine. Data from FGIS. Amounts in milions of tonnes (Mt); only harvests > 1 Mt are shown. Marine 'aquatic plants' are mainly seaweeds.

Land Area	Env	organisms	Mt
China	BW	crustaceans	1.23
	FW	crustaceans	2.43
	FW	FW fish	24.47
	M	aquatic plants	13.50
	M	M fish	1.12
	M	molluscs	12.73
China	all	all	57.11
Asia	all	all	89.38
World	all	all	97.05

organisms (from nature or from hatcheries), and the breeding of improved strains for cultivation;

containment - how the farmed organisms are held (in tanks, nets, on the seabed), and how much they are exposed to the natural environment;

feed - how the farmed organisms are fed, or obtain their food or (in the case of algae), inorganic nutrients.

Here are few examples:

mussels in Carlingford Lough, Ireland - blue mussel 'seed'[3] is collected by trawling from shallow seabed around Ireland (Anonymous, 2008), planted in leased areas of the sea-bed in the lough to feed on natural phytoplankton and particulate organic matter, which they filter from water currents; they are finally harvested by dredging;

mussels in the Adriatic, Italy - Mediterranean mussels are grown in netting 'lanterns' either attached to poles in the sea-bed or suspended from floating long-lines, feeding on natural phytoplankton etc;

salmon in Argyll, Scotland - young Atlantic salmon (smolts) are raised in freshwater hatcheries, transferred to floating net-pens in sheltered sea-water lochs (small fjords), where they are fed on pelleted diet made from mixed fish and vegetable matter;

carp in Békécs County, Hungary - shallow freshwater ponds are fertilised to stimulate benthic production as food for carp; young fish are reared in an enclosed, hatchery with some recycling of the freshwater;

mixed species in Sanggou Bay, China - mixed cultivation of seaweed (suspended from floating long-lines), molluscs (in netting lanterns), and fish in net-pens.

Mussel farming in Carlingford lough relies on nature as a source of both seed and feed; it is aquaculture only because the shellfish in the leased areas are treated as property once they have been laid. Lantern-contained mussels exposed to flowing water (as in the Adriatic case) grow faster and can be harvested more efficiently, but

[3] Mussel eggs hatch to produce planktonic larvae, which after some days begin to develope shells and to settle on the sea-bed, producing the 'seed'.

operating costs are greater. The fish in the Scottish and Hungarian case studies are grown under controlled conditions, especially in their hatcheries, but are subject to conditions in the water flowing through the net-pens or contained in the the ponds; the salmon receive a more controlled diet than the carp. The extreme of technological development and growth control is reached in *Recirculating Aquaculture Systems* (RAS: Appendix A), currently only widely used in freshwater hatcheries. Finally, the Sanggou Bay case is an example of *Integrated MultiTrophic Aquaculture* (IMTA), in which waste from fish and molluscs can provide some of the nutrients needed by the seaweeds. The term 'Integrated' implies that this is done by design.

5 Sustainable Aquaculture

Aquaculture interacts with its environment. Here are a few examples of what the environment can provide to aquaculture:

ambient conditions - for example, of flow of water of adequate oxygen content and optimum temperature and salinity for fish growth;

food supply - for example, a continuously replenished supply of phytoplankton for filter-feeding shellfish;

harmful plankton - for example, certain pelagic micro-algae can harm farmed fish or intoxicate shellfish making them unsafe to eat (Davidson et al., 2011).

And here are a few examples of aquacultural impact on the aquatic environment (Tett et al., 2018).

release of organic and nutrient waste by fish, potentially leading to the smothering of sea-bed communities of organisms and to *eutrophication*;

environmental pollution by chemicals released from farm structures or used to treat farmed animals;

spreading disease from farmed organisms to those in other farms or to wild relatives of the farmed organisms.

Eutrophication (Ferreira et al., 2011) is

> "a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of organisms; and water quality degradation"

and it is possible that discharges of nutrients or organic waste by aquaculture might result in so much disturbance to the balance of organisms in marine ecosystems that these systems reconfigure to a new state, damaging biodiversity and the provision of ecosystem services. Two key ideas are:

assimilative capacity the amount of waste that an ecosystem can absorb without significant damage to its health (Tett et al., 2011);

carrying capacity the amount of harvestable biomass of one or more species that can be obtained through aquaculture, while maintaining appropriate ecological balance within the natural system, and respecting social values of stakeholders (Ross et al., 2013).

6 Expanding EU Aquaculture

Currently, only about 10% of the fish products consumed in the EU28 comes from EU aquaculture, with another 30% from EU fisheries. The remaining 60% is imported from third countries. There is little capacity in fish stocks to sustain any increase in capture fisheries, and thus the gap between production and consumption of aquatic products can only be bridged by aquaculture (European Commission, 2013).

The Strategic Guidelines for Aquaculture produced by the European Commission (2013) identified this need to increase aquaculture across Europe, arguing that "European aquaculture offers good quality products, respecting strict environmental sustainability, animal health and consumer protection standards" which should "constitute a major competitive advantage for EU aquaculture" in global competition and thus support employment. Nevertheless, "the EU aquaculture production is stagnating, in contrast with strong growth in other regions of the world."

If EU production is to increase, the area occupied by aquaculture needs to expand. However, to avoid clashes with other uses of the sea (such as fisheries, or nature protection), and to ensure best use of environmental assimilative and carrying capacities for aquaculture, the expansion needs to be planned. This is the case for *Marine Spatial Planning* (MSP), the topic of this module. In addition the expansion needs to be "environmentally, economically and socially sustainable" (European Commission, 2013), which is also the aim of the *Ecosystem Approach to Aquaculture* (EAA) introduced in the next unit.

7 AquaSpace

The EU H2020-funded AquaSpace project (2015-2018) had the goal of finding ways to increased the amount of suitable space available to aquaculture in both marine and freshwater environments, by adopting the Ecosystem Approach to Aquaculture and spatial planning for aquaculture, in the context of EU Directives and policies. The module of which this text is a part was produced as part of AquaSpace and draws extensively on its results.

Although EU aquaculture was the central focus, the project had partners in Norway, North America, China, Australia and New Zealand, because the principles of the EAA and MSP are universally applicable. The case of Chile, which neglected these principles (Buschmann et al., 2009) and suffered a halving of salmonid production due to disease, shows what can happen if insuffcent attention is paid to planning, biosecurity and environmental regulation.

8 Further study

View the accompanying slides, which provide more information about the themes presented in this text, as well as illustrations of species and technologies.

View the short videos on the AquaSpace Library/videos page for introductions to:

- the Ecosystem Approach to Aquaculture;
- shellfish cultivation in the Adriatic and more about the context for marine spatial planning;
- pond cultivation of carp in Hungary;
- net-pen cultivation of salmon in Scotland and some of the planning issues that arise from this.
- use the FAO Fisheries Global Information System to extract[4] a time-series of salmonid production in Chile from 1990 until 2015;

Read one or more of:

- Ferreira et al. (2015) concerning IMTA in south-east Asia;
- Lopes et al. (2017) for a critical look at fish production and consumption data;
- Ellis et al. (2016) concerning the Scottish salmon-farming industry.

[4] Use the tabs 'country', 'species' and 'display' to build a query.

Commentary

Readers may have noticed some small discrepancies between the numbers for salmonids in figure 2 and those in table 1. This might have come about because the values in the two presentations were taken from FGIS in in different years, and the FAO data-base might have been updated in the intervening period. Alternatively, there may have been errors in aggregating production data over countries. Whatever the explanation, these discrepancies could lead a critical reader beyond concern with local errors in arithmetic to to ask, how reliable are the data assembled by the FAO for production in different parts of the world?

We (the authors of this unit) argue that they are the best data currently available, and that small errors do not compromise our story about trends in aquaculture and the comparative position of Europe and the EU28 in the world. Nevertheless, this unit is the first in a Masters-level module, and specifications for this level (for EQF level 7) require critical thinking, as explained in the Module *Introduction and Study Guide*. Thus we have suggested the scientific paper by Lopes et al. (2017) for further reading, because it explores the issue of data reliability. We have qualified our suggestion as optional, because the paper comments on rather than adds to the main story in this unit, and the student might prefer to explore another option. Nevertheless it is only by reading in the scientific literature, and by exploring the data sources, that the student will begin to develop a critical understanding of the material.

9 Self Assessment Questions

The SAQs that follow test your achievement of the learning outcomes and help you think actively about the points raised in this lecture. No answers are given. The (parenthetical) numbers refer to sections.

1. Given likely world population in 2050 and the knowledge that capture fisheries were in 2013-2014 already at (or above) maximum sustainable yield, what global total of aquacultural production will be needed to maintain an annual 20 kg per capita supply of fish and other aquatic products? (2, 3) (Human population in 2013-2014 was about 7.2 billion.)

2. What type of European aquaculture is most successful in the global context? (3)

3. Contrast mussel farming and salmon farming in their requirements for recruitment, containment and feed (4);

4. Explain how pelagic micro-algae (i.e., the phytoplankton) can provide both benefits and risk to shellfish farming (5);

5. Give an example of a harm that aquaculture can do to its aquatic environment (5);

6. Do the FGIS data (see section 8) about Chile support the assertion made in section 7 ?

Appendix

The following text is an edited copy of parts of sections 3.4.2 and 8.4 in Tett et al. (2018), which dealt with salmon farming; it is however applicable to most farmed fish.

A Recirculating Aquaculture Systems

An alternative to releasing farm waste products into the wider environment is to culture the fish within a system in water exchange with the outside environment is restricted and controlled. Typically, these RAS are land based, but analagous closed containment systems are being developed for deployment at sea, such as the Hauge Aqua AS Egget.

Fish in RAS generate waste water that is enriched with both dissolved and particulate waste. RAS therefore need to remove most of these to prevent recycled water becoming harmful to the farmed fish.

The particulate waste from RAS systems is mainly comprised of uneaten feed, cell mass material from biofilters and faeces (Piedrahita, 2003). Removal technologies include swirl separators, mechanical filters, media filters, flocculation or foam fractionators (Cripps and Bergheim, 2000). However regardless of the technology used, there is a need to deal with the resultant aggregated solid waste. Amounts can be considerable, given that the waste may amount to 30% of the feed input (Cripps and Bergheim, 2000; van Rijn, 2013), and so 1000 tonnes of salmon may produce 400 tonnes of solid waste over the course of a production cycle. The first step in this, depending on the separation technology that has been used, is to dewater the waste.

Although some excreted nitrogen, and more excreted phosphorus, are removed by filtering particulate waste, there is also the need to remove dissolved compounds of nitrogen and phosphorus. In the case of nitrogen, excreted mainly as ammonia, there are a number of different technologies available, either to reduce the toxicity of the nitrogen compounds through conversion (nitrification) of ammonia/ammonium to nitrate through the action of bacteria, or the incorporation of the nitrogen into bacterial biomass through the addition of a carbon source (van Rijn et al., 2006). The latter adds to the solid waste for disposal, the former will lead to a build-up of nitrate unless a denitrification step is added.

Bregnballe (2015) notes that even a 'super-intensive' freshwater recirculating system should expect to replace about 10% of its water each day, and comments that "[t]he higher the rate of recirculation the less new water will be used, and the less discharge water will need to be treated. In some cases, no water at all will return to the surrounding environment. However, this kind of 'zero discharge' fish farming is costly to build and the running costs for the waste treatment are significant. ....[even] for zero-discharge fish farming one should also be aware that a certain amount of water exchange is always needed to prevent the accumulation of metals and phosphorous compounds in the system."

In short, a RAS needs its own sewage treatment plant, but, like even the most effective plant used for urban waste water, will have a fluid discharge containing some nutrients and other compounds, and the requirement to get rid of solid waste. The usual regulation of such outputs will presumably apply, but it seems likely that any RAS discharging into the sea will need to make some use of nutrient assimilative capacity.

By retaining wastes, RAS prevent organic and nutrient impacts on the environment. In addition, by isolating cultivated fish from the natural environment, RAS provide security from diseases, infestations and predators and eliminate the risk of harming wild populations of the cultivated fish.

Their potential commercial use in Scotland was reviewed by Murray et al. (2014), who identified their use in hatcheries and increasingly for salmon smolt production. Although freshwater RAS are widely used to rear freshwater fish (see also Bregnballe (2015), there is less experience of salt water systems.

On the basis of Canadian experience (Ayer and Tyedmers, 2009, 2010), the energy costs for pumping and treating large amounts of water are high, about ten times those of net-pen rearing. Unless this energy is supplied from renewable sources, RAS will add to emissions of carbon dioxide. The removal of organic waste results in solid material that needs to be disposed of, and 100% nutrient stripping from recirculated water seems unlikely. RAS wastes will therefore continue to make some demands on environmental assimilative capacity; however, there is uncertainty as to the extent to which this may occur.

Significant marine RAS will either be large floating structures or will occupy extensive land alongside the sea. At least one example of the former is in commercial development in Norway. However, it seems likely that the majority of salmon production in the sea will, for the foreseeable future, continue to take place in net-pens.

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