

Farming up Mediterranean Food Webs

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One of the effects of fisheries on ecosystems is that they tend to remove the larger, higher-trophic-level species and thus progressively lower the mean trophic level (TL) of the landings. This effect is known as “fishing down the food web” (Pauly et al. 1998; but see also Essington et al. [2006] for addition of low-TL fisheries instead of decline in high-TL fisheries, termed “fishing through marine food webs”). At the same time, however, mariculture efforts, originally devoted mainly to low-TL invertebrates, such as mussels or oysters (see Bardach et al. 1972), are increasingly concentrating on producing high-TL fish (i.e., “farming up food webs”; Pauly et al. 2001). Indeed, the mean-weighted TL of mariculture products in countries such as Chile, Canada, Norway, and the United Kingdom increased since 1970 (Pauly et al. 2001).

Here, we used Food and Agriculture Organization (FAO) mariculture (brackish aquaculture was excluded) production data (Aquaculture Production: Quantities 1950–2004 database for mariculture; FishStat Plus, version 2.31) and estimates of the fractional TL of the farmed species as given in FishBase (www.fishbase.org; Froese & Pauly 2007) and Stergiou and Karpouzi (2003) to assess the trophic signature of the Mediterranean marine aquaculture industry. In aquatic ecosystems TL can have values of between 2.0, for herbivores and detritivores, and >4.5, for piscivores and carnivores (see www.fishbase.org for methods for its estimation). In 2004 (the most current statistics available), mariculture production of farmed species in the Mediterranean was dominated by the Mediterranean mussel (*Mytilus galloprovincialis*) (38%), gilthead seabream (*Sparus aurata*) (29.5%), seabasses (*Dicentrarchus labrax* and *D. punctatus*) (27%), and, to a lesser extent, oysters (*Ostrea* spp. and *Crassostrea* spp.) (3.5%). The production of herbivorous species (TL = 2), such as bivalves (mussels and oysters), increased from approximately 2,000 t in 1970 to over 100,000 t in 2004. At the same time, the mariculture of intermediate predators (TL = 3.1–4.0; e.g., *S. aurata*,

D. labrax) and of top predators (TL = 4.1–4.5; e.g., bluefin tuna [*Thunnus thynnus*], meagre [*Argyrosomus regius*], greater amberjack [*Seriola dumerilii*]) increased from 20 t in 1983 to 140,000 t in 2004 and from 9 t in 1986 to 1,274 t in 2004, respectively (Fig. 1a). As a result, the mean-weighted TL of mariculture production in the Mediterranean Sea increased from 2.0 during 1970–1985 to 2.85 in 2004 (Fig. 1b). The decrease in the mean-weighted TL in 2002 and 2003 was due to short-term doubling of the Italian production of *M. galloprovincialis* (Figs. 1b & 2). Moreover, we know that *T. thynnus* production (actually a grow-out, capture-based operation, also known as fattening in which juvenile tuna are caught in the wild, penned, and fattened prior to harvesting) has increased rapidly since 1995, reaching about 23,000 t in 2004 and 30,000 t in 2005 (Kirsch 2006), whereas FAO reported production of 535 t for 2004.

The question is whether the overall Mediterranean trend is driven by wide between-country variation in the species farmed and trends in production or whether different mechanisms can explain trends in different countries. Our analyses of Mediterranean mariculture production showed that although the mean TL in Greece started to increase in the late 1970s (Fig. 2), its production was very low compared with the total Mediterranean until the early 1990s. Greek mariculture production averaged 252 t for 1970–1989 and 53,102 t for 1990–2004, which accounted for <1 and 30%, respectively, of the total Mediterranean production. Similarly, the relative production in Turkey started to exponentially increase from the early 1990s. Turkish mariculture production averaged 55 t for 1970–1989 and 19,561 t for 1990–2004, which accounted for <0.1 and 10%, respectively, of total Mediterranean production. In contrast, the relative mariculture production of France and Italy, both of which operate at a much lower mean TL than Greece and Turkey (Fig. 2), declined after the 1990s. The mean percent contribution of French mariculture declined from 34% for 1970–1989

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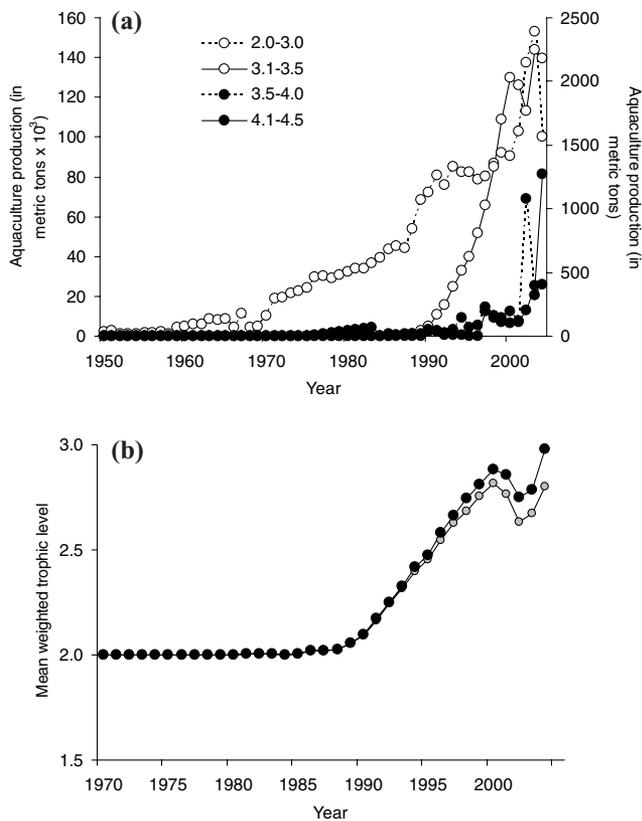


Figure 1. (a) Production of Mediterranean marine farmed species per trophic-level (TL) class (the lower the class number, the lower the TL; open circles, left axis; solid circles, right axis). (b) Mean weighted TL of the Mediterranean marine farmed species for 1970–2004 (gray circles) and recalculated mean weighted TLs (black circles), including production of *Thunnus thynnus* (fattening) from non-FAO (Food and Agriculture Organization) sources (see text for explanation). Only a small part of Turkish marine aquaculture (about 8%) is derived from the Black Sea (Deniz 2000; FAO 2007); thus, it is not shown here.

to 20% for 1990–2004, and that of Italian mariculture declined from 63% for 1970–1989 to 37% for 1990–2004. Thus, farming up the food web in the Mediterranean mainly coincided with the relative production increase in Greece and Turkey and was only felt after the 1990s.

When we considered data other than that from the FAO for *T. thynnus* (Kirsch 2006), the farming-up effect was enhanced, especially after 2000, and the adjusted mean-weighted TL reached 2.98 in 2004. This is important given that *T. thynnus* farming has many adverse ecological effects, including overfishing of its stocks (through illegal fishing) and of the small pelagic fish stocks to meet its feeding requirements (CIESM 2007). Indeed, *T. thynnus* stocks are highly threatened. Fishing for this species in the eastern Atlantic and the Mediterranean was banned starting in September 2007 for the rest of that year

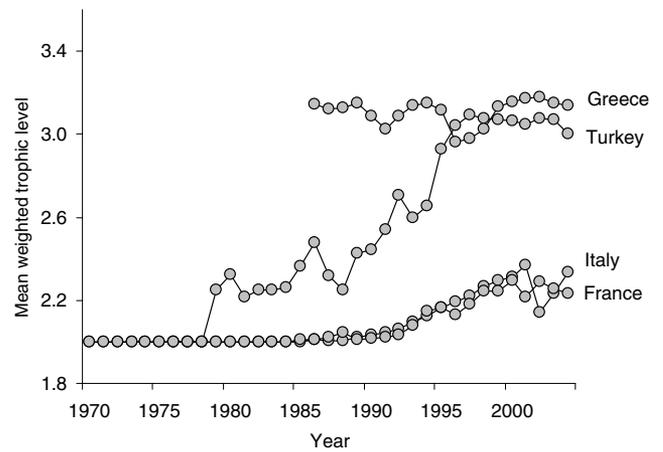


Figure 2. Mean weighted trophic level of the marine farmed species in the 4 main aquaculture countries for 1970–2004.

because the total allowable catch (29,500 t) had been reached (EU Press release-IP/07/1355). It is noteworthy that the capacity of tuna farms in the Mediterranean is about 55,000 t (CIESM 2007). The fact that the capacity of tuna farms greatly exceeds the total allowable catch indicates lack of conservation planning in development of the tuna-fattening industry, which, ideally, should have been linked to fisheries management policies, and may lead to illegal fishing.

Similar to the general Mediterranean trend, the mean-weighted TL of the marine-farmed products increased considerably during the same time period in 3 out of the 4 main producing countries, which represented more than 90% of the total production of Mediterranean farmed fisheries products in 2004 (i.e., TLs from 2.0 in 1976 to 3.0–3.1 in 1997–2004 in Greece; from 2.0 in 1970 to 2.3 in 2004 in Italy; and from 2.0 in 1970 to 2.2 in 2004 in France) (Fig. 2). In Turkey the mean-weighted TL, which was much higher than in the remaining countries and the Mediterranean as a whole, fluctuated around 3.4 (Fig. 2).

The Mediterranean is being “farmed up.” This farming up has masked the full extent of “fishing down” in the Mediterranean (Pauly et al. 1998, see their figure 2d), rather than generating fishing down as an artifact, or enhancing it, as has been suggested by Pinnegar et al. (2003). They maintain that the TL decline of marine fisheries landings in the Mediterranean is due to the progressively higher contribution of cultured low-TL organisms, such as bivalves and gray mullets.

The Mediterranean aquaculture industry, therefore, is a net fish consumer because the production of high-TL species requires large amounts of animal feed, derived from small pelagic fishes (e.g., sardines, anchovies, some of which are caught locally), which earlier were used for direct human consumption.

Mariculture of high-TL species raises not only ecological concerns but also socioeconomic and ethical concerns because large quantities of fishes suitable for direct human consumption are turned into animal feed, used for the production of relatively small quantities of fishes destined for affluent consumers (Naylor et al. 2000). Thus, the Mediterranean mariculture industry poses economic, conservation, and equity problems. Many of these problems could be addressed by a course reversal—a return to the farming of lower-TL species.

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