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Modeling population dynamics and small-scale fisheries yields of fish farming escapes in Mediterranean coastal areas

David Izquierdo-Gomez[a,*], Just T. Bayle-Sempere[a,b], Francisco Arreguín-Sánchez[c], Pablo Sánchez-Jerez[a]

[a] Dept. de Ciencias del Mar y Biología Aplicada, Edificio Ciencias V, Facultad de Ciencias, Universidad de Alicante, Aptdo. Corr. 99, E-03080 Alicante, Spain
[b] Instituto Multidisciplinar para Estudio del Medio "Ramón Margalef", Edificio Ciencias II, Universidad de Alicante, Aptdo. Corr. 99, E-03080 Alicante, Spain
[c] Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas (CICIMAR-IPN), Aptdo. Postal 592, La Paz 23000, BCS, Mexico

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ABSTRACT

Coastal ecosystems put up a number of impacts from human activities in the sea; the most recent is fish farming, interacting synergistically with the other impacts and with the natural structure and dynamics of the coastal ecosystem. In the Mediterranean Sea, the number of fish farms has increased dramatically from early '80s in coastal waters, releasing a substantial amount of organic matter, modifying the habitat and communities beneath cages and changing the spatio-temporal distribution of species. Among all the effects derived from fish farming, escape events of cultured fish are a relevant issue for management given their potential impact over wild counterparts in terms of habitat and food competition, genetic flow, biodiversity, spread diseases or parasites, and interaction with local fisheries, decreasing the price of the catches. This paper shows the first approach to model the temporal trends of biomass and yields of escapes from aquaculture by means of an EwE model. Three levels of escapes ($\times 1$, ordinary level: 5000 ind year^{-1} fish farm^{-1}, corresponding to 1.31 t year^{-1}; massive event: ordinary level $\times$ 91; total destruction of fish farm: ordinary level $\times$ 1800) and four levels of fishing effort (ordinary E, $\times 2$, $\times 5$, $\times 10$) were modelled as mechanism to recapture escapees. Temporal variation of biomass and yield is used to define how long should be maintained the effort to catch escapees. The total destruction of a fish farm generates the higher increase of escapees' landings, dissapearing in less than 6 months if fishing effort reach 10-fold the ordinary fishing effort. Differences among revenues from recaptures and derived expenses were always negative but tending to be greater for low levels of fishing effort and/or levels of escapes which means no fishery can be expected to be maintained by escapes. In general, fleets benefit from escapees in terms of yield but gains will depend on how escapees affect either positively or negatively the value of the catch. Simulations using EwE models may result a useful tool to design suitable recapture plans of escapees.

1. Introduction

Nowadays, farmed fish contributed a record 42.2% of the total 158 million tons of fish produced by capture fisheries (including for non-food uses) and aquaculture in 2012, accounting for 13.4% in 1990 and 25.7% in 2000 (FAO, 2014). This trend is still to grow and it is predicted that 62% of fish will be aquaculture-produced by 2030. Although the aquaculture output of some industrialized regional producers as Spain, France and Italy, has fallen in recent years, the overall European production trend is still ascending (FAO, 2014). The economic losses associated to fish escaping from floating cages are considered a major handicap for industry showing related to the standard of materials and production procedures at farms (Jackson et al., 2015). While losses in Atlantic salmon (*Salmo salar*) producing countries of northern Europe are estimated in €4.7 million per annum, losses of Mediterranean producers of sea bass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) rise up to a staggering €42.8 million (Jackson et al., 2015).

Fish escaping from farms entail ecological risks as feral stock establishment, pathogen transmission, genetic interactions or competition with wild fish for mating, space, and prey, all reviewed, regarding Atlantic salmon, by Naylor et al. (2005). In the same way, escapes of cultured species in the Mediterranean Sea have shown direct effects on the ecosystem (e.g. Diana, 2009), as well as genetic introgression in wild populations (Šegvić-Bubić et al., 2011) or food competition (Toledo-Guedes et al., 2009; Arechavala-Lopez et al.,

* Corresponding author. Tel.: +34 669194216.
E-mail address: david.izquierdo@ua.es (D. Izquierdo-Gomez).

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2012; Valero-Rodriguez et al., 2015). Escapes occurring in areas where there is no wild population of the cultured species can raise ecological and socioeconomic issues as in the western coasts of both North (Volpe et al., 2000) and South America (Soto et al., 2001) and in the Canary Islands, Spain (Toledo-Guedes et al., 2014).

Fisheries are as well influenced by fish escaping from fish farms. Schiermeier (2003) estimated in two million, the salmon individuals escaping from farms every year into the North Atlantic area. Hansen et al. (1999) estimated the incidence of escaped Atlantic salmon in the North Atlantic High Seas fisheries (off the Faroes islands) between 20% and 40%. In the Mediterranean, there are as well evidences that the wild stock of sea bream is enhanced in areas where aquaculture is present (Dimitriou et al., 2007). The latter, although at a different scale, is in conflict with the stagnation and decline of fisheries catches since late 1980s (Pauly et al., 2003). The future scenario of world fisheries predicts that there will be no fish for developing countries by 2050 (Pauly et al., 2003). At a lower scale, there is an increasing need for a sustainable exploitation of target species in coastal areas (Tzanatos et al., 2013). Ecopath with Ecosim (Christensen et al., 2008) is a well-known tool to model and evaluate the impact of fisheries and ecological changes on the ecosystem (Pauly et al., 2000), however it has never been used to evaluate how fisheries can recapture fish escaping from floating cages in fish farms. In terms of management, the escape events are regulated either in Norway, Canada, United States, Scotland, Chile or Australia (regulations links at Izquierdo-Gomez et al., 2014) all describing fishing actions as part of their contingency plans to be activated as soon as a fish escape occurs. Surprisingly, none of the Mediterranean fish producing countries regulate the escape events under a legal framework, most likely as a consequence of the scarce knowledge about fisheries and escape events interaction, among others.

In this study the ability of a small-scale fleet to recapture escaped fish from a fish farm was modelled and several scenarios of different escape magnitudes and fishing efforts were simulated by using Ecopath with Ecosim. The outputs of the model will be useful to develop management measures by answering questions as (1) how long will the escaped fishes remain in the ecosystem and how will be its population dynamics? (2) For how long would the fishing fleet be able to recapture escaped fish?, (3) Is it cost-effective to recapture the escaped fish as an independent activity?

2. Materials and methods

2.1. Study area

The study area is situated in the southeast of Spain (West Mediterranean Sea) covering 891 km^2, between 38°17–37°36′N and 00°43–00°18′W (Fig. 1). This area includes four floating-cage fish farms, one 14 km^2 marine protected area around Tabarca Island and two fishing ports harboring 60 trammel-netters and 32 bottom-otter-trawlers. This area is characterized by a relative wide shelf with low slopes, reaching 100 m depth at tenths of km's from the shore, exhibiting oligotrophic waters with surface temperature values ranging from 13 °C in winter to 28 °C during summertime. Water clarity (Secchi disk depth) varied between 8 m and 30 m from winter to summer. Bionomically, the shelf is composed by *Posidonia oceanica* meadows, sandy seabeds close to the shoreline, some rocky bottom spots mainly around Tabarca Island, and soft muddy seabeds in the deeper zones and off the Segura River.

Fish farms are located 3 mi offshore on soft muddy bottoms at depths ranging from 21 to 30 m, off the mouth of the Segura River. Each fish farm consists of 20–24 floating cages of 450 m^3, each rearing around 775 t of fish biomass. All together, they grow ca. 6500 t year^{-1} of european seabass (*D. labrax*) and gilthead seabream

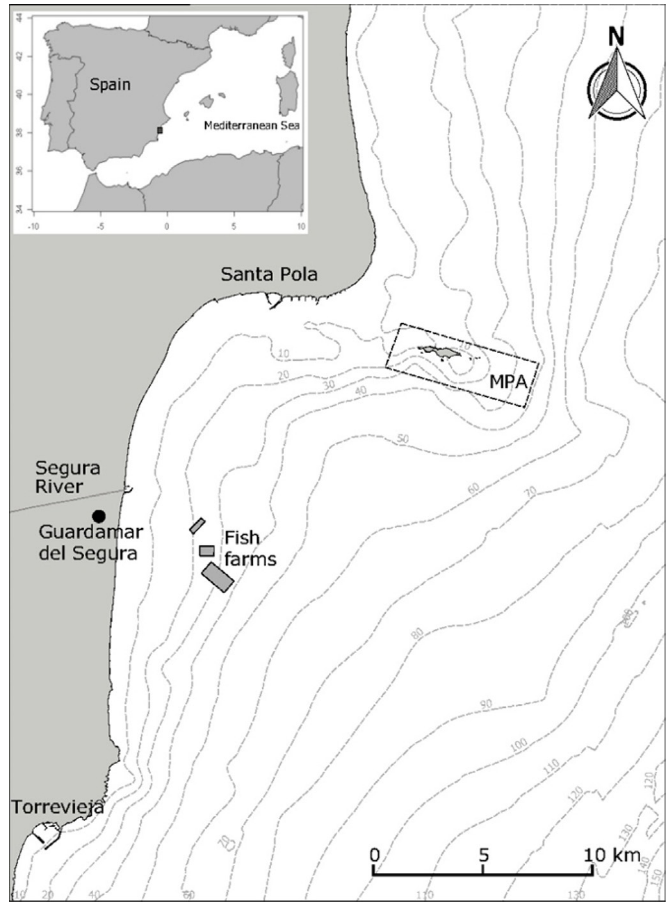

Fig. 1. Location of the studied area.

(*S. aurata*); in average, 5000 fish year^{-1} fish farm^{-1} escape to the wild environment (1.21 t year^{-1}) contributing to the commercial catches or remaining naturalized in the study area (Arechavala-Lopez et al., 2012).

2.2. The model

An Ecopath model (Christensen et al., 2008) was assembled describing the trophic relationships among 32 ecological groups sharing similar feeding roles, keeping as individual groups those of particular interest (see Table 1). The model provides a static description of an ecosystem at a precise period in time, based on the premise that the considered system is balanced in the given time period (Polovina, 1984); being production equal to consumption following the equation: $B_i\ (P/B)_i\ \mathrm{EE}_i - \Sigma_j\ B_j\ (Q/B)_j\ \mathrm{Dc}_{ji} - Y_i - \mathrm{BA}_i - E_i = 0$; where for an i group, P_i is production, B_i is biomass (t km^{-2}) and EE_i is ecotrophic efficiency. Moreover, Q_j is the consumption for predators, BA_i is the biomass accumulation rate for i and E_i is the net migration rate of the group. Because material transfers among groups take place through trophic relationships, this equation is re-expressed including the biomass of predators and the instantaneous rate of total mortality (Z) at equilibrium (Allen, 1971) in the form of P/B rate, describing the biomass flow balance between inputs and outputs for each group (see Christensen et al., 2008, for a complete explanation). A system of linear equations was established in which three parameters were introduced: biomass (B), total biological production rate (P/B); total food consumption rate (Q/B) and only one, EE, was estimated by the model. Diet composition is expressed as a fraction of prey in the average diet of a predator. Fishing data are also included by adding data on landings (t km^{-2}).

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