

Article

A Definition of Aquaculture Intensity Based on Production Functions—The Aquaculture Production Intensity Scale (APIS)

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Abstract: Aquaculture intensity has been used for years as a means to gauge how much production a site makes using three terms: extensive, semi-intensive and intensive aquaculture production systems. The industry has a relatively coordinated understanding of these terms, but an explicit general definition does not seem to exist. This paper aims to use three kinds of production function groups; the input, treatment and output functions to describe and define the terms extensive, semi-intensive and intensive explicitly. This is done with extensive literature review to find the meaning of the terms. The terms are then mapped onto the three production function groups. The resulting framework accomplishes two things. Firstly, it defines extensive, semi-intensive and intensive aquaculture in terms of production functions. Secondly, it creates an eight level scale, the aquaculture production intensity scale (APIS), that provides three levels of extensive systems, two level of semi-intensive systems and three level of intensive systems. APIS allows mapping of all uses of the terms in current literature to an APIS score, though some results might differ from current usage.

Keywords: aquaculture; intensity levels of aquaculture; production view; extensive; semi-intensive; intensive

1. Introduction

Aquaculture practices have a long history, but aquaculture as a food production sector on a global scale is relatively young. The sector is growing steadily and according to FAO [1], the aquaculture sector represented 53% of the total seafood production from fisheries and aquaculture in 2015. Aquaculture production has constantly increased its share in the total fish production, while the annual capture from fisheries has remained almost unchanged since the 1990s [1]. Fish consumption has been growing and the extra demand has been met by the aquaculture sector. The intensification of aquaculture to product more aquatic organisms, without using too many resources nor harming the environment, is one of the main challenges that the industry faces [1]. This article aims to generate a framework that defines intensification from a production perspective.

The starting point of the present investigation is a previously generated map of aquaculture production systems [2] based on a systematic literature review. The purpose of the map is to provide an overview of the production functions needed to farm aquatic organisms in aquaculture systems. The map also gives an overview of the methods used to carry them out and the main parameters used to measure each function. This paper then extends that work into definitions of aquaculture intensity based on what production functions are carried out. The plan is to create a coherent framework that explicitly defines extensive, semi-intensive and intensive aquaculture for all aquatic organisms. The definition is based on production functions, but is still in line with the current use of the terms. The current use of the terms is by no means coherent, rarely defined explicitly, not used in the same manner,

related to different aspects of aquatic species farming and differ between what species of organism is being cultured. This is apparent in most of the literature used in this article with good examples in Ahmed et al. [3], Abraham et al. [4] and Joffre and Bosma [5].

2. Materials and Methods

The work in this paper is based on literature and as such is theoretical in nature. This paper does not try to apply the framework to different kinds of systems, and only defines it. The paper first presents how the literature was found; both for the descriptions of the terms and a search for previous definitions. The literature review builds on papers found in Thomson Reuters' Web of Science™ (ISI) database. The middle step is the description of the meaning of the terms extensive, semi-intensive and intensive based on the literature. The final step constructs a framework that links the terms to the production functions.

2.1. Scope

This article is based on previous literature and that has its limitations. Some previous definitions might not show up in the literature review searches. The scope is limited to only published ISI articles.

2.2. Method

This research follows the process suggested by Handfield and Melnyk [6] when creating theory. They suggest a five step process. The first step uses observation; to both discover the purpose of the system and for description of the topic in question. In the second step empirical generalizations are used to generate mapping of the territory. In steps 3 to 5, theories are presented, theories are tested with hypotheses and finally the theory is extended. This work deals with step 2 of the method [6] and is about identifying and describing key variables. This is done by drawing maps of the territory and answering questions like: what are the key variables and what are the salient/critical themes, patterns or categories [6]? Key variables is the focus of this article and the definition of their meaning. The variable intensity and its levels, *extensive*, *semi-intensive* and *intensive* are the ones we want to define. To do this, several steps were applied:

- (1) Literature review to find how the literature talks about intensity of aquaculture.
- (2) Create definitions by finding what production functions are used in each of the terms.
- (3) Check if the new definitions are in line with previous definitions found in the literature.
- (4) Expand the definitions to a scale that allows more granular descriptions of the intensity of aquaculture systems. This is done by adding levels to each variable based on how aquaculture intensifies its production of product pr. volume of water.

2.3. Literature Search to Find Descriptions of Intensity in Aquaculture

In earlier work the author constructed a functional view of aquaculture production based on literature review [2,7–9]. That literature review searched Web of Science™ to find articles that could have definitions of intensity. The search string was: TS = (aquacultur* AND (input OR output)) and the search gave 144 hits. Abstract review was performed on those 144 papers and the paper selected for full review if it used production relevant approach. Backward literature search was then performed on the selected article. This resulted in 106 papers. Of those, 48 were linked to intensive systems, 11 to semi-intensive and seven to extensive systems. These articles did not necessary define the term but did use it. A total of 45 articles were not linked to intensity, two articles mentioned a 'semi-extensive' system but no explanations were found. Semi-extensive is not included in the maps. Note that some article link to more than one intensity. These articles contributed to the construction of the system map framework and are better explained later in this article. A more complete description can be found in Björndóttir et al. [2].

2.4. Literature Search to Find Previous Definitions

A second literature review was performed to find definitions of aquaculture intensity. Literature searches were carried out in July 2019 using The Web of Science™ to find articles that could have definitions of intensity. The search string was: TS = ((aquacultur* or maricul*) AND ((defin* OR character* OR explana* OR taxonom* OR classifi*) NEAR (Extensive OR (Semi NEAR/1 intensive) OR Intensive))). The search gave 117 hits (3 July 2019) that underwent abstract review. Of those, 49 articles were selected for full review. Definitions or attempts were found in four of these papers.

3. The Production Functions of Aquaculture Systems

One way to look at aquaculture is to find what kind of functions or actions are needed to make such an endeavour work. These function can be grouped into three groups: inputs, treatments and outputs. This approach is the content of previous work in finding them [2], analyzing how they are solved [7,8] and how these solutions interact [9]. These functions can be presented as a map of the production functions in aquaculture production systems. It is called a map as it gives an overview of functions, parameters and methods. The production functions are grouped into three groups: inputs, treatments and outputs. The input functions are the operations needed before the rearing area, what to put into the system. The treatment functions are the operations done on the rearing area, what is continuously being done on the rearing area. The output functions are the operations done after the rearing area, what is being taken out of the system or making sure that escapees do not leave the rearing area. For the purpose of this article we will use a simplified representation of this map as shown in Figure 1. A full version of the production functions map can be seen in Björndóttir et al. [2].

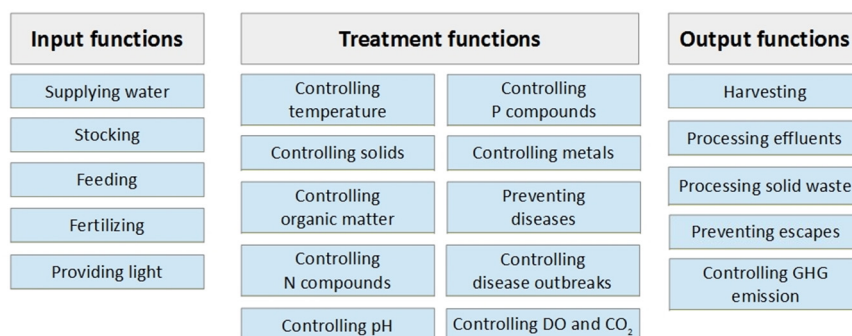


Figure 1. Simplified aquaculture production functions map.

The production functions are linked. The input function of ‘supplying water’ affects all of the treatment functions and three of the output functions (‘processing effluents’, ‘processing solid waste’ and ‘controlling GHG emission’). Simply by supplying more water it is possible to solve all the linked functions. The challenge arrives when one tries to lower water usage (or water is scarce) but still maintain high production rate. For example, in the case of rearing Arctic Char [10], lowering water supply would first require ‘controlling DO and CO₂’ function to be added. It would be Oxygen that is the first threshold and then CO₂. System with no treatments could handle up to 30 kg fish pr. litre/second inflow of water. Adding DO (dissolved oxygen) control would allow masse to be raised to about 100 kg pr. litre/second and adding CO₂ handling would allow up to 400 kg pr. litre/second inflow. The next treatment function would be ‘Controlling N compounds’ to deal with Nitrogen compounds. That would allow up to 800 kg pr. litre/second inflow. The third and fourth functions would be ‘Controlling solids’ and ‘Controlling organic matter’ that would raise the masse even further [10]. To paraphrase: to make 800 kg of fish one could either use 1 litre/second inflow with the treatment functions of ‘controlling DO and CO₂’ and ‘Controlling N compounds’ or use 27 litre/second of inflow.

Aquaculture is the raising of aquatic organisms for the purpose of selling them. This can be done in several ways and with different amount of human interaction. The number of production functions

used indicate the amount of human interaction with the aquaculture system. All aquaculture systems have most of those functions present, the only question is how are they solved.

The foundation for the approach presented here is that these functions can be solve on a continuum, from completely natural to human designed with (daily) operations. For simplification we consider this continuum to have four stages: natural, design by placement, structural design and design with operations. These stages can be explained by looking at the treatment function of controlling DO and CO₂. In a pond with no inlet of water and no aeration this is solved naturally e.g., by transfer of O₂ and CO₂ across the water to air surface. In mariculture, this is solved e.g., by placing the pen strategically where enough flow-through of water is present, a design by placement. In a race-way system, this function can be solved by designing a sequence of raceways with cascading flow between water bodies, a structural design. Finally, in a RAS system, this could be solved e.g., by mechanically aerate the water or by pumping O₂ into it, designed with operations.

This continuum can be visualized and linked to the production function approach, see Figure 2.

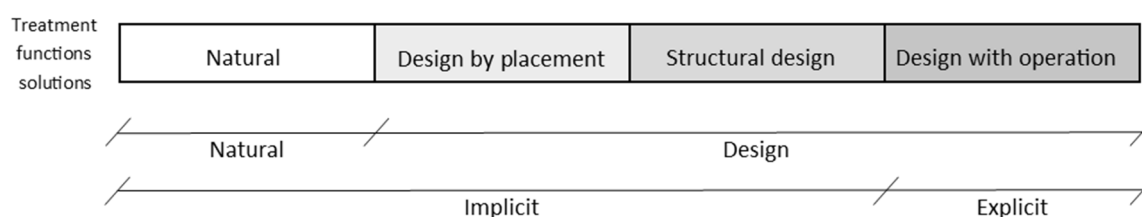


Figure 2. Implicit and explicit treatment function solutions.

A fuzzy line exists between when a designed solution is implicit or explicit. In this paper the following rule of thumb is used: if function requires operations (much more frequent than the lifetime of the design, e.g., daily or near daily) it is explicit. Otherwise it is an implicit design, i.e., design by placement or structural design.

In the production function approach, the function is present if it is explicitly solved, i.e., design with operation on that specific function. Operations that deal with the design itself are not included, like when pens are moved to rest an area.

4. Systems of Different Intensity Levels

The production functions map can be made specific to different levels of production intensity. Using the literature from previous work a description of the terms extensive, semi-intensive and intensive aquaculture is framed. As mentioned earlier, over 60 articles linked the production system to intensity by using one or more of the three terms. These descriptions framed out the meaning of extensive, semi-intensive and intensive aquaculture production systems.

4.1. Extensive Aquaculture Systems

As widely identified in the literature, the most extensive systems are those where there is little or even no human interference. As a consequence, those systems generally produce less than those of more intensity. A common type of an extensive system is where a restricted zone created by a net, cage or some type of a fence is inserted in a larger water body where animals can be cultured inside. Another type can be a pond farm where no additional feeding is used and the ecosystem inside the pond provides feed for the cultured animals [11].

Extensive systems do not seem to have gained much attention judging on the material analyzed for this review. That should not come as a surprise considering the fact that those systems apply a minimum amount of functions. Iwama [12] stated that extensive aquaculture systems resembled the natural environment of the inhabitants without applying supplemental food. Gomiero [13] defined extensive aquaculture as lightly stocked systems where water throughput is not boosted and feed or fertilizer inputs not applied. Edwards and Demaine [14] provided a similar definition and referred to extensive

systems as those depending on natural food sources within the culture unit where feed additional feed inputs are not added intentionally. Nevertheless, extensive systems have been connected to functions such as feeding or fertilizing in the literature [15–17]. This indicates an inconsistency in the definitions about intensity of aquaculture systems.

In accordance with how extensive systems are generally described in the literature, we assume that extensive systems apply the minimum amount of functions required for an aquaculture system to be functional. The map in Figure 3 shows the functions applied in extensive systems. Mandatory functions are marked as ‘required’ while functions that are optional are displayed as ‘optional’. In extensive systems the output function of harvesting is always applied and hence marked ‘required’. The functions of supplying water, stocking, feeding, fertilizing, and preventing escapes need to be applied in some cases. The output function of ‘preventing escapes’ is also sometimes used. Other input and output functions that are not displayed in the map were never linked to extensive systems in the articles reviewed. The same goes for treatment functions that are also excluded from Figure 3.

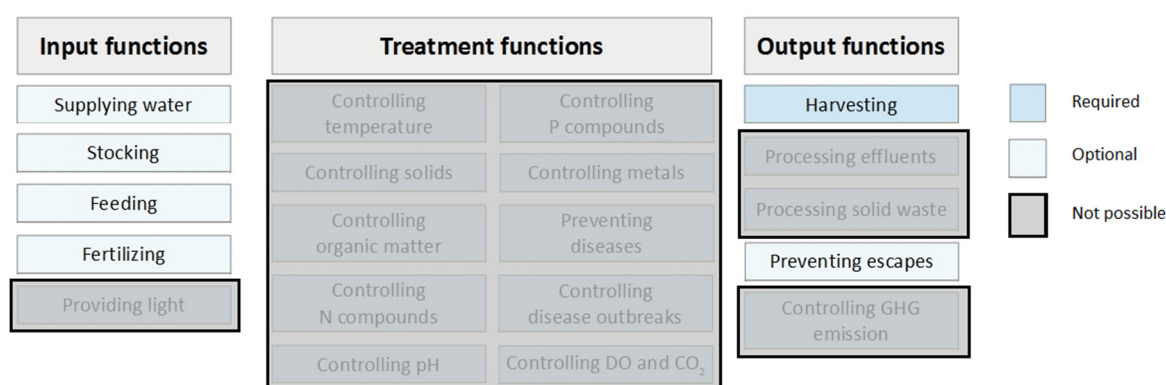


Figure 3. System map describing extensive aquaculture systems.

4.2. Semi-Intensive Aquaculture Systems

Defining what distinguishes semi-intensive systems from extensive or intensive systems is not an easy task. Definitions of semi-intensive systems vary between countries and they do not always consider the same criteria [18]. Lekang [11] described semi-intensive system as a combination of an extensive and an intensive production and mentioned as an example an intensive fry production that is combined with an extensive on-growing rearing area. Semi-intensive systems have also been connected to feed and fertilization dependency. Nilson and Wetengere [19] defined semi-intensive aquaculture systems as a farms where feeding is carried out at least twice per week and fertilizing once per week. Edwards and Demaine [14] followed a similar line and stated that semi-intensive system mainly rely on natural food sources but also supported by supplementary feed or fertilization. They also acknowledged that the intensity of the system is not only correlated with the level of feed or fertilizers brought to the system but also with the level of seed, labour, capital and management.

It seems that mechanical treatment methods are generally not applied [18] in the articles reviewed here. Water exchange seems to be widely used in semi-intensive systems in order to improve water quality [20] as well as chemicals such as lime can be added to disinfect and dry semi-intensive ponds [18,21].

In Figure 4 the map of semi-intensive systems is presented. The only functions that are always carried out in semi-intensive systems are stocking and harvesting along with either feeding or fertilizing (shown as ‘or’ in a box in Figure 4). However, the map clearly shows that there are more optional functions available for semi-intensive systems than for extensive systems. More input and output functions have been added and the treatment functions are no longer excluded and may be applied as required. For the system to be semi-intensive at least one treatment function has to be applied.

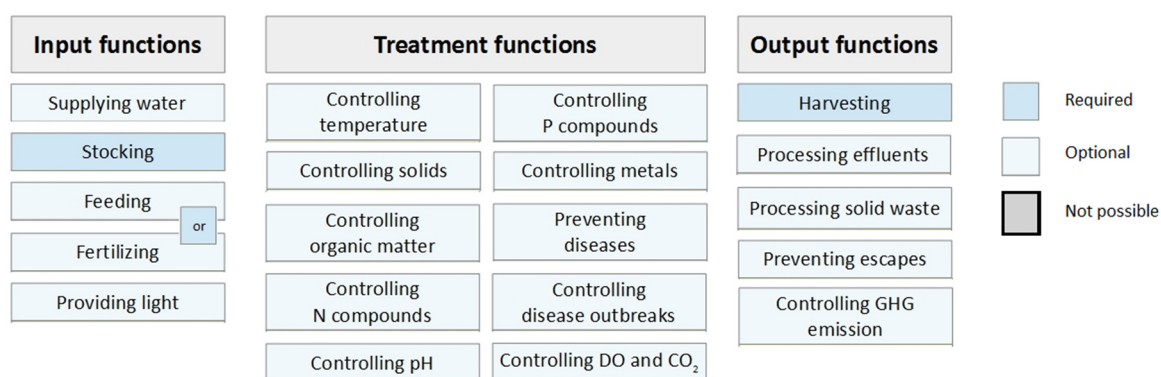


Figure 4. The system map describing semi-intensive aquaculture systems.

4.3. Intensive Aquaculture Systems

In the map describing intensive aquaculture systems the input functions of supplying water, stocking and feeding are always applied while fertilizing and providing light are presented as optional. Intensive systems maintain high stocking levels and high feeding rates to maximize the production. Therefore, we assume that all intensive systems need to apply the treatment functions that focus on maintaining the quality of the water. These system at least control oxygen and carbon dioxide, control solids in both organic and non-organic versions along with controlling N compounds. The functions of preventing diseases and controlling diseases are not applied to maintain water quality. Thus they are presented as optional. All intensive systems apply the harvesting function. Some intensive systems, such as flow-through systems, maintain steady water throughput and not all of them seem to apply the functions of processing effluent water or solid waste. Therefore, those functions are optional. Controlling greenhouse gasses was not frequently related to systems of high intensities and therefore it is assumed that not all intensive systems apply methods to reduce greenhouse gasses emissions. Preventing escapes should be applied for aquaculture systems that are fenced off inside a larger water body. Figure 5 displays the system map for intensive systems.

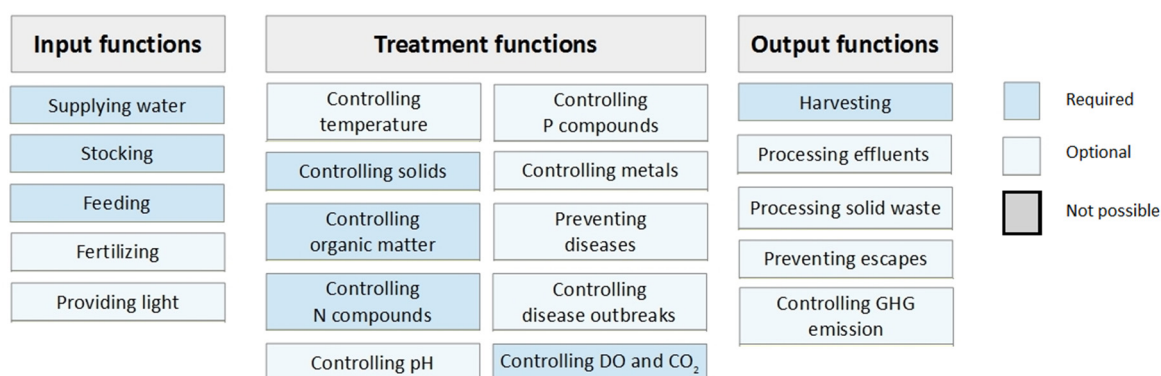


Figure 5. The system map describing intensive aquaculture systems.

5. Definitions of System Intensity Levels in Terms of the Production Functions

The analysis of system intensity levels has revealed that they differ in terms of their application of the production functions. This has provided a foundation to build definitions of the intensity levels in terms of the production functions. Intensity of a system is the kilos of aquatic animals produced per litre of water used. The new definitions are based on the aquaculture production map constructed from the literature review. The definitions are sharpened from the current use as foreseeable changes in technology developments in aquaculture systems, social aspects of aquaculture and environmental regulations will pressure the industry into further industrialization. More systems in the future will

become intensive and will have to deal both with better controlling the inputs, especially water usage and to deal with outputs like effluent water and solid waste. The definitions are as following:

Extensive aquaculture systems are systems that always supply the output function of ‘harvesting’ and have at least one of the input functions or the output function of ‘preventing escapes’. The other input functions apart from ‘providing light’ are optional. Extensive aquaculture systems have no treatment functions.

The extensive definition is the lowest denominator for calling a system aquaculture. Aquaculture system must have human interventions so usually at least stocking and harvesting is needed. The other output functions are not possible here as they indicate much more complex system.

Semi-intensive aquaculture systems are systems that always supply the input function of ‘stocking’, and either ‘feeding’ or ‘fertilizing’ and the output function of ‘harvesting’. The other input and output functions are optional. These systems have at least one treatment function.

These are the minimum requirements for calling a system semi-intensive. These aquaculture systems differ from extensive ones as they allow treatment functions and must include feeding or fertilizing.

Intensive aquaculture systems are systems that always supply the input functions of ‘supplying water’, ‘stocking’ and ‘feeding’, the treatment functions of ‘Controlling DO and CO₂’, ‘Controlling organic matter’, ‘Controlling nitrogen compounds’ and ‘Controlling solids’ and the output function of ‘harvesting’. All other functions are optional.

These are the minimum requirements for calling a system intensive. A semi-intensive system becomes an intensive system when it has all the functions listed in the intensive definitions.

6. Previous Definitions of Aquaculture Systems Intensity

In the full paper review made for this article, the 49 papers were searched for three actual levels of aquaculture intensity. The levels were a definition, a hint towards a definition and no attempt nor hints of definitions. There are only four articles that attempt any kind of definition of aquaculture intensity explicitly in some form. None of these four can be said to be a full definition as they are either incomplete, too specific, linked to specific species or region or blend of all aforementioned.

Abraham et al. [4] try to describe extensive and semi-intensive system with density, water exchange need, use of aeration, water treatment with microbial product and feed usage. The descriptions are not actual definitions nor are they complete. Joffre and Bosma [5] use 13 factors to establish four types of farms: intensive commercial, intensive family farms, extensive brackish water polyculture and rice–shrimp farms. The factors are a blend of production factors, economic factors and social factors. Although the types serve that case well, they are not easily extended to general definitions. Ahmed et al. [3] use catfish farming as an example to classify system into extensive, semi-intensive and intensive. Six inputs or explanatory variables (i.e., farm size, stocking, seed, feed, fertilizer, and labour) and the derived factor yield were assumed to explain the fish production by the economic Cobb-Douglas production function model. The input factors are a blend of production and economic factors. The resulting classification is very case specific and not easily generalized. Valente et al. [22] describe extensive systems based on water parameters (salinity, temperature), density, growth rate and quality parameters. Semi-intensive systems add feeding but are not described in detail. Intensive systems are not described.

There are 16 papers that hint at definitions in several areas: volume/density, feed, water, yield, size and functions. A quick summary is that three articles hint using volume or density as definition [23–25], three use feed [26–28], three use water usage [29–31], two then combine water and feed [32,33], one uses water and density [34] and one uses volume, feed and water [35]. The last three papers use

yield [36], size [37] and functions [38] as bases for their definitions. There are 27 articles with no definitions nor hints on definitions [39–65]. These articles use the intensive/extensive terminology without defining what they mean. Two articles [66,67] were not accessible.

Definitions Compared to Previous Work and Definitions

The new definitions only use the actual production system so all definitions or hints at such that use economic factors or social factors do not compare. Those factor can though often be mapped to production factors. For example, the factors Contracted workers (man/ha) or Ratio family/total labor in Joffre and Bosma [5] can be map to a production function by looking at what workers are doing instead of who is doing it. Most articles use factors in their talk on intensity that are completely in line with the new definitions. Those few factors that are not in line, like social factors can be mapped to a production function. When mapping those descriptions to the definitions one could get different results like a semi-intensive system in the article could become extensive according to the definitions.

A comparison of the descriptions found in the articles and the new definitions are as follows. The paper by Abraham, Ghosh [4] on page 277 defines modified extensive in two ways. First as:

Stocking density 8–18 PL/m², need-based water exchange, aeration by pumping, use of commercial pelleted feed and microbial products, with or without reservoir, water depth 1–2 m.

This uses the input functions of ‘stocking’, ‘supplying water’ and ‘feeding’; the treatment function of ‘controlling DO and CO₂’ and the output functions of ‘harvesting’. If reservoir is present, that is probably the output function of ‘processing effluence’. This would hence be *semi-intensive* according to the new definitions. The second modified extensive is:

Stocking density 4–8 PL/m², need-based water exchange, no aeration, use of locally prepared feed, water depth 1 m.

This uses the input functions of ‘stocking’, ‘supplying water’, ‘feeding’ and the output functions of ‘harvesting’. This would be *extensive* according to the new definitions. The new definitions do not differentiate commercial feed and locally prepared feed; both are the input function of ‘feeding’. The authors [4] also define traditional as:

Stocking density <4 PL/m², no water exchange, no aeration, occasional use of locally prepared feed, water depth 0.75–1 m. Partial stocking and partial harvesting throughout the culture.

Here are present the input functions of ‘stocking’, ‘feeding’ and the output functions of ‘harvesting’. This would be extensive according to the new definitions. The new definitions do not differentiate occasional feeding and feeding. The authors [4] finally define semi-intensive as:

Stocking density >18 PL/m², frequent water exchange, aeration by aerators, use of commercial pelleted feed and microbial products, reservoir for water treatment, water depth 1 m.

In this system the input functions of ‘stocking’, ‘supplying water’ and ‘feeding’; the treatment function of ‘controlling DO and CO₂’ and the output functions of ‘harvesting’ and ‘processing effluence’. This would hence be *semi-intensive* according to the new definitions.

Ahmed et al. [3] describe the aquaculture systems as a black box with inputs. They list five inputs or explanatory variables (i.e., farm size, stocking, feeding, fertilizing and labour) but no talk on what is being done in terms of production functions. The stocking density is the main difference and the authors list extensive farming as low stocking density (average 12,065 fingerling/ha), semi-intensive as intermediate levels of stocking (23,575 fingerling/ha) and intensive production system as high stocking (35,900 fingerling/ha). They mention that most farmers do not exchange water in spite of poor water quality while only a few advanced farmers periodically exchange water. Only a few intensive farmers

use an aerator in their ponds. Using this description, one would map all systems by using the input functions of 'stocking', 'fertilizing', 'feeding' and the output functions of 'harvesting'. All these systems would be *extensive* according to the new definitions as there are no treatment functions.

7. The Aquaculture Production Intensity Scale

It was the purpose of this work to suggest a new way of talking about intensity that describes all variants encountered. The author would like to call this the Aquaculture Production Intensity Scale or APIS. It takes an outset in the previous work of production functions and then maps those to the current use of extensive and intensive terminology, as described in previous sections. The point is to gain more granularity, sharper definition but still adhere to previous terminology. The suggested scale, the APIS has 8 levels, numbered 0 to 7. The difference between levels is explained with production functions and the extensive/intensive logic is then overlaid. The resulting scale or index is presented in Table 1.

A production function is present if it is solved explicitly, as explained earlier. The degree of control over the aquaculture system increases as more functions are solved explicitly. The higher the APIS value the more control is over the system and its rearing area. It is worth noting that the efficiency of the solution is not necessarily connected to how they are solved (design vs. explicit). In Table 2 we present the APIS in more concrete way to allow quicker overview and comparison of levels.

The purpose of APIS is to be able to talk about the aquaculture production system in a clear way. A pond with fish in it where one goes fishing is not aquaculture. The level 0 in APIS could apply to fishing if not for the 'at least one design solution' clause. This means that at least one input, treatment or output function is solved with design by placement or structural design solution of that function. This level 0 in APIS goes beyond the definition for 'extensive' systems. It could be argued that having APIS only based on explicit solutions is a drawback. This is done on purpose to simplify the framework. It would be possible to use all design aspects (placement, structure and explicit) instead of only explicit. The definition would be the same but sites would probably get slightly higher APIS score that way in the lower part of the range, but for a higher APIS score the difference would likely be smaller. This check of the framework foundation can be done in future work.

Intensification of aquaculture is to increase volume of fish produced in regards to water and land use. The APIS framework focuses on getting more granularity to the intensive part of aquaculture systems so it can better describe the intensification process. There exists a threshold sequence of when a production function is needed when reducing water usage. This sequence was presented for the Arctic Char. The sequence might be the same for other species but the value of the threshold probably differs. Future work might include gather these sequences for many species and comparing them to the APIS framework. Another interesting aspect is the correlation between the density of aquatic organism in the rearing area and the APIS index. That could be worked out in detail. It is suspected that increased density follows increased APIS value just like in the Arctic Char example presented earlier.

Note that all treatment functions can be solved with water exchange through supplying water input function. To reduce water exchange, it is possible to either use treatment functions or to increase land use, make system extensive. To reduce both water and land usage but to still increase production the only viable way seems to be to use more treatment functions. The issue of the environment, the ecological footprint of aquaculture and how to increase food production without negative environmental indicators that the increased use of treatment or output functions is imminent. The purpose of this framework is to facilitate coordinated talk on how aquaculture production is done.

Table 1. Aquaculture Production Intensity Scale (APIS) and its levels.

APIS	Functions Involved	Descriptions
0	Only the output functions ‘harvest’ and at least one design solution (placement or structural) of a production function.	Extensive system can use structural or environmental (including placement) designs to solve one or more of treatment functions
1	The output function ‘harvest’ and at least one of the input functions or output function of ‘preventing escapes’. No treatment functions.	
2	At least ‘stocking’, and either ‘feeding’ or ‘fertilizing’ and ‘harvest’, other inputs than ‘providing light’ are optional along with output function of ‘preventing escapes’. No treatment functions.	
3	The input function of ‘stocking’, and either ‘feeding’ or ‘fertilizing’ and the output function of ‘harvesting’. The other input and output functions are optional. These systems have at least one treatment function.	Semi-intensive system can use structural or environmental (including placement) designs to solve one or more of treatment functions
4	The input function of ‘stocking’, and either ‘feeding’ or ‘fertilizing’ and the output function of ‘harvesting’. These systems have at least one of the treatment functions of ‘Controlling DO and CO ₂ ’, ‘Controlling organic matter’, ‘Controlling nitrogen compounds’ and ‘Controlling solids’. The other functions are optional.	
5	The input functions of ‘supplying water’, ‘stocking’ and ‘feeding’, the treatment functions of ‘Controlling DO and CO ₂ ’, ‘Controlling organic matter’, ‘Controlling nitrogen compounds’ and ‘Controlling solids’ and the output function of ‘harvesting’. All other functions are optional.	Intensive systems mostly solve treatment functions explicitly, not through design only.
6	the input functions of ‘supplying water’, ‘stocking’ and ‘feeding’, the treatment functions of ‘Controlling DO and CO ₂ ’, ‘Controlling organic matter’, ‘Controlling nitrogen compounds’ and ‘Controlling solids’ and the output function of ‘harvesting’. At least one of the other output functions is used. All other functions are optional.	
7	the input functions of ‘supplying water’, ‘stocking’ and ‘feeding’, use all of the treatment functions and the output function of ‘harvesting’. At least one of the other output functions is used. All other functions are optional.	

Table 2. Mapping of functions to APIS level (legend: ‘-’ = not possible, x = required, aⁿ = at least one from group n and o = optional).

APIS	Input Functions									Treatment Functions							Output Functions			
	Supplying Water	Stocking	Feeding	Fertilizing	Providing light	Controlling Temperature	Controlling Solids	Controlling DO and CO ₂	Controlling pH	Controlling N Compounds	Controlling Matter	Controlling P Compounds	Controlling Metals	Preventing Diseases	Controlling Disease Outbreaks	Harvesting	Process effluent Water Process Effluent Water	Process solid Waste	Controlling GHG Emission	Preventing Escapes
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-
1	a ¹	a ¹	a ¹	a ¹	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	a ¹
2	o	x	a ¹	a ¹	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	o
3	o	x	a ¹	a ¹	o	a ²	a ²	a ²	a ²	a ²	a ²	a ²	a ²	a ²	a ²	x	o	o	o	o
4	o	x	a ¹	a ¹	o	o	a ²	a ²	o	a ²	a ²	o	o	o	o	x	o	o	o	o
5	x	x	x	o	o	o	x	x	o	x	x	o	o	o	o	x	o	o	o	o
6	x	x	x	o	o	o	x	x	o	x	x	o	o	o	o	x	a ¹	a ¹	a ¹	a ¹
7	x	x	x	o	o	x	x	x	x	x	x	x	x	x	x	x	a ¹	a ¹	a ¹	a ¹

8. Discussion

Defining terms is any researcher's dream. Giving names to things aids in explaining them, helps to talk about them and even promotes them, but giving appropriate names is also surprisingly hard, as it requires that things be explained in detail. Name giving also should serve a purpose. This work is about naming precisely what is being done. Doing so puts pressure on keeping links to other things and assumptions to the minimum. This is one of the reasons why APIS is only based on production function. Resulting states like density, yield pr. volume, environmental impact and elements like water usage, feed management are directly linked to the production functions. Labour, infrastructure, land use, size of sites and other economic factor are not included as they do not directly impact the production system but are consequences of the production functions used. Mapping out all those linkages can now be done in future work. The APIS framework also indicates a path for intensification of aquaculture production sites. This is obviously nothing new but is only given a concrete form here. Further laying out this part is a future work. The technology used to solve the production function has been mapped out in the authors previous work [7–9] but more work could be done on specific species approaches and to generate some sort of 'threshold' approach on what to implement and when. These can then be linked directly with APIS. It is the author's hope that the APIS framework can aid in further industrialisation of aquaculture and help in producing more aquatic organisms of better quality with much less environmental impact than current systems.

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