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Research Note

Shift in Trophic Level of Mediterranean Mariculture Species

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Abstract: *The mean trophic level of the farmed fish species in the Mediterranean has been increasing. We examined the farming-up hypothesis (i.e., the increase in the production of high-trophic-level species) in the Mediterranean by determining the trophic level of the aquafeeds (i.e., what the fish are fed) of 5 species of farmed marine fishes: common dentex* (Dentex dentex)*, common pandora* (Pagellus erythrinus)*, European seabass* (Dicentrarchus labrax)*, gilthead seabream* (Sparus aurata)*, and red porgy* (Pagrus sp.)*. The mean trophic level of aquafeed used in mariculture from 1950 to 2011 was higher (3.93) than the prey farmed fish consume in the wild (3.72) and increased at a faster rate (0.48/decade) compared with that based on their diets in the wild (0.43/decade). Future expected replacement of the fishmeal and oil in aquafeeds by plant materials may reverse the farming-up trend, although there are a number of concerns regarding operational, nutritional, environmental, and economic issues. The farming-up reversal can be achieved in an ecologically friendly manner by facilitating the mariculture of low-trophic-level fishes and by promoting high efficiency in the use of living marine resources in aquafeeds.*

Keywords: aquafeeds, farming up, fishmeal replacement

Cambios en el Nivel Trófico de las Especies de Maricultura Mediterránea

Resumen: *El nivel trófico medio de las especies de peces criados en el Mediterráneo ha estado incrementando. Examinamos la hipótesis* farming up *(es decir, el incremento en la producción de especies de alto nivel trófico) en el Mediterráneo al determinar el nivel trófico del alimento acuático (es decir, lo que se le da de comer a los peces) de cinco especies de peces marinos en crianza:* Dentex dentex*,* Pagellus erythrinus*,* Dicentrarchus labrax*,* Sparus aurata *y* Pagrus *sp. El nivel trófico medio del alimento acuático usado en la maricultura de 1950 a 2011 fue más alto (3.93) que las presas que los peces cultivados consumen en vida libre (3.72) e incrementó en una tasa más rápida (0.48/década) comparado con aquel basado en sus dietas en vida libre (0.43/década). El futuro remplazo esperado del alimento para peces y el aceite en los alimentos acuáticos por materiales vegetales puede revertir la tendencia de* farming up*, aunque existe un número de preocupaciones con respecto a temas operacionales, nutricionales, ambientales y económicos. La reversión del* farming up *puede lograrse de una manera ecológicamente amigables al facilitar la maricultura de peces de bajo nivel trófico y al promocionar la alta eficiencia en el uso de recursos marinos vivos en el alimento acuático.*

Palabras Clave: alimento acuático, *farming up*, remplazo de alimento para peces

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Introduction

Mediterranean fish mariculture is currently producing high-trophic-level species and having effects on marine fish stocks because small pelagic fishes are caught and used to produce aquafeeds (food for farmed fish, usually fishmeal and oils) for farmed species (e.g., Naylor et al. 2000; Pullin et al. 2007; Tacon & Metian 2009). The substitution of fishmeal and oil with plant products is not only theoretically possible, but being realized, and the inclusion of fishmeal and oil in aquafeeds has been reduced substantially in recent years (Kaushik et al. 2004; Tacon & Metian 2008; Shepherd & Jackson 2013) and should continue in the future. However, there are intraspecific differences in the average amounts of fishmeal and oil used in aquafeeds (Tacon & Metian 2008).

Stergiou et al. (2009) report that the mariculture industry in the Mediterranean Sea is shifting from culturing low-trophic-level species to culturing high-trophic-level species, a phenomenon known as farming up (Pauly et al. 2001). This phenomenon, which is amplified by the faster increase of fish production relative to shellfish production, is more pronounced when only fishes are considered (Tsikliras et al. 2010). The transition to farming high-trophic-level fish species has consequences for fisheries because it increases the demand for fishmeal-and-oil based aquafeeds (Tacon et al. 2010).

Stergiou et al. (2009) used the diet composition each species would have in the wild (as expressed by their trophic level) to calculate the mean weighted trophic level of aquaculture production (i.e., they did not consider the actual composition of aquafeeds provided to farmed species). However, research on fishmeal and oil replacement in aquafeeds has sharply increased recently. A search in Scopus revealed that the annual number of articles on aquafeed replacement published from 2008 to 2012 doubled relative to 2002–2007.

We tested the farming-up hypothesis by calculating the mean weighted trophic level of aquaculture production based on the composition of the aquafeeds of farmed fish species in the Mediterranean and by comparing it with the trophic level based on their diet in the wild.

Methods

We calculated the mean weighted trophic level of the farmed species in the Mediterranean on the basis of their diet composition in the wild (i.e., the natural trophic level of each species in the wild [TL_N]) and their diet in mariculture (i.e., composition of their aquafeeds [TL_F]).

The TL_N of all species was taken from FishBase (www.fishbase.org; Froese & Pauly 2013), which provides estimates of trophic levels based on diet composition data. For the farmed fish species in the Mediterranean Sea, TL_N ranges from 2.0, for herbivores (e.g., molluscs) and detritivores (e.g., the flathead mullet [*Mugil cephalus*]), to about 4.5 (e.g., common dentex). The corresponding TL_Fs were calculated based on the current percentages of fishmeal (and oil) and plant materials included in their aquafeeds, as reported in the most recent publications for the Mediterranean (Table 1). The TL_F was calculated as

$$TL_F = 1 + \sum_{j=1}^{G} DC_{ij} * troph_j, \qquad (1)$$

where $troph_j$ is the trophic level of the aquafeed ingredient j, DC_{ij} is the fraction of j in the aquafeed i, and G is the total number of aquafeed ingredients.

For all aquafeeds for which we estimated TL_F, we used the control diet formulations of replacement experiments, with the exception of seabream, for which the diet formulation of the commercial aquafeed was known and used.

The ecological investment in fish oil is far greater than the ecological investment in fishmeal. The production of 1 kg of fishmeal requires 4.5 kg of whole fish, whereas the production of 1 kg of fish oil requires around 20 kg of whole fish (Shepherd & Jackson 2013). However, we combined fishmeal and oil in our calculations of TL_F because they are derived from the same group of fishes and thus have the same trophic level. The trophic level of fishmeal and oil was assumed to be equal to 3.25, which is the average trophic level of small pelagic fishes (sardines, anchovies, sardinellas) (Stergiou & Karpouzi 2002; Froese & Pauly 2013) that are commonly used as ingredients in aquafeeds. This value is consistent with the average trophic level of the main fish species used in production of fishmeal as reported by Shepherd and Jackson (2013). The trophic level of these species ranges from 2.2 (Gulf Menhaden [*Brevoortia patronus*]) to 4 (blue whiting [*Micromesistius poutasssou*] and Japanese jack mackerel [*Trachurus japonicus*]) (mean [SE] = 3.2 [0.14]). The trophic level of plant material was taken as 1.0, which is the trophic level of photosynthetic plants. The TL_F was estimated using the fishmeal and oil and plant material, whereas the remaining ingredients were not taken into account in the analysis. Thus, for example, the trophic level of a species fed on an aquafeed containing 50% fishmeal derived from small pelagic fishes (trophic level 3.25) and 50% plant meal (trophic level 1) would be 3.125.

The TL_F was estimated for 5 fish species (Table 1; for the remaining farmed species of the Mediterranean the TL_N was used, according to the methods of Stergiou et al. 2009) for which there were available data regarding their aquafeed. The fish we considered were common dentex (*Dentex dentex*), common pandora (*Pagellus erythrinus*), European seabass (*Dicentrarchus labrax*),

Table 1. Mediterranean mariculture production (Food and Agricultural Organization 2013), trophic level, and type and formulation of the diets of 5 fish species for which fishmeal substitution data were available.

Species[a]	*Production 2011 (t)*	*Production (%)*	TL_N[b]	TL_F[c]	*Ingredients in g/kg (%)*[d] FM	PM	FO	W	VMP	MCP	*Type of diet*[e]
Sparus aurata, 1	127,029	34.4	3.26	3.65	500 (50.1)	235 (23.5)	140 (14.0)	117 (11.7)	5 (0.5)	2 (0.2)	Com
Dicentrarchus labrax, 2	112,239	30.4	3.79	3.79	560 (56.5)	160 (16.1)	70 (7.1)	180 (18.2)	11 (1.1)	10 (1.0)	Exp
Pagellus erythrinus, 3	20	<0.1%	3.40	4.25	768 (69.9)	– (0)	34 (3.1)	291 (26.5)	5.5 (0.5)	– (0)	Exp
Dentex dentex, 4	8	<0.1%	4.50	4.25	696 (71.3)	– (0)	149 (15.3)	80 (8.2)	20 (2.0)	31 (3.2)	Exp
Pagrus sp., 5	0	0	3.65	3.72	666 (66.7)	223 (22.3)	65 (6.5)	– (0)	40 (4.0)	5 (0.5)	Exp

[a] *Numbers correspond to references: 1, Carter et al. 2012; 2, Güroy et al. 2013; 3, Kousoulaki et al. 2007; 4, Chatzifotis et al. 2008; 5, Schuchardt et al. 2008.*
[b] *Trophic level of the species in their natural environment taken from FishBase (Froese & Pauly 2013).*
[c] *Trophic level of the species based on the constituents of their aquafeeds.*
[d] *Abbreviations: FM, fish meal; PM, plant material; FO, fish oil; W, wheat; VMP, vitamin and mineral premix; MCP, monocalcium phosphate.*
[e] *Abbreviations: com, commercial diet; exp, experimental diet.*

gilthead seabream (*Sparus aurata*), and red porgy (*Pagrus* sp.). In 2011, seabream and seabass together made up 95% of Mediterranean mariculture produced fish (Food and Agricultural Organization 2013). The type of aquafeed (experimental or commercial) and formulation of the feed for each species is shown in Table 1. We assumed no change in the fishmeal and oil in the aquafeeds for the entire study period.

Annual mean weighted series of TL_N and TL_F trophic levels were calculated based on the Food and Agriculture Organization (FAO) mariculture production data (Aquaculture Production: quantities 1950–2011 database for mariculture; Food and Agricultural Organization 2013). This data set extends across the Mediterranean and the Black Sea, includes all producing countries and all groups of farmed animals (bivalves, gastropods, cephalopods and fish), but excludes brackish-water farming.

Results

Overall, the mean TL_N for the 5 species was 3.72 (SE 0.20), and their mean TL_F was 3.93 (0.12), that is, TL_F was 5.4% higher than TL_N (Table 1). In 3 of the 5 species, TL_F was higher than TL_N by 2.0% (red porgy: 3.72 instead of 3.65) to 20.0% (common pandora: 4.25 instead of 3.40). In one species it was lower by 6% (common dentex: 4.25 instead of 4.50), whereas in European seabass TL_N and TL_F values were identical.

The mariculture production of invertebrates increased from 1980 up to the early 2000s, at a rate lower than that of fish mariculture production, and declined thereafter. Fish mariculture production increased exponentially from 1980 to 2011 (Fig. 1a). The annual mean weighted TL_F was higher than TL_N and increased more quickly than TL_N after 1990 (TL_F 0.48/decade; TL_N 0.43/decade; Fig. 1b). Results with both data sets were highly dependent on 2 species, the European seabass and seabream, because 65% of total mariculture production (368 778 t in 2011) and around 95% of fish mariculture production (256 798 t in 2011) in the Mediterranean was derived from seabream (127 029 t in 2011; 34.5%) and seabass (112 239 t in 2011; 30%).

Discussion

In Mediterranean mariculture, a shift from culturing invertebrates (mainly mussels) and detrivorous fish (grey mullets, family Mugilidae) to culturing seabass and seabream (Fig. 1) occurred in late 1980s. This shift lead to an inverse invertebrate to fish production ratio and changed the trophic signature of the Mediterranean marine aquaculture industry (Stergiou et al. 2009). The transition to farming higher trophic level fishes instead of mussels and detritivores and the gradual increase in production of fishes increased the mean weighted trophic level of species farmed in the Mediterranean. Many other fish species with even higher trophic levels, such as the wreckfish (*Polyprion americanus*) ($TL_N = 4.1$), greater amberjack (*Seriola dumerili*) ($TL_N = 4.5$), and meagre (*Argyrosomus regius*) ($TL_N = 4.3$), are now experimentally farmed in the Mediterranean. The industrialized farming of these fishes and the mass production of common dentex and red porgy in the future may well cause a new transition and change the trophic signature of the Mediterranean aquaculture once again.

What is clear from Fig. 1(b), is that TL_N, which was used as a proxy of TL_F to examine potential farming up trends (e.g., Pullin et al. 2007; Stergiou et al. 2009; Campbell & Pauly 2013), is a conservative approximation. Thus, these authors' contention that the food webs are being farmed up is not an exaggeration. The TL_F can be used for estimating the trophic level of any aquafeed and to check the ecological dimension of various farming options.

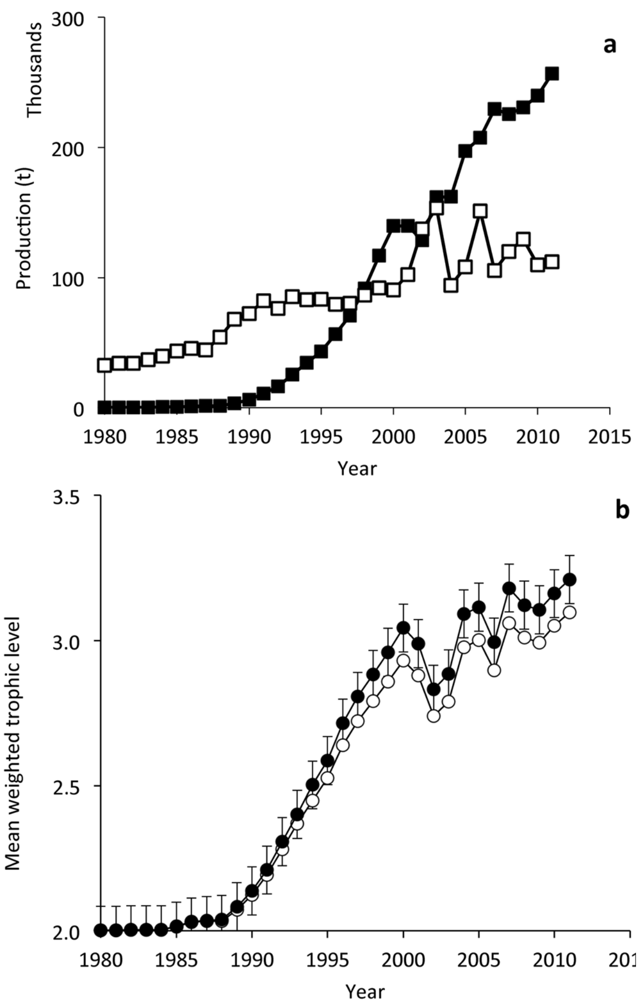

Figure 1. (a) Fish (solid squares) and invertebrate (open squares) mariculture production in the Mediterranean from 1980 to 2011 (data from Food and Agricultural Organization 2013). (b) Mean weighted trophic level of Mediterranean mariculture species from 1980 to 2011, calculated based on their natural diet (open circles) and their diet in mariculture based on the proximate composition of the actual aquafeeds of 5 species (black circles). Data points from 1950 to 1979 are not shown; their mean trophic level is near 2 due to the dominance of bivalve mariculture over that period.

Our results show that aquafeeds used in mariculture still contain a large proportion of fishmeal, usually derived from small pelagic fishes (Tacon & Metian 2008). Future reduction in the fishmeal and oil percentage or replacement by plant materials could, in theory, reverse the farming-up trend observed in many parts of the world (Campbell & Pauly 2013), including the Mediterranean Sea (Fig. 1b).

However, the substitution of fishmeal and oils with plant material (e.g., soya beans, peas) may have important consequences at different levels (i.e., operational, production, nutritional, environmental, economic, health). A plant-based diet may adversely affect the nutritional profile of the final product by decreasing ω-3/ω-6 ratio (Simopoulos 2002); lead to decreasing growth rates and thus a longer period for a species to attain commercial size (e.g., Chatzifotis et al. 2008); and eventually lead to increased production cost that will be passed to consumers. In addition, when fish are held in cages longer the probability of escape increases (escape can have large effects on local stocks and biodiversity through biological pollution [Naylor et al. 2000; CIESM 2007]). In addition, the probability of the exposure of caged fish to pathogens and parasites increases. Consequently, the use of prophylactic and therapeutic drugs used to prevent infection increases. These drugs affect fishes, terrestrial animals, the ecosystem, and the health of farm workers, human populations living nearby, and consumers (e.g., Cabello 2006; CIESM 2007; Sapkota et al. 2008).

We conclude that the farming-up reversal trend can be achieved in an ecologically friendly manner by facilitating the mariculture of low-trophic-level fishes (e.g., the detritivore grey mullets or the sharp-snout seabream [*Diplodus puntazzo*] with a $TL_N = 2.9$) and by promoting high efficiency in the use of living marine resources in aquafeeds. Further research into, for example, alternative sources of aquafeeds (e.g., algae, microorganisms, and oil seeds) and the nutritional needs of farmed species is necessary to generate viable solutions and strategies for an environmentally friendly mariculture industry (Mente et al. 2011).

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