Hydrobiologia (2023) 850:203–214
https://doi.org/10.1007/s10750-022-05054-w

PRIMARY RESEARCH PAPER

First releases of hatchery-produced Senegal sole (*Solea senegalensis*), brill (*Scophthalmus rhombus*), and wedge sole (*Dicologoglossa cuneata*) juveniles in the South-western Spanish coast

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Received: 15 March 2022 / Revised: 3 October 2022 / Accepted: 9 October 2022 / Published online: 26 October 2022

Abstract The regression of fisheries in the Gulf of Cadiz is evident since current fish catches are 33% of that 30 years before. Consequently, some initiatives for the replenishment of exhausted wild stocks are welcome. The objective of the present work is to describe and analyse the results coming from the first flatfish stock enhancements in Andalusia. A total of 3189 fish from three flatfish species: Senegal sole (*Solea senegalensis* Kaup), wedge sole (*Dicologlossa cuneata* Moreau), and brill (*Scophthalmus rhombus* Linnaeus) were tagged and released. Several variables were calculated through the data analysis of recovered fish. Some variables were calculated only for Senegal soles since wedge sole and brill recaptures were not significant. The Senegal sole recapture rate was 2.71 ± 0.72, similar to other published data, the recapture rates for bigger fish being higher though not significant. No significant differences were detected for distance, time, growth, or recapture rate amongst initial Senegal sole sizes. Around 80% of recaptures were registered within 15 weeks after release. The results show that it is possible for the release and recovery of tagged Senegal soles in the Gulf of Cadiz. Future long-term programmes on stock enhancement could help to determine the effects on fisheries and recover stocks.

Keywords Flatfish · Senegal sole · Fish stock enhancement · Recapture · Tag

Handling editor: Grazia Pennino

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Introduction

Fish stock enhancement is aimed at several different purposes though all of them focus on the reinforcement of the wild stocks, for both productive (fisheries enhancement) and ecological (ecosystem and/or species protection) targets. In this way, releasing hatchery-produced (cultured) fish juveniles in the wild can improve the system productivity through different ways: replenishing severely depleted fisheries, enhancing the production of recruitment-limited fisheries, and aggregating/relocating adults for some species (Bell et al., 2006).

The first stock enhancement programmes took place in Japan (1963) and Norway (1999). Currently the former has released 72 species of fish, shellfish, and other invertebrates, supposing 2000 millions of released fish, mainly chum salmon (*Oncorhynchus keta* Walbaum) (Kitada et al., 1992; Ishino, 1999; Yamashita & Yamada, 1999; Kitada, 2018). Norway has also developed several restocking programmes with some species, mainly Atlantic salmon (*Salmo salar* Linnaeus) and cod (*Gadus morhua* Linnaeus) (Svåsand et al., 2000; Andersen et al., 2005; Støttrup & Sparrevohn, 2007; Hagen et al., 2020). In fact, fish stock enhancement is an usual activity involved in long-term programmes and several works have reported its beneficial effects on the wild stocks of some species as the barfin flounder (*Verasper moseri* Jordan & Gilbert), the spotted halibut *Verasper variegatus* (Temminck & Schlegel), the Japanese sea bream (*Pagrus major* Temminck & Schlegel) and flounder (*Paralichthys olivaceus* Temminck & Schlegel), the flathead grey mullet (*Mugil cephalus* Linnaeus), and the red drum (*Sciaenops ocellatus* Linnaeus) (Rutledge, 1989; Leber & Arce, 1996; Kitada & Kishino, 2006; Wada et al., 2012, 2014).

In addition to Japanese and barfin flounders and spotted halibut, other stock enhancement programmes with flatfish have been carried on 1990–2004 in Denmark. Concretely, nearly one million of turbots (*Scophthalmus maximus* Linnaeus) have released in several places from the Danish coast (Støttrup et al., 2002; Paulsen & Støttrup, 2004; Sparrevohn & Støttrup, 2007). Thanks to those works, the authors have reported that some variables such as the depth distribution, growth, and nutritional status were similar between released and wild turbots. Hence, they have stated that this species is robust and unaffected by release procedures and handing and, consequently, the release of hatchery-produced turbots can increase the fishery recruitment.

Therefore, the fish stocking activities have usually contributed to the protection of fish stocks and the maintaining of a sustainable development of coastal fisheries (Chen et al., 2015). Nevertheless, Kitada (2018) has reported that a general lack of evaluation of positive and negative effects of hatchery releases exist, despite stocking activities are economically profitable in the most of cases. For this reason, many works continue publishing focused on the study and reduction of genetic and ecological impacts, and the improvement of the fish tagging methods and the fisheries assessment (Berejikian et al., 2012; Christie et al., 2012; Nakajima et al., 2013; González et al., 2015; Szuwalski et al., 2015; Bolstad et al., 2017; Grant et al., 2017; Yang et al., 2017).

In the Southern Spanish coast the first marine fish stock enhancements were carried out in 1993 with gilthead sea bream (*Sparus aurata* Linnaeus) juveniles (Sánchez-Lamadrid, 2002). Later, this and other fish species were released in that coast: Senegal soles (*Solea senegalensis* Kaup), white seabreams (*Diplodus sargus* Linnaeus), red-banded sea breams (*Pagrus auriga* Valenciennes), red sea breams (*Pagrus pagrus* Linnaeus), and rubberlip grunts (*Plectorhinchus mediterraneus* Guichenot) (unpublished data). In Spain also turbot juveniles have been released in the Northern coasts (Pérez et al., 2004).

Nevertheless, the most of those activities were not involved in any research project/programme, hence the available information about them is scarce. In fact, our research team also released 10,000 Senegal sole alevins (1–1.5 g body weight) in the Gulf of Cadiz (2 miles from Huelva's coast) in 2005. These fish were not tagged because of their small size, hence no research on recapture could be carried out. Only Sánchez-Lamadrid (2002, 2004) provided information on size, tags, and other parameters in several releases of gilthead sea breams made in the Bay of Cadiz.

The Senegal sole and wedge sole are very valuable commercial flatfish in the Gulf of Cadiz. These species joint to other soleids have reached a worldwide fishery production of 41,000 MT in 2016, and the main countries are the Netherlands, Nigeria, France, and Morocco (FAO, 2018). They inhabit Eastern Atlantic muddy and sandy bottoms (0–65 m depth), from Senegal to the Iberian Peninsula; being also present in the Western Mediterranean sea (Bauchot, 1987; Ben-Tuvia, 1990). Senegal soles have nocturnal feeding habits and prey upon benthic invertebrates: crustaceans, polychaetes, and molluscs (Garcia-Franquesa et al., 1996). Wedge sole feeding is based on polychaetes, amphipods, and bivalves (Belghyti et al., 1994; Ramos et al., 1996; Cabral et al., 2002). Both species are gonocoric, reaching the sexual maturity at 15 cm (+ 1 year) and 25 cm (+ 3 years) length for wedge and Senegal sole, respectively (Dinis, 1986; Jiménez et al., 1998). The maximum length in adults is 30 and 60 cm for *D. cuneata* and *S. senegalensis*, respectively (Desoutter, 1990; Pérez and Rodríguez, 2001). Both soleid species are mainly fished near coast with gillnets and bottom trawls, and the fishery catches in Andalusia are around 17 and 97 MT for *S. senegalensis* and *D. cuneta*, respectively (Consejería de Agricultura y Pesca, 2001; Consejería de Agricultura, Pesca y Desarrollo Rural, 2017). In the Gulf of Cadiz, Senegal and wedge soles are fished all year around; their peaks usually being in Feb–Mar and Jan–Feb, respectively. There are no seasonal restrictions for their fishing although they have minimum legal sizes, 24 and 15 cm for Senegal sole and wedge sole, respectively.

Worldwide, the fishery production of brill is around 5700 MT, the Netherlands, France, and the UK being the main producers (FAO, 2018). This species is not abundant in the Gulf of Cadiz although its market value is one of the highest in the Andalusian fish markets (19 € Kg^{-1}). In fact, a small fishery production of 6 MT supposed 127,000 € in 2017, being the second most expensive fish species (Consejería de Agricultura, Pesca y Desarrollo Rural, 2017). It inhabits coastal waters (5–50 m depth) from Eastern Atlantic to the Mediterranean Sea and its feeding is based on fish and big crustaceans. Brills are gonocoric and reach the sexual maturity at 37 cm (around 3 years old) (Bauchot 1987). As the previous species, they are fished all year around in the Gulf of Cadiz, with no seasonal restrictions, the minimum legal size being 30 cm.

The regression of the fisheries in the Gulf of Cadiz (Spanish South-west) is evident since current fish catches are 33% of that 30 years before (Consejería de Agricultura, Pesca y Desarrollo Rural, 2017). Currently, there are no accurate and consistent data on brill and Senegal sole fishery production since they are often mixed with other species in general groups, like "Soles" and "Turbots". Nevertheless, the wedge sole catches have dropped up to 3% in 30 years. Consequently, some initiatives for the replenishment of close to depletion wild stocks were welcome. Taking this into account, the objective of this work is to describe and analyse the results coming from the first flatfish stock enhancements in Andalusia (Southern Spain).

Materials and methods

This work was directed by trained scientists (category C) and it was carried out in compliance with the Guidelines of the European Union Council (86/609/EU), and the Spanish Government (RD1201/2005) for the use of animals in research.

Zootechnical and transport procedures

Fish were reared at the IFAPA Agua del Pino, sited in Cartaya (South-western Spain). This research centre had several broodstocks from three different commercial flatfish species: *Solea senegalensis*, *Scophthalmus rhombus*, and *Dicologlossa cuneata*. Those spawners were fished from the wild and adapted to captivity during 2002–2005, and the whole broodstock was consisted of 78 Senegal soles, 58 wedge soles, and 32 brills.

Specific culture protocols (from egg to juveniles) for every species were followed in order to get juveniles (Ribeiro et al., 1999; Herrera et al., 2008; Hachero-Cruzado et al., 2009). Briefly, the eggs were collected through natural spawning and incubated at 20 °C (Senegal and wedge soles) and 14 °C (brill) for 2–5 days. After hatching, the larval rearing was carried on 250-l cylinder-conical tanks at 20 °C in a flow-through system. Brill larvae were progressively acclimated to that temperature (1 degree/day increase). The larval feeding consisted of rotifer and *Artemia* until the weaning at 40–60-day post-hatching. Later fish were fed commercial marine fish feed (Skretting LE-3, Burgos, Spain) according to the manufacturer recommendations (around 1–3% biomass daily). Three weeks before the fish release they were fed commercial frozen natural food (mussels and squid), since it has been proposed that a previous natural food-based diet can increase the stock enhancement efficacy (Walsh et al., 2013).

Fish were starved 24 h prior the release day, and the water culture temperature during the last week was progressively modified to 16 °C, similar to the natural seawater temperature. Fish were transported from IFAPA Agua del Pino to Mazagón's harbour into 600-l isothermal tanks (89 × 110 × 57 cm) through a refrigerated truck. The water temperature was 16–17 °C and every tank was linked to an oxygen bottle through air-stones in order to keep the water dissolved oxygen above 5 ppm. The stocking density was less than 16 kg m^{-2}. The tanks were moved out the truck to the ship by a crane. Once tanks were placed on the ship deck, the oxygen supply was stopped and tanks water was renewed through pumping from the sea water, hence fish could be acclimated to the natural water physical–chemical conditions for more than one hour before releasing.

Several batches of tagged flatfish (2010 Senegal soles, 756 wedge soles, and 423 brills) were released in two artificial reefs (El Rompido and Matalascañas) placed in the South-western Spanish coast (see more details in Table 1 and Fig. 1). These places were chosen to ensure an initial shelter for released fish since the most of fishing gears (mainly gillnets) cannot be used in those areas (risk of breaking or hooking).

Tagging, sampling, and data collection

Prior transport and release, all fish were measured (total length and body weight, Table 1) and T-tagged (FF-94® from Floy Tag, Seattle, USA). Fish survival after handling and tagging was 99.5 and 95.9%

Table 1 Place (artificial reef name, code, and depth) and date of every stocking enhancement, including number, species, and mean (± SE) weight and total length of released fish

Place	Date	Code	n	Species	Weight (g)	Length (cm)
El Rompido (10 m depth)	Nov 29, 2006	ROM	257	*Solea senegalensis*	142 ± 4.2	21 ± 0.19
			756	*Dicologlossa cuneata*	23.7 ± 0.2	13.4 ± 0.03
			194	*Scophthalmus rhombus*	55.9 ± 1.8	15.7 ± 0.17
Matalascañas (13 m depth)	Mar 21, 2007	MAT1	856	*Solea senegalensis*	152 ± 2.1	21.2 ± 0.09
	Jun 13, 2007	MAT2	468	*Solea senegalensis*	119 ± 2.2	20.1 ± 0.12
	Dec 11, 2007	MAT3	429	*Solea senegalensis*	191 ± 3.2	23.2 ± 0.48
			229	*Scophthalmus rhombus*	130 ± 3.8	20.3 ± 0.19
TOTAL			2010	*Solea senegalensis*	156 ± 3.1	21.3 ± 0.12
			756	*Dicologlossa cuneata*	23.7 ± 0.2	13.4 ± 0.03
			423	*Scophthalmus rhombus*	84.4 ± 2.3	18 ± 0.17

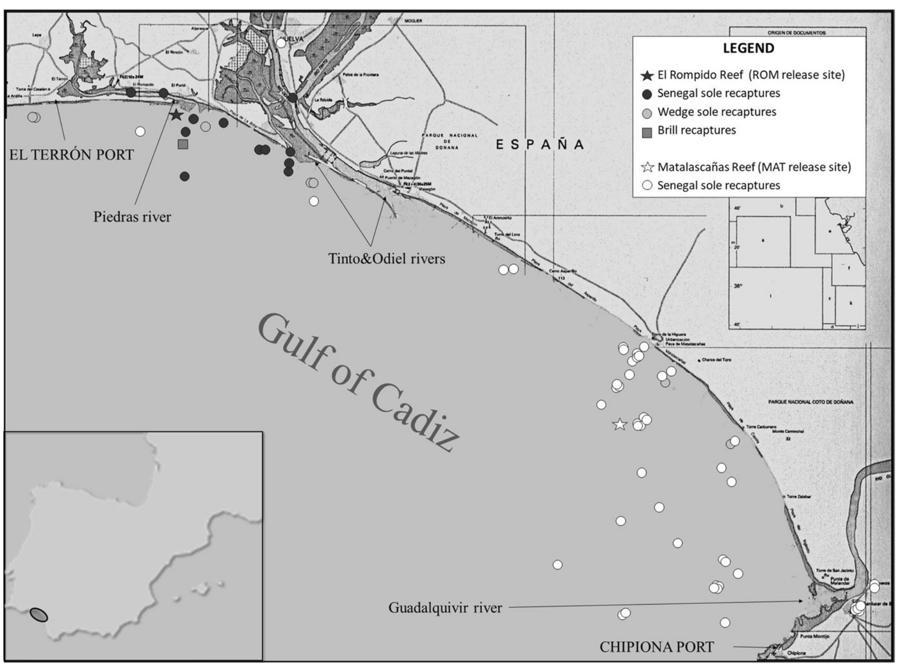

Fig. 1 Map of the South-western Spanish coast (Gulf of Cadiz). Release (stars) and recapture (circles) sites for all fish are marked (see legend for details)

for the Senegal sole and brill, respectively. However, this variable decreased to 73.7% for the wedge sole. It was surely due to the mean size of this species (23.7 ± 0.07 g and 13.4 ± 0.03 cm).

A different identifier code (four digits) and a single free telephone number were printed in every tag. The code was associated with every individual biometric data and the telephone number was which fishermen could call in when captured any tagged fish and provide the next data: fish code, weight and length, fishing gear, date, and location.

Just after every fish release, several informative sessions were carried out along the Gulf of Cadiz coast (from Chipiona, 36° 44′ N; 6° 26′ W, to El Terrón, 37° 13′ N; 7° 10′ W, see Fig. 1). The aim was to collect data about tagged fish in fishermen associations, fish markets, ports, and related. Many flyers and posters were delivered in all these places. The instructions to follow when somebody fished a tagged fish were clearly explained in them.

Tagged fish data were collected from 29 November 2006 to 30 November 30 2008. Several parameters are calculated: individual-specific growth rates (SGR = 100·[ln(final weight) − ln(initial weight)]/time); individual elapsed time (time between releasing and recapture dates); recapture rate (100 number of released fish/number of captured fish); and individual movement (distance between releasing and recapture places).

Natural (M) and fishing (F) mortalities are calculated according to Lin et al. (2010), based on the Gulland (1955) likelihood function:

$$L = m\left[1 - \frac{F}{F+M}\left(1 - e^{-(F+M)T}\right)\right]^{N-n} F^n e^{-(F+M)\sum_{i=1}^{n} t_i},$$

where N is the number of fish tagged and released, n is the number recaptured, t_i is the recapture time for recaptured fish i, m is the combination constant = $N!/n!(N–n)!$, and T is the last recapture time. F and M were estimated by maximizing L using a non-linear optimization through the Global Optimisation Tool (Generic Algorithm) from MATLAB (MathWorks Inc., MA, USA).

Statistical analyses

Normality and homoscedasticity of all datasets were checked through the Kolmogorov–Smirnov and Levene tests, respectively. Groups were compared through a Student's t or one-way ANOVA test performing a Duncan post hoc test to detect homogeneous groups (for normal groups), or a Kruskal–Wallis or Mann–Whitney U test (for non-normal groups). Statistical differences amongst capture rate percentages were checked through a Chi-square test. Data are expressed as mean ± standard error of mean. The significance level was 0.05.

Results

Figure 1 shows the map of the South-western Spanish coast, pointing out the artificial reefs and recapture places for all recovered tagged fish. The spatial distribution of fish released in the Matalascañas reef was more disperse than that for the El Rompido reef. In fact, distances were significantly different ($p = 0.01$): 12.3 ± 10.3 and 6.63 ± 4.45 km (mean ± SD) for Matalascañas and El Rompido reefs, respectively. Moreover, many recaptures took place into and near rivers and river mouths (Guadalquivir, Piedras, and Tinto & Odiel rivers) for all releases. Only seven wedge soles and two brills were recovered, thus their recapture rates were very low, 0.9 and 0.4/0.5% (two different releases), respectively. Therefore, their data could not be processed for the calculation of some post-release parameters.

The summary of post-release data coming from the fishermen information is shown in Table 2. One wedge sole swam the maximum distance, around 58 km (for 65 days) from the release area. However, the highest time in the wild, 159 days, was registered for a Senegal sole. Overall, the wedge soles swam larger distances than Senegal soles, 23.9 ± 8.2 km *versus* 11.1 ± 0.13 km.

Table 3 shows some post-release parameters depending on initial fish size only for Senegal soles. No significant differences were detected for any parameter amongst sizes ($p > 0.5$) or releases ($p > 0.3$). Neither amongst season release, being autumn for ROM and MAT3 and spring for MAT1 and MAT2 ($p > 0.3$ except for displacement, $p = 0.079$) nor release site (El Rompido and Matalascañas, $p > 0.3$). The effects of initial size on recaptures or fish displacements were not significant ($p > 0.5$). Finally, the release area/reef (El Rompido or Matalascañas) did not affect the final weight or recapture rate,

Table 2 Recapture rate (%), time from release (days), and distance from release area (Km) for the tagged fish recaptured after every stocking enhancement

		Mean (±SE)	Minimum	Maximum
Recapture rate	*S. senegalensis*	2.71±0.72	1.28	4.28
	D. cuneata	0.92	0.92	0.92
	S. rhombus	0.48±0.04	0.44	0.52
	Total	2±0.9	0.1	5.6
Time	*S. senegalensis*	51.6±3.99	0	159
	D. cuneata	52±13.2	12	65
	S. rhombus	32±11.5	20	43
	Total	49±4	0	159
Distance	*S. senegalensis*	11.1±0.13	1	55.2
	D. cuneata	23.9±8.2	2.2	58.1
	S. rhombus	2	2	2
	Total	12.3±1.5	1	58.1

although the initial weight was significantly different between both reefs (Table 4). The relatively high fish size for releasing could have been the reason of the lack of differences between the analysed variables (see Discussion).

The fishing mortality was always higher than the natural one, as shown in Table 5. Moreover, both rates in releases during spring (MAT1 and MAT2) were higher than the others, despite there was no significant difference amongst release parameters (see above, Table 3).

Figure 2 shows the temporal evolution of distance from the release site and time after release. The distance from the release site did not follow a clear pattern over the time, although only after 2 weeks some fish had swum over 15 km. Also, it seems that the most of fish released in Matalascañas reef moved to South (Guadalquivir river mouth). The recapture rates depending on time after release are shown in Fig. 3. Around 80% of recaptures were registered within 15 weeks for every release.

Discussion

These have been the first flatfish stock enhancements carried out in the South of Spain, although other works have been published in Asia, America, and Europe with other flatfish species such as the turbot (*Scophthalmus maximus*), Japanese flounder (*Paralichthys olivaceus*), barfin flounder (*Verasper moseri*), spotted halibut (*Verasper variegatus*), winter flounder (*Pseudopleuronectes americanus* Walbaum), and summer flounder (*Paralichthys dentatus*) (Ishino, 1999; Støttrup et al., 2002; Kellisson et al., 2003; Fairchild et al., 2005; Sparrevohn & Støttrup, 2007; Wada et al., 2012, 2014). Therefore these pioneer stock enhancements in the Spanish Southern coast can provide a first approach on these species biology and restocking efficiency.

Prior to release, fish survival after handling and tagging was 99.5%, 95.9%, and 73.7% for Senegal sole, brill, and wedge sole, respectively. Some researchers have reported that T-tag can decrease the growth in turbot (Støttrup et al., 2002; Paulsen & Støttrup, 2004). In fact, Støttrup et al. (2002) used the colour marking of otoliths with tetracycline or alizarin complexone for smaller fish. Additionally, the external T-tags can cover with mussels and algae, which renders them heavier and more cumbersome, and the relatively sedentary, benthic lifestyle of flatfish may encourage tag fouling, as reported in Støttrup et al. (2002). Nevertheless, the external T-tags can be easily readable for fishermen and their collaboration can be crucial in this type of studies.

The recapture rates obtained in this work for Senegal soles (1.3–5.5%) were similar to those reported in both Perciformes and Pleuronectiformes fish stock enhancements (Bergstad & Folkvord, 1997; Sánchez-Lamadrid, 2002). Although no significant differences were detected amongst groups (Table 3), large and intermediate fish showed higher recapture rates, which leads to hypothesize that survival was better. Similarly, in another flatfish as the turbot, recapture rates (through research surveys) were lower for

Table 3 Mean (± SE for total values) distance from release area (Km), time from release (days), specific growth rate (% day^{-1}), and recapture rate (%) for only tagged Senegal soles (*Solea senegalensis*) recaptured depending on the initial size (small, intermediate and large, 32 fish/size group)

Name	Distance				Time				SGR				Recapture rate			
	Small (< 131 g)	Interm. (131–198 g)	Large (> 198 g)	Total	Small (< 131 g)	Interm. (131–198 g)	Large (> 198 g)	Total	Small (< 131 g)	Interm. (131–198 g)	Large (> 198 g)	Total	Small (< 131 g)	Interm. (131–198 g)	Large (> 198 g)	Total
ROM	6.79	6.5	6.5	6.63 ± 13.4	44	63.8	78	56 ± 13	0.21	− 0.01	np	0.1 ± 0.3	3.65	5.88	2.44	4.18
MAT1	10.8	12.7	13.6	12.6 ± 1.92	54.2	54.4	46.9	51.2 ± 4.41	− 0.26	− 0.02	0.26	0.04 ± 0.12	3.35	4.93	10.8	5.48
MAT2	12.3	10.6	nf	11.7 ± 3.17	52	50	nf	51.3 ± 20.8	0.29	− 0.02	nf	0.01 ± 0.08	1.26	1.72	nf	1.28
MAT3	11.8	6.69	np	9.26 ± 2.56	52	45.5	45	46.6 ± 5.89	0	0.83	− 0.09	0.3 ± 0.42	1.26	1.12	2.78	1.52
TOTAL	10.1 ± 1.44	10.3 ± 1.56	13.1 ± 3.7	11.1 ± 1.33	51.5 ± 6.29	55.3 ± 7.54	48.1 ± 7.08	51.6 ± 3.99	− 0.07 ± 0.13	0.06 ± 0.19	0.22 ± 0.17	0.07 ± 0.09	2.49	3.47	6.91	3.6

np data not provided by the fisherman

nf No fish released/captured in that size

There were no significant differences amongst reef or size range for any parameter

Table 4 Mean (± SE) initial and final weights and number of recaptured fish in every release area/reef (El Rompido = ROM; Matalascañas = MAT1 + MAT2 + MAT3)

	Recaptured fish (n)	Initial weight (g)	Final weight (g)
El Rompido	11	130.8 ± 9.81^{a}	137.2 ± 25.5
Matalascañas	62	181.69 ± 11.2^{b}	185 ± 10.9

Different letters indicate significant differences between release areas

smaller fish (around 0.16–0.22%), increasing in larger individuals up to 11% (Støttrup et al., 2002).

Otterå et al. (1999) have reported high significant correlations between size and recapture rates in cod (*Gadus morhua*), and Sánchez-Lamadrid (2004) have shown similar results in gilthead sea bream (*Sparus aurata*), indicating that 15-g fish registered lower recapture rates due to fish and bird predation and the difficulty to identify small tags. Neither of those hypotheses is applicable to our work because Senegal soles had a significant size, and all tags were identical and clearly visible. In that sense, it has been established that the dependence between size and recapture may be higher for roundfish species with high vulnerability to predation and cannibalism than for flatfish species (Støttrup et al., 2002). Anyway, it is logical to suppose that bigger fish have more probabilities to be fished by typical fishing gears (gillnets and related) than smaller ones.

In other flatfish species such as *Pseudopleuronectes americanus*, low cryptic abilities have related to low released fish survival (Fairchild & Howell, 2004). Although there is no evidence on the cryptic changes in released Senegal soles, it is expectable that this species would adapt its colour skin quickly, as several works have been demonstrated in laboratory experiments (Ruane et al., 2004; Rodiles et al., 2005).

Analysing the recapture rates evolution (Fig. 3), it seems that around 80% of recaptures were registered within the first 15-week post-release, reaching the total rate at 23 week. Sánchez-Lamadrid (2004) reported tagged gilthead sea breams (*Sparus aurata*) caught within 50–100-week post-release, the most of them (80–90%) being recaptured during the first 28–43 weeks. Those differences could be

Table 5 Fishing (F) and natural (M) mortalities (year$^{-1)}$ obtained in every release according to the non-linear maximization of the Gullan (1955) function

Reef	ROM	MAT1	MAT2	MAT3
F	0,0006	0,0015	0,001	0,0002
M	0,0117	0,0241	0,0512	0,0032

due to the final total amount of tagged fish, which was much higher than ours.

The release site and its hydrodynamic and ecological features can affect the fish survival, especially in semi-closed areas. However, our releases were performed in open sea artificial reefs and, in fact, no difference for any parameter was detected amongst release sites (El Rompido and Matalascañas). The estimation of survival through recapture rates is difficult in so large areas, and recapture rates usually are lower. Contrarily, Nakagawa et al. (2007) and Wada et al. (2012) have reported recapture rates over 15% in Japanese bays.

According to Sánchez-Lamadrid (2004), a high recapture rate is related to food abundance. We did not find significant differences for any parameter amongst release site or date although MAT1 showed the highest recapture rate. The fishing pressure is another factor involving in the recapture rates, nevertheless that parameter is relatively stable in the Andalusian coast all-year-around except for July and August, when it grows and, paradoxically, no recapture was registered. Therefore, it is difficult to explain the higher recapture rate in the MAT1 release, when fishing pressure was lower than that for MAT2. Perhaps the bigger fish released and the high natural spring productivity which would improve the fish survival and growth, could justify that higher recapture rate. Nevertheless, as said before, the differences were not significant amongst releases.

No significant differences for distance were found amongst sizes. The release site also can affect the fish movements. According to Fairchild et al. (2005), generally, the more favourable the release site, the less dispersion there is. In fact, tagged turbots released in Galicia (Spanish North-western coast) swam up to 9 km when were released in a 25-m depth area; this distance significantly grew when the depth was higher than 25 m (Iglesias & Rodríguez-Ojea, 1994). Nevertheless, the results in Norway were different since a fish dispersion within a 50 km radius or higher (Bergstad & Folkvord, 1997). In our work, the maximum displacement was registered for a wedge sole (58 km), and it could be related to the swimming

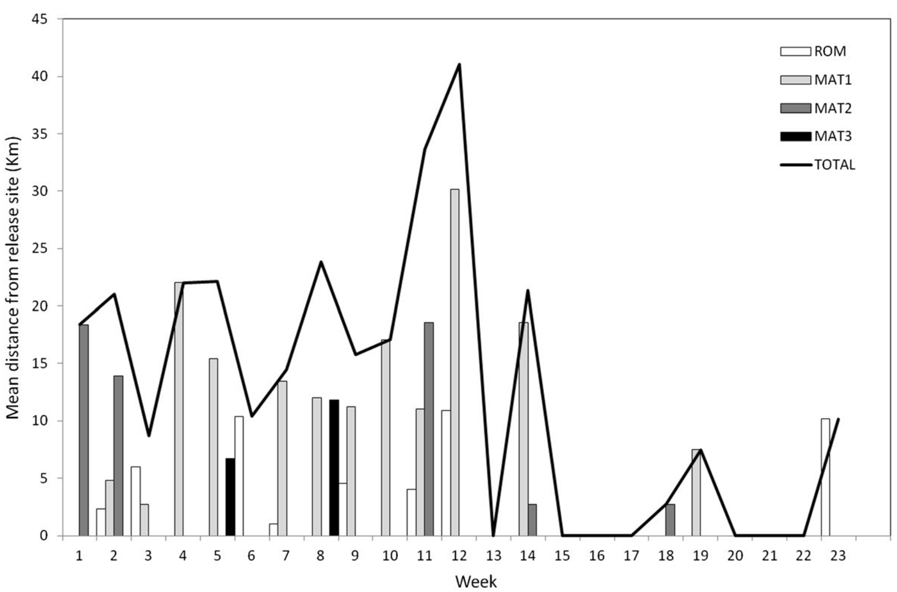

Fig. 2 Mean distance from the release site for tagged fish recaptured depending on time from release (only Senegal soles)

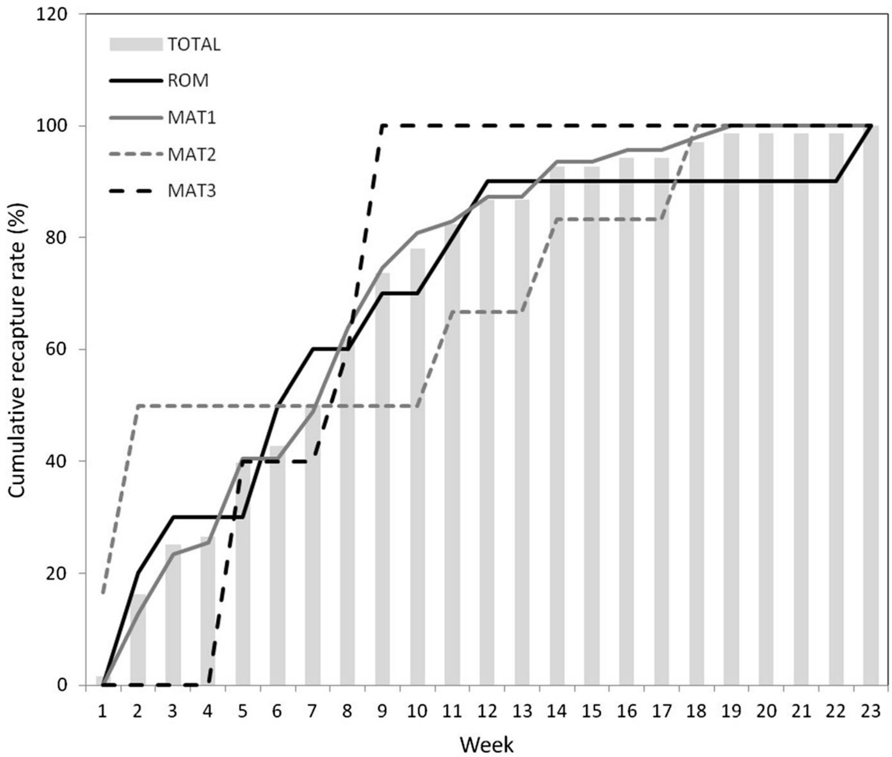

Fig. 3 Evolution of recapture rates depending on time from the release (only Senegal soles)

behaviour of this species, being more active than other flatfish (Herrera et al., 2008). The maximum displacement for the Senegal sole was 55 km, belonging to a fish released in the Matalascañas reef.

Moreover, fish dispersion in El Rompido release was significantly lower than those in Matalascañas reef (see Fig. 1 and Results). It has been reported that river mouths and estuaries are high productivity areas (Broadley et al., 2022). In fact, the Guadalquivir mouth and adjacent marine waters have been described as an important nursery ground for several commercial species in the Gulf of Cadiz (Llope, 2016). The difference between fish dispersion in our work seems to be related to the fish movements to look for higher productivity areas. Therefore, fish released in El Rompido did not displace meaningfully since they were close to the Piedras and Tinto & Odiel river mouths; however, fish from the Matalascañas reef swam to the Guadalquivir mouth, supposing a higher displacement.

The effects of these flatfish releases on the fishery production are very difficult to assess. The low amount of fish released and short time of these activities are the major factors. According to Fig. 4, Senegal sole catches in the Gulf of Cadiz grew from the first stock enhancements although we cannot evidence a relationship amongst commercial captures and releases. At least, it seems clear that the releases did not affect the fishery production negatively. The establishment of long-term stock enhancements programmes and projects could be a useful tool to evaluate the effects on the recovery of natural stocks.

Concluding, after the first hatchery-produced flatfish releases in the Gulf of Cadiz, we can conclude that the design of long-term stock enhancement programmes in the Gulf of Cadiz according to the described methodology is feasible and necessary to recover commercial and endangered species stocks. Future programmes should also include research surveys besides the fishermen information to achieve more data and accurate information. Additionally, laboratory experiments on fish tagging and its effects on fish survival, growth, and welfare are necessary.

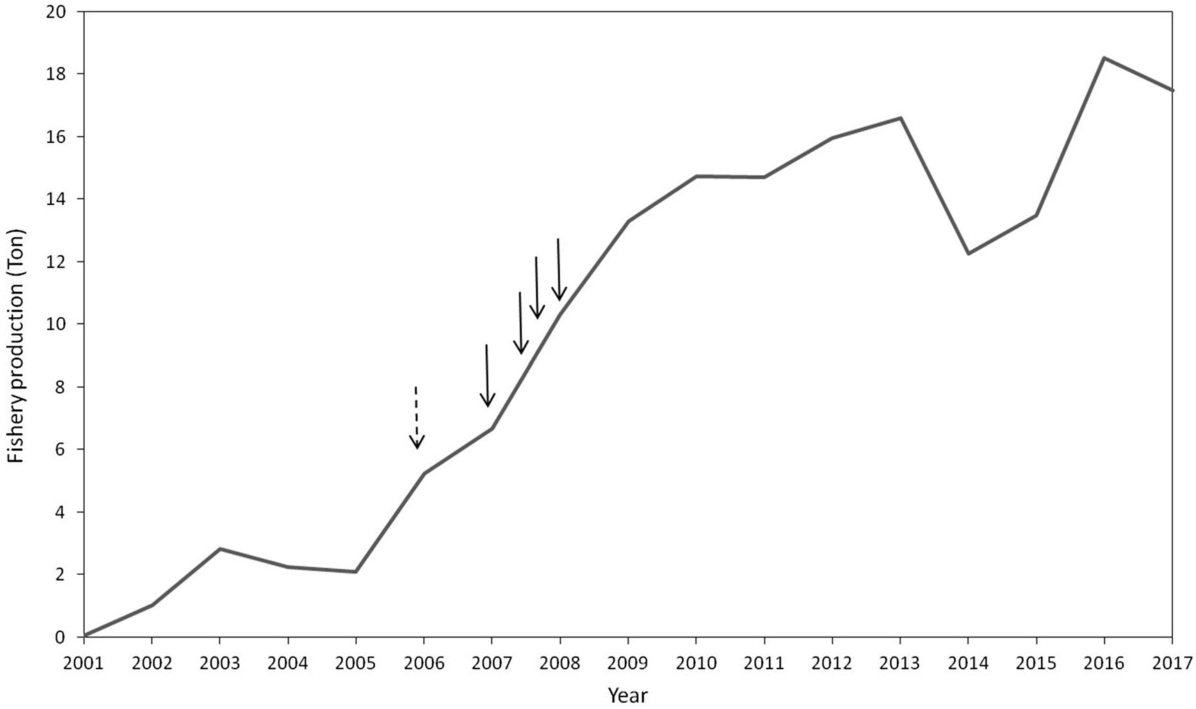

Fig. 4 Senegal sole catches from 2002 to 2016 (source: Junta de Andalucía). The dashed arrow points to the first hatchery-produced Senegal sole release (no data available, see Introduction). Solid arrows represent the other Senegal sole releases analysed in this work

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This study has been financed by the Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible of the Junta de Andalucia. M. Herrera's post-doc contract is supported by the National Institute of Agricultural Research and the European Social Fund (INIA-FSE). Funding for open access charge: Universidad de Huelva / CBUA.

Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interest The authors have no competing interests to declare that are relevant to the content of this article.

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