



WWF

REPORT

JUNE

2016



Low Footprint Seafood in the Coral Triangle

Footprint Monitoring Approaches
and Sustainability Criteria

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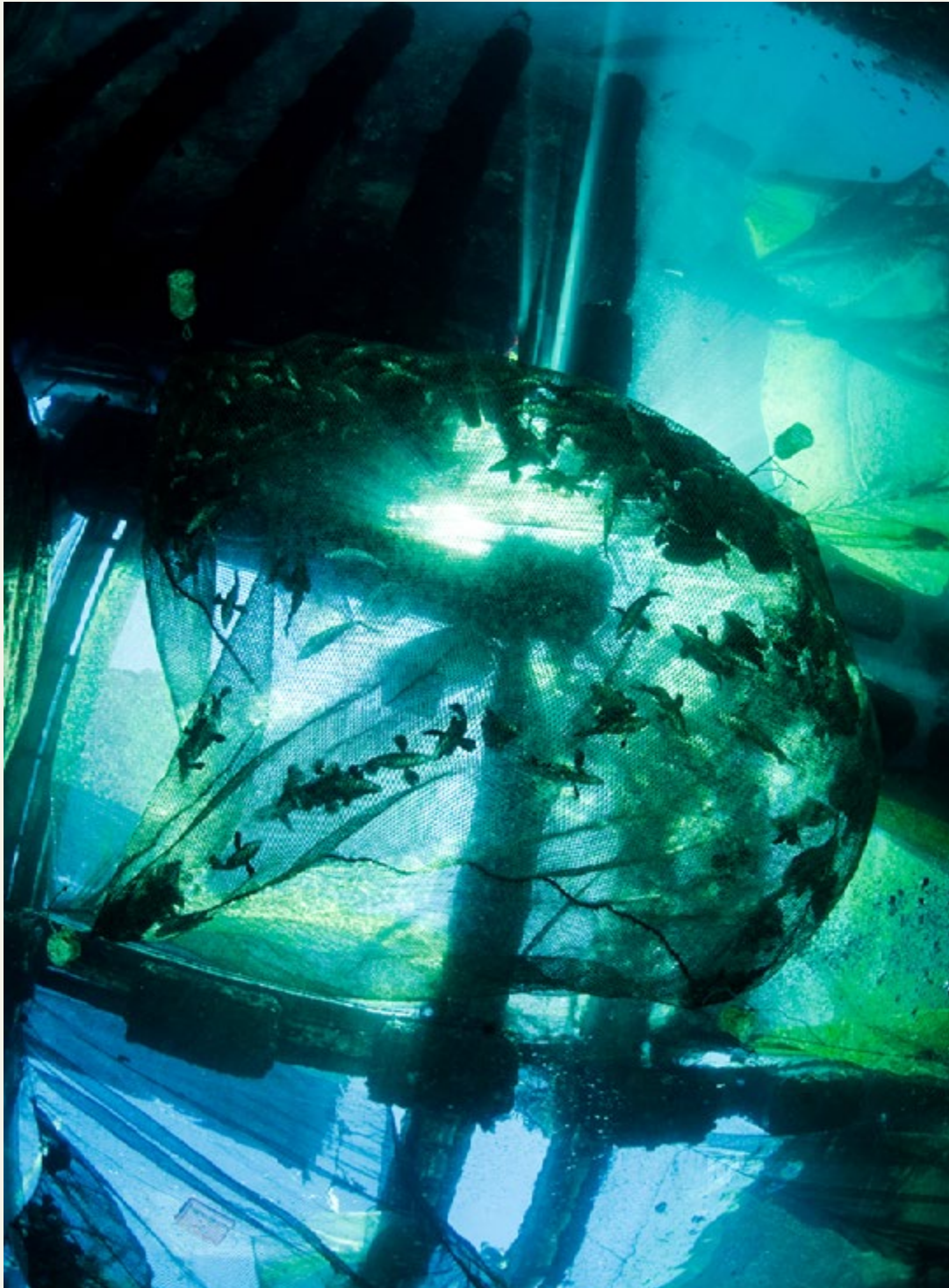
WWF Coral Triangle Programme

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Farmed barramundi cod, Buyat Bay, Indonesia.

SUMMARY

Seafood footprint is a neglected issue that could undermine future development of fisheries and aquaculture. Seafood footprint is a measure of the efficiency of use of aquatic resources by seafood production. Managing seafood footprint is important because the resource use of existing fisheries and aquaculture appear to be at the limit of ocean productivity. Sustainability criteria that include seafood footprint can be used to evaluate seafood production and identify the most resource-efficient products.

Future development of fisheries and aquaculture in the Coral Triangle should include an emphasis on limiting the seafood footprint. To achieve this goal, tools that evaluate seafood footprint are needed. The trophic level of seafood species can be used to calculate primary production required for seafood production, which is a measure of seafood footprint and the largest contributor to ecological footprint. Broader measures of sustainability that evaluate other impacts that arise during seafood production can complement the seafood footprint and provide practical guidance to improving the sustainability of seafood.

Improving the sustainability of seafood production is essential in securing future seafood supplies. One aspect of seafood sustainability that is receiving increasing attention is the efficiency of use of primary production in producing seafood. Seafood footprint is a helpful tool that evaluates the efficiency of use of primary production in producing seafood. Expanded use of this tool in sustainability assessments will be helpful in ensuring human use of ocean ecosystems remains within sustainable limits.

WWF has recently developed a Foundational Measures approach comprising a set of specific, quantitative indicators that can be used to evaluate sustainability of all farmed species and can have specific application to low footprint aquaculture. The Foundational Measures address seafood footprint and also other ecosystem impacts of aquaculture, and they're designed for use in the developing countries where monitoring data are often sparse and market incentives for assessment and certification are weak.

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Using seafood footprint as a tool in improving the sustainability of seafood

BY COMBINING
SEAFOOD
FOOTPRINT WITH
TOOLS THAT
MEASURE A
WIDE RANGE OF
ENVIRONMENTAL
ISSUES, A BROADER
AND MORE
COMPLETE PICTURE
OF SUSTAINABILITY
IS POSSIBLE

As discussed below, seafood footprint¹ measures the efficiency of seafood production.

An emphasis on low footprint seafood in future development will allow a sustainable increase in seafood production. Alternatively, if production of high footprint seafood increases, then such increases are unlikely to be sustainable. The challenge for high footprint fisheries and aquaculture is the increasing competition for oceanic productivity that will prevail in the future since existing fisheries are constrained by the ultimate limit of global aquatic primary productivity (Chassot, et al., 2010; Swartz, et al., 2010). This challenge is likely to show up as higher costs for fish meal to feed farmed species and increased competition for wild fish in fisheries.

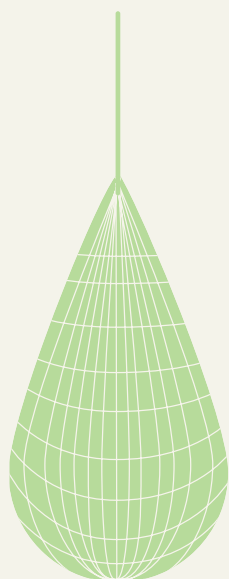
Explicit analysis of seafood footprint is not included in most existing seafood sustainability assessments. Most aquaculture sustainability measures include some evaluation of the use of fish meal or fish oil or overall feed use. Some measures such as Seafood Watch compare feed use across species and low footprint species receive higher sustainability ratings. However, some measures such as ASC standards do not compare feed use across species so a farmed salmon is evaluated only compared to other farmed salmon.

By combining seafood footprint with tools that measure a wide range of environmental issues², a broader and more complete picture of sustainability is possible. Emphasis on this neglected issue of seafood footprint is necessary to ensure that fisheries and aquaculture production do not exceed sustainable use of global aquatic primary productivity. In addition, footprint is useful at the scale of individual fisheries and farms because high footprint seafood will likely face increasing cost and competition for aquatic primary productivity. Such challenges are evident in the increasing price of fish meal in world markets (Tacon and Metian, 2008; FAO, 2009).

¹ Note to the term “footprint.” The term footprint has many uses. Ecological footprint is a precisely-defined measure of the resource requirements of production of seafood or other activities. Yet footprint is also used less precisely to describe the ecosystem impacts of human activities. For this paper, seafood footprint is used to describe the primary production required for seafood production, a measure of resource-use efficiency. The term footprint is used to describe the ecosystem impacts of seafood production, consistent with the typical use of footprint.

² Such as sustainability certification by the Marine Stewardship Council and Aquaculture Stewardship Council or WWF’s Foundational Measures approach for aquaculture.

The environmental significance of low footprint fisheries and aquaculture



**A RECENT STUDY
DEMONSTRATED THAT
HUMANITY'S GLOBAL
TROPHIC LEVEL IS
ABOUT 2.2
AND RISING, AND THE
INCREASE IS CREATING
GRAVE RISKS FOR
OUR FUTURE**

Aquaculture and fisheries are important for food and employment in the Coral Triangle region and in the broader Asia Pacific region. These sectors are expected to remain important (fisheries) or grow further (aquaculture). Minimizing the footprint of aquaculture and fisheries is essential for these industries to contribute to sustainable development. Existing low footprint aquaculture and fisheries are a success story that is little appreciated and can help guide future development.

Low footprint aquaculture and fisheries³ produce plants and low trophic level animals and production of such species typically has fewer environmental impacts than production of top predator species (Neori and Nobre, 2012; Tacon, et al., 2010; Greenberg, 2010). Farming of low trophic level seafood is ecologically efficient because less primary productivity is required to produce low trophic level animals compared to production of high trophic level top predators. This ecological efficiency is an important but often neglected aspect of sustainability since the sustainability of global fisheries are constrained by the ultimate limit--global oceanic primary productivity (Chassot, et al., 2010; Swartz, et al., 2010).

Existing trends towards high footprint aquaculture are a threat to coastal and ocean ecosystems. For example, consumption of farmed salmon is increasing in China and elsewhere and salmon is viewed as the “Prada of seafood” in China--a prestige product that is attractive to investors (Rabobank, 2012). If consumers in China and elsewhere in the Asia Pacific shift away from traditional low footprint seafood towards high footprint seafood like farmed salmon, the demands for consuming ocean productivity will increase dramatically and threaten ocean ecosystems.

The environmental harm caused when people eat a high trophic level diet has long been noted (Lappe, 1971). A vegetarian diet places less demand on natural systems than a meat-heavy diet, and WWF's Living Planet Report advises reducing meat consumption as a key step in reducing humanity's footprint. A recent study demonstrated that humanity's global trophic level is about 2.2 and rising, and the increase is creating grave risks for our future because of the intense resource demands and environmental impacts of meat production (Bonhommeau, et al., 2013).

Seafood has the unique characteristic among food categories of having trophic levels that range from 1 to 4, or above. The trophic level of other food categories tends to be uniform or nearly uniform: grains have trophic level 1 (plants), and most meat eaten by humans has trophic level from 2.0 to 2.1 (Bonhommeau, et al., 2013). Predatory fish are the highest trophic level food humans eat (Bonhommeau, et al., 2013). The significance of the range of trophic levels for seafood species is that the seafood footprint can vary dramatically with species.

³ See “Defining footprint” section on page 5 for the definition of footprint.

As explained below, seafood at trophic level 4 requires much more primary production than seafood at lower trophic levels, up to 10 times more per trophic level (Pauly and Christensen, 1995; Greenberg, 2010). For example, predatory salmon require about 100 times more primary production than herbivorous tilapia. As humanity reaches global limits such as global ocean productivity (Chassot, et al., 2010; Swartz, et al., 2010), the impact of ecologically inefficient high trophic level seafood may become the most important impact of seafood.

In contrast to seafood, other food categories do not have a range of trophic levels. For example, a human vegan diet contains only plant products so shifting among items can shift production impacts but the trophic level is always 1.0. Similarly, different beef production systems have different impacts but the trophic level is 2.0.

Because of the wide range of trophic levels of seafood and the impacts associated with human consumption of high trophic level food, it is important to manage the trophic level and footprint of aquaculture and fisheries. The footprint reduction caused by shifting from high trophic level seafood to low trophic level seafood can reduce resource demand on coastal and ocean ecosystems and support further development of aquaculture.

Most aquaculture in Asia is farming of low trophic level species (FAO, 2012), but existing trends are towards farming and consumption of higher trophic level species such as farmed salmon (Rabobank, 2012). To ensure that aquaculture and fisheries contribute as hoped to sustainable development, managers should promote low trophic level aquaculture and fisheries as an important part of future development.



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Aquaculture operation in Sarawak, Malaysia.

Defining footprint



The term footprint can be confusing because it has more than one usage in referring to environmental impacts. Ecological Footprint is a precise technical term used by WWF in the Living Planet Report as a specific measure of the resource requirements of human activities (WWF, 2012; 2016). Ecological Footprint is useful because it can compare the resource demands of dissimilar activities like energy and food production. However, footprint is also used more generally as a useful metaphor for human over-use and degradation of the earth's resources. The broader use of the term footprint to refer to human impacts is a less precise usage of the term footprint. Nevertheless, it is a commonly-understood term that has value. Used more generally, the term footprint refers to human impacts and in this usage, the term low footprint aquaculture means aquaculture with low impacts on ecosystems.

This paper defines seafood footprint as a measure of the requirement for aquatic primary productivity in seafood production. This usage is consistent with the term Ecological Footprint and focuses on the dominant factor in the Ecological Footprint of seafood, the use of fish meal and fish oil in aquaculture and the trophic level of wild-caught species (Global Footprint Network, 2010; Tyedmers, 2000; Trujillo, 2008; Parker and Tyedmers, 2012). It is also consistent with the term SeafoodPrint used to measure the oceanic primary production required to produce ocean species caught in fisheries (Greenberg, 2010). This definition of seafoodprint avoids the complicating factor in Ecological Footprint of converting primary productivity required for seafood production into ocean area required for seafood production (based on average productivity per hectare).⁴ The specific term SeafoodPrint has utility in evaluating and managing key aspects of seafood sustainability, the resource efficiency of seafood in utilization of primary production.

The definition of seafood footprint above provides a useful tool for comparing seafood products and identifying which seafood products have the lowest requirement for using the limited resource of aquatic primary productivity. It is also useful in evaluating the critically important issue of the use of fish meal and fish oil in aquaculture, a potentially limiting factor or bottleneck that could inhibit future expansion of aquaculture (Boyd, et al., 2015).

⁴ Ecological footprint of seafood uses the primary productivity required and converts to the area required for seafood production using conversion factors for productivity per hectare. This conversion is one of the most widely criticized aspects of Ecological Footprint, and is avoided by the definition of footprint used in this report.

Sustainability standards and footprint



A review of existing fisheries and aquaculture sustainability standards shows that ecological footprint is not evaluated for most of the commonly used standards.⁵ The best coverage of ecological footprint for fisheries is in the seafoodprint approach used by Pauly and collaborators (Pauly and Christensen, 1995; Swartz, et al., 2010). The best coverage of ecological footprint for aquaculture is in the SeafoodWatch criteria for aquaculture and the Foundational Measures approach developed by WWF (Boyd, et al., 2015).

The seafoodprint of fisheries is a measure of how much primary productivity is required to produce seafood, which directly relates to the ecological footprint of seafood. Seafood with a lower seafoodprint requires less primary productivity to produce. Seafood from animals at lower trophic levels requires much less primary productivity to produce because the transfer efficiency for ocean animals is around 10% (Pauly and Christensen, 1995).⁶ Thus, 1000 kg of plant biomass at trophic level 1 can produce 100 kg of herbivore at trophic level 2, 10 kg of predator at trophic level 3 that eats herbivores, and only 1 kg of top predator at trophic level 4 that eats lower level predators. So low trophic level seafood has a lower seafoodprint.

SeafoodWatch criteria for aquaculture evaluates and places significant weight on the feed requirements of aquaculture, giving products a lower sustainability rating if their feed requirements are higher (similar to the primary productivity required for wild fisheries). This means that a product would receive a lower sustainability rating if the marine ecological footprint (feed requirement) is higher. Other aquaculture systems provide very little evaluation of marine ecological footprint or feed requirements. For example, the Aquaculture Stewardship Council and Common Method used by WWF give high ratings to aquaculture products that are produced with sustainable feed even if the Fish In: Fish Out (FIFO)⁷ ratio is high (indicating a high use of feed). The ASC can certify a salmon as responsible if it has a high FIFO ratio of 2.95.⁸ This means

⁵ Standards evaluated: Aquaculture Stewardship Council (ASC), GlobalGAP, Global Aquaculture Alliance Best Aquaculture Practices (GAA BAP), Friend of the Sea, Common Aquaculture Methodology (WWF and others), Common Methodology Wild Capture Fisheries (WWF and others), Monterey Bay Aquarium SeafoodWatch Rating Method, Marine Stewardship Council (MSC) and Seafoodprint (Sea Around Us, University of British Columbia).

⁶ A herbivore eating a plant requires about 10 kg of plant biomass to produce 1 kg of herbivore biomass, and a predator eating an animal requires about 10 kg of animal biomass to produce 1 kg of predator biomass.

⁷ FIFO, or the Fish In: Fish Out ratio, indicates the amount of fish (or other aquatic animal products) used to produce an aquaculture product. FIFO of 1 indicates 1 kg of product requires 1 kg of fish input in feed. FIFO greater than 1 indicates a net loss of fish product, and FIFO less than 1 indicates a net gain of fish product.

⁸ FIFO = 2.95 for farmed salmon means that 2.95 kg wet weight of fish was used in feed to produce 1 kg wet weight of farmed salmon.

that a salmon can be certified as responsible by ASC even if it requires 5-10 times more marine fish in feed than uncertified pangasius or tilapia with a FIFO of 0.2-0.5. In this example, the certified salmon would have a much higher marine ecological footprint than the uncertified pangasius or tilapia. Similarly, the Common Method for Aquaculture puts more emphasis on the issue of certification of source fisheries used to produce feed and less emphasis on the FIFO ratio indicating amount of fish products used in feed.

The Foundational Measures approach is intended to spur improvement in the sustainability of aquaculture by providing a tool that can be used at all scales and when relatively little data are available. It assesses aquaculture production impacts by focusing on the 6-8 most important impacts. The use of fish meal and fish oil in feed is included, so seafood footprint, the term used henceforth in this paper, is addressed by this approach. Papers describing the Foundational Measures approach do not include a method of integrating fish meal and fish oil use together with other impact metrics that measure water pollution, habitat conversion, health management, or other factors to produce a single metric of sustainability.

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ECOLOGICAL EFFICIENCY IS
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PRODUCTION**

The most broadly applicable tool, which can be applied to all fisheries and aquaculture, is the trophic level of farmed and fished species. Trophic level is a direct indicator of seafood footprint for wild-caught species. Trophic level is a reliable indicator of the ecological footprint of farmed species at present, because predator species currently require higher levels of ocean-derived ingredients in feed (table 1 below; Tacon and Metian, 2008). As substitution of non-fish ingredients for fish meal and fish oil advances, then trophic level will become less reliable as an indicator of seafood footprint. Some examples exist of substitution of other ingredients for fish meal and fish oil, including genetically modified yeast⁹ and insects.¹⁰ These technologies can transform high footprint aquaculture such as typical farmed salmon into lower footprint aquaculture. For now, trophic level remains a reliable indicator of the use of fish meal and fish oil in aquaculture (Tyedmers, 2000; Warren-Rhodes, et al., 2003; Trujillo, 2008; Tacon and Metian, 2008; Tacon, et al., 2010; Tacon, et al., 2011; Parker and Tyedmers, 2012).

The primary production required to produce seafood—the seafood footprint—is a useful measure of the ecological efficiency of seafood production. Ecological efficiency is a critically important aspect of seafood production because oceanic primary productivity is the ultimate limit to seafood production, and more efficient seafood production can produce more seafood from a given amount of oceanic primary productivity.

⁹ Verlasso salmon, fed yeast modified to produce omega-3 fats. https://www.seafoodwatch.org/-/m/sfw/pdf/reports/s/mba_seafoodwatch_verlassofarmedsalmonreport.pdf

¹⁰ For example, Enterra Feed Corporation's insect meal made from black fly larvae. <http://www.enterrafeed.com/products/feed-ingredients-2/>

Reducing the footprint of aquaculture of high trophic level animals

The ecological footprint of aquaculture can be reduced through reduction in the use of fish meal and fish oil in aquaculture feed. This can be accomplished by farming lower trophic level species, or by innovations in farming of top predator species. One option for reducing the footprint of aquaculture of top predator fish is the use of genetically modified (GM) yeast or insects as a source of omega-3 fatty acids. Verlasso salmon produced with GM yeast in feed is reported to have a FIFO ratio of 1.0 compared to the more typical FIFO of 2.95 or above for farmed salmon, so Verlasso salmon has an ecological footprint that is only 1/3 of the footprint of typical farmed salmon (www.verlasso.com). This footprint reduction is the reason Verlasso salmon is the only farmed Atlantic salmon rated “yellow” (good alternative) by SeafoodWatch.¹¹ All other farmed Atlantic salmon are rated “red” (avoid).

Insect meal has the potential to be a low footprint substitute for fish meal in aquaculture, especially when insects are fed on garbage or other waste products that would otherwise be discarded. FAO has produced a report on the potential of insect meal as a substitute for fish meal in aquaculture (FAO, 2013). Insect meal is currently being developed and tested for use as a fish meal substitute in aquaculture in several countries including South Africa, the US, Norway, the Netherlands and Malaysia.

¹¹ Seafood Watch listing of Verlasso salmon:
<https://www.seafoodwatch.org/seafood-recommendations/groups/salmon>





Seafood footprint analysis



Practical tools and approaches for evaluating seafood footprint are needed for future development to emphasize low footprint seafood. The trophic level of seafood is considered by the author of this report to be the best overall tool for evaluating seafood footprint. For wild-caught fisheries, seafood footprint is determined by trophic level according the following equation:

$$\text{Seafood footprint} = \text{CC} \times (1/\text{TE})^{(\text{Trophic level} - 1)}$$

TE=transfer efficiency of biomass between trophic levels, typically 0.1 (10%)

CC=carbon content of wet-weight fish biomass

The seafood footprint of a seafood product species is the mass ratio of harvested fish to the primary production needed to sustain the harvested species, based on its average trophic level, as first developed by Pauly and Christensen (1995), and later expanded by Global Footprint Network (2010). As shown by the equation above, if the trophic level increases by 1, the seafood footprint increases by 10. Seafood footprint is the ecological efficiency of seafood—the efficiency in using aquatic primary productivity to produce seafood.

For aquaculture, the above equation would apply if farmed species received the same food as they would obtain in the wild. However, aquaculture feed is usually different than the natural food of the farmed species. Despite the use of artificial feed, the trend of increasing footprint for aquaculture of higher trophic level species remains reliable (Tacon, et al., 2010). Studies of the feed usage of aquaculture show that farming of higher trophic level species consumes more aquatic primary production than farming of lower trophic level species (Tacon and Metian, 2008).¹² Using data from Tacon and Metian, 2008, and trophic levels from FishBase.org, the relationship between trophic level and Fish In:Fish Out ratios is evident (table 1).

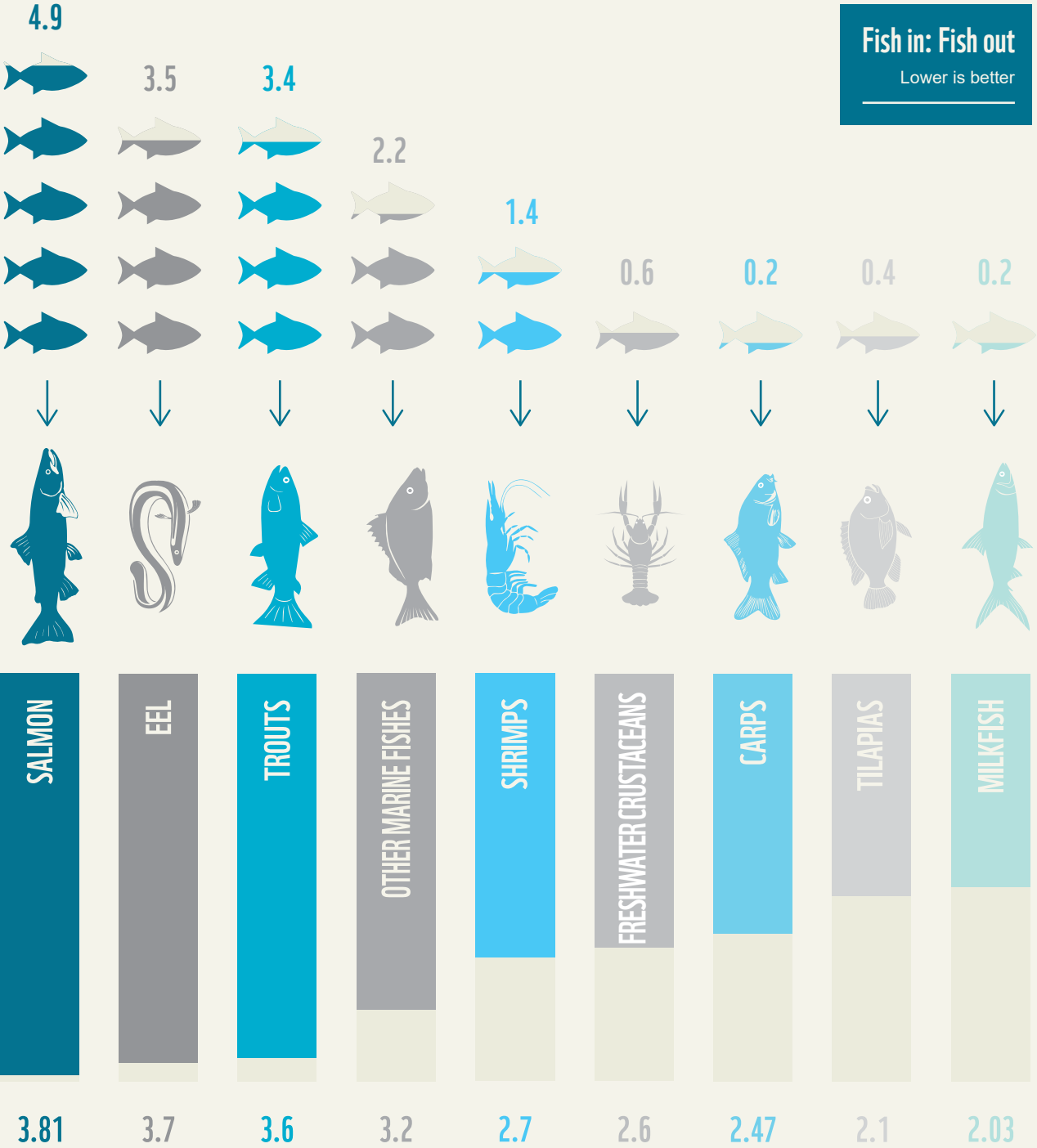
SPECIES/SECTOR	TL	FISH IN:FISH OUT
Milkfish	2.03	0.2
Tilapias	2.1	0.4
Carp	2.47	0.2
Freshwater Crustaceans	2.6	0.6
Shrimps	2.7	1.4
Other Marine Fishes	3.2	2.2
Trouts	3.6	3.4
Eels	3.7	3.5
Salmon	3.81	4.9

Table 1: Trophic level and Fish In:Fish Out ratio of aquaculture sectors

Substitution of feed ingredients may change this relationship in the future. Aquaculture that effectively reduces reliance on fish meal and fish oil, or that substitutes alternatives to fish meal and fish oil can effectively lower the footprint of farming a particular species. If this happens, future developments may make trophic level less reliable as an indicator of seafood footprint for farmed species.

¹². The Fish In:Fish Out ratio (FIFO) is a common measure of feed use, and a higher FIFO ratio indicates a higher use of aquatic primary productivity. The reference shows FIFO ratios for farmed species and shows the trend that higher trophic level aquaculture has a higher FIFO ratio.

Ratio of main farmed species / species groups



Sustainability measures for low footprint aquaculture

Aquaculture in developing countries tends to be low trophic level species that can be produced efficiently

Low footprint aquaculture is important in the Coral Triangle for food security and livelihoods (Pet-Soede, and Muldoon, 2013). The term low footprint aquaculture in this context is used to refer to aquaculture with low impacts on ecosystems, and it includes seafood footprint as well as other impacts on ecosystems. To evaluate and manage seafood footprint as part of efforts to support low footprint aquaculture, tools are needed that evaluate seafood footprint along with other aquaculture impacts. Some widely-used sustainability criteria do not identify or give a positive rank to products with a low seafood footprint.

Aggregation across multiple impacts to produce a single score is a common feature of many sustainability evaluation systems. This is true for sustainability certification systems and seafood guides such as those produced by Seafood Watch or WWF. Seafood Watch criteria are the only system that explicitly includes seafood footprint (see below). For other systems such as Aquaculture Stewardship Council and WWF Seafood Guides, feed use in aquaculture is evaluated, but the highest scores do not go to systems with low seafood footprint. Instead, the highest scores are awarded for the use of certified sustainable feed sources and for achieving best practices for each species in minimizing the use of fish meal and fish oil.

Seafood Watch criteria for aquaculture includes the “feed footprint” in the overall evaluation that produces a single sustainability score. This feed footprint evaluates the primary productivity required and converts to ocean area required for feed used, plus the land area required for feed production. This would make Seafood Watch criteria useful for evaluating and managing low footprint aquaculture, except for one challenge. Seafood Watch criteria require a large amount of information to produce a result, and the criteria should be applied by a trained assessor to be reliable and comparable to other species assessed using Seafood Watch criteria. For low footprint aquaculture in developing countries, this level of information is rarely available and there are few incentives for collecting the information and hiring a qualified assessor.

The Foundational Measures approach developed by WWF is a set of criteria designed to evaluate the most important impacts of aquaculture operations (Boyd, et al., 2015). This approach is intended for use where aquaculture is primarily subsistence farming or for products that are traded in domestic or regional markets. Information is often lacking on the impacts of such products because they are not traded internationally and are not subject to the same market forces that drive analysis of impacts and improvement efforts for species exported to Europe and the U. S. Many important aquaculture species in developing countries, such as carps and milkfish, do not have ASC standards and have not been evaluated by Seafood Watch because they are not export products destined for U. S. or European markets. Aquaculture in developing countries tends to be low trophic level species that can be produced efficiently (Tacon, et al., 2010). Such species would benefit from application of improvement tools such as WWF’s Foundational Measures, which can help guide improvement by focusing efforts on the most important issues while minimizing the cost and effort required to collect the required information.

Foundational Measures cannot be used currently as specific numerical targets or performance criteria. Unfortunately, such standards or targets for the Foundational Measures are not yet available because “there are few instances where sufficient data are available at the farm level to reveal the range and normal efficiencies of resource use for different species, culture methods and regions. Without such information it is impossible to set target efficiency levels that are both economically feasible and ecologically meaningful.” (Boyd, et al., 2013). But Foundational Measures could be specified in development plans as data needs and ongoing funding criteria, and the results could be used in continuous improvement efforts designed to improve low footprint aquaculture.



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Milkfish being transferred for deboning and further processing.

Recommendations for a sustainability indicator for low footprint aquaculture

The best approach currently available for evaluating the ecosystem impacts of low footprint aquaculture is to use WWF's Foundational Measures (Boyd, et al., 2015). These indicators include seafood footprint and other impacts, and they can be used to compare performance, develop performance targets, and determine what practices are successful in achieving performance targets. A key value of the Foundational Measures is that they are designed for the typical context of low footprint aquaculture, which is developing country production for subsistence, or domestic or regional markets. As such, they are intended to be relatively simply to measure and use. In contrast, tools and approaches developed for the more demanding Western markets such as Europe and the U. S. tend to require more information and specially-trained assessors.

The Foundational Measures indicators are listed in table 2.

INDICATOR	UNITS OF MEASURE
Fish in: fish out ratio	Forage fish in feed/production (kg/kg or t/t)
Land use	Total land area/production (ha/t)
Water use (based on discharge)	Effluent volume/production (m ³ /t)
Survival	Number stocked/number harvested x 100 (%)
Energy use	Energy use/production (GJ/t)
Impact on receiving water	Diurnal DO flux (afternoon DO-morning DO = Δ mg/L)
Feed conversion ratio	Feed applied/production (kg/kg or t/t)

Table 2: Foundational Measures indicators for evaluation of resource use efficiency, waste production and environmental impact at aquaculture facilities.

Data are not available to construct a simple table comparing low footprint aquaculture (LFA) species and non-LFA species using the Foundational Measures. Results found in literature comparisons provide insight and allow a comparison, but the results are typically not always exactly comparable across species and require some discussion.





Example comparison across low footprint aquaculture (LFA) and non-LFA species

Fish-in fish-out ratio (FIFO):

Table 1 shows FIFO for a range of species groups. The LFA species (milkfish, tilapias, and carps) show FIFO in the range 0.2-0.4, while predatory species (trouts, salmon, other marine fishes, catfishes) show FIFO in the range 0.5-4.9, with only the catfishes being below 2.2. FIFO and feed use impacts are consistently and substantially lower for LFA species. This is the most dramatic trend among the Foundational Measures indicators, and it applies to the “major global impact of aquaculture” (Boyd, et al., 2015).

Land use:

Aquaculture production systems differ dramatically in the type of farming areas used. For example, salmon are often produced in ocean net pens while tilapia are often produced in ponds (land area). Analyses of farm area use sometimes include areas appropriated for feed production, so comparisons can be difficult. Comparison using similar production methods seems most useful. Comparison across species in the Blue Frontiers Report from the Worldfish Center does not show any systematic trend across species groups, but pond culture appears to occupy more land than other production systems (Hall, et al., 2011).

Water use:

Similar to land use described above, water use is different for different production systems. Water use can not be measured for pens or cages, and comparison across species and production systems can be difficult. The clearest result seems to be that intensification of production, regardless of species, minimizes water use (Verdegem, et al., 2006).

Survival:

The factors cited in Boyd, et al., 2015 as likely to affect survival include poor quality and poor handling of seed stock. Data on typical survival rates for different species was not obtainable, however, there is no reason to expect a systematic trend across species since decisions and actions taken by farmers are likely the most important factors.

Energy use:

Data on energy use show some clear trends by production system. Tanks or flow-through systems that require pumping have the highest energy use, while the lowest energy use is for extensive culture systems for bivalves. Within a production system, low trophic level species appear to have lower energy use, but the trend is suggestive rather than clear (Troell, et al., 2004).

Waste discharge:

Waste discharge that leads to dissolved oxygen flux is a measure of eutrophication caused by aquaculture waste. The choice of this method is driven by ease of measurement, however, literature values for DO flux caused by aquaculture were not available. Phosphorus and nitrogen are the nutrients of most interest and Hall, et al., 2011 reported eutrophication potential caused by different species and culture systems. One clear trend is that filter-feeding and other herbivorous animals reduced eutrophication potential of water. Other animals showed no clear trend by species. Pond culture appeared to have a slightly higher eutrophication potential than cage culture.

Feed conversion ratio:

Data on feed conversion ratios (FCR) do not show a clear trend by species, ranging from about 1-3 for all species, with average levels around 1.5-2, based on a comprehensive global overview of feed use in aquaculture (Taon and Metian, 2008). Good feed management practices are likely to be responsible for differences in FCR.

Summary comparing LFA and non-LFA species using Foundational Measures:

The Foundational Measures appear viable as sustainability criteria for low footprint aquaculture (LFA). The fish-in fish-out ratio clearly shows the greater sustainability of low seafood footprint species, and the other indicators seem to provide a set of indicators of on-farm performance that evaluate the major impacts of aquaculture.

TO USE THE FOUNDATIONAL MEASURES FOR SUSTAINABILITY EVALUATION, DATA CAN BE USED TO COMPARE FARMS (EVEN FARMS RAISING DIFFERENT SPECIES). OPTIONS FOR SIMPLE SCORING SCHEMES IN SUSTAINABILITY EVALUATIONS INCLUDE:

Developing a set of red-yellow-green or high-medium-low criteria for each indicator, and a scheme for synthesizing the 7 indicators into one overall ranking.

Comparing 2 evaluations (e.g. 2 farms) by counting the indicators showing an advantage for 1 farm over the other.

Avoiding the use of comparisons between farms, and instead relying on the indicators as tools to drive improvement.



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CORAL TRIANGLE

US\$ 1 billion

Annual tuna trade from Indonesia, Papua New Guinea, Philippines, Solomon Islands, and Fiji

6 million km²

Total area of the Coral Triangle

+130 million

People directly dependent on the Coral Triangle's marine natural resources

6 of 7

of the world's marine turtle species

1.7 million tonnes

Fisheries exports from Coral Triangle countries in 2011, worth nearly US\$5.2 billion

US\$ 810 million

Annual regional trade in live reef food fish in Asia-Pacific



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