

## The purple dye murex *Bolinus brandaris* (Gastropoda: Muricidae) fishery in the northwestern Mediterranean: from overfishing to depletion over a two-decade period

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### Abstract

The purple dye murex (*Bolinus brandaris*), a gastropod mollusc, is a resource of local importance within the Mediterranean Sea (Spain, France, Italy, Tunisia, Greece and Turkey). It is fished all along the Catalan coast (NW Mediterranean), although fishing is concentrated in the area of the Ebro River Delta, where it is caught with bottom trawl, boat dredge and trammel nets. In the last two decades, from 2002 to 2023, a steady decreasing trend along the Catalan coast has been observed in landings (92% reduction, from 240.5 to 19.8 t), daily catch per vessel (78% reduction, from 14.1 to 3.1 kg/day/vessel), and fishing effort (fishing days with the sale of purple dye murex at the auction; 63% reduction, from 17068 to 6400 days). The three types of fishing gear involved in the purple dye murex fishery operate on different fishing grounds at different depths, which implies that the purple dye murex is fished throughout its bathymetric distribution and size range. The boat dredge and bottom trawl hourly yields markedly declined by 69% and 40%, respectively, over the past six years. Immature and below-minimum landing size individuals represent an important proportion of the catch. Considering the presence of immature individuals in the catch, boat dredging is the most detrimental for the species. At present, the economic dependence of fleets on purple dye murex is very low (1.3% revenue from first sale at the auction). The results of the assessment indicate that the purple dye murex population in the Ebro Delta is depleted.

**Keywords:** small-scale fishing; gastropods; population decline; overfishing; production maps.

### Introduction

The purple dye murex *Bolinus brandaris* (Linnaeus, 1758) has been exploited in the Mediterranean since ancient times. Numerous Phoenician and Roman archaeological remains have been found, aimed at the production of the purple dye, which was one of the most expensive dyes in the ancient world (Alfaro *et al.*, 2014). The purple dye murex is a prosobranch gastropod mollusc that is common in the Mediterranean and is also spread in Atlantic waters to the coasts of Portugal and Morocco (Poppe & Goto, 1991). A carnivorous species that feeds mainly on bivalves and supplements its diet by scavenging dead fish (Lahbib *et al.*, 2022; Ganiats *et al.*, 2023), it inhabits sandy-muddy bottoms, mainly at depths between 5 and 50 m, and can be found down to a 150-m depth (Houart, 2001).

The available information on the biology and fishery of the species is limited. A number of studies have been performed on the Algarve coast (southern Portugal), addressing different aspects of its biology, such as

growth, reproduction, meat yield (soft tissue proportion), morphometric relationships, penis length variation and its implications, and the muricid gastropod fishery (Vasconcelos *et al.*, 2008, 2011, 2012a, 2012b, 2016, 2017). Within the Mediterranean Sea, research has focused on the reproductive biology and imposex (Ramón & Amor 2001, 2002; Amor *et al.*, 2004; Abidli *et al.*, 2012; Elhasni *et al.*, 2013) and feeding behaviour of this species (Lahbib *et al.*, 2022). The exploitation of *B. brandaris* by boat dredging in the northwestern Mediterranean three decades ago was characterized by Martín *et al.* (1995).

Purple dye murex constitutes a resource of local importance in different zones of its area of distribution (Fischer *et al.*, 1987). At present, the species is caught mainly in the Mediterranean (Spain, France, Italy, Tunisia, Greece and Turkey) and in Atlantic waters in the Gulf of Cadiz and southern Portugal. According to FAO statistics, the current (2022) landings in the Mediterranean amounted to 1308 t, the largest part of which was caught in the Adriatic Sea (1056 t). In the western Mediterranean, the reported landings were 196 t in the Gulf of

Lion and 37.6 t along the Iberian coast. On the adjacent Atlantic coast, purple dye murex reported landings in the Gulf of Cadiz of 49.5 t and 68.5 t in 2022 and 2023, respectively (IDAPES, 2024), whereas in the Portuguese Algarve coastal landings of *búzios* (*Bolinus brandaris* and *Hexaplex trunculus*), the amounts were 2 t and 4 t, respectively, in 2022 and 2023 (INE, 2025).

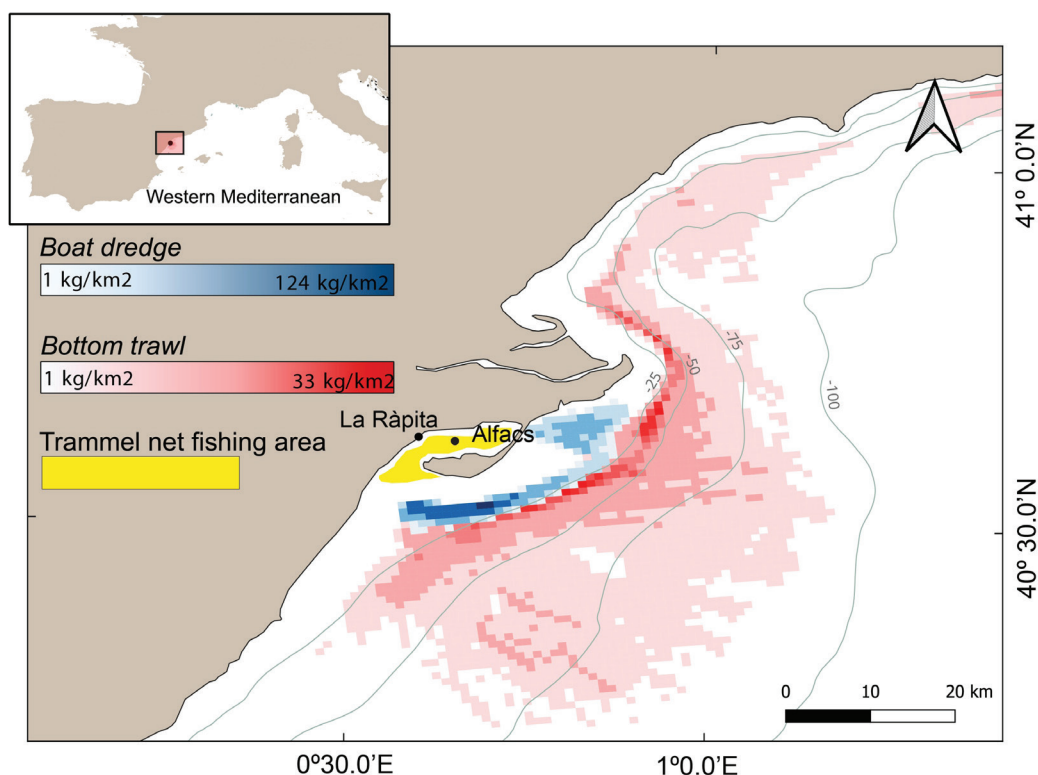
In the Adriatic Sea, the purple dye murex is among the species that form a catch assemblage that is captured by so-called *rapido* trawlers (Armelloni *et al.*, 2021). In the Gulf of Lion, purple dye murex is the target species of boat dredges (*drague barre, radasse*), which fish between 3 and 40 m depth, and trammel nets, which operate at depths of 5–25 m (Guillou & Crespi, 1999). On the Algarve coast, small-scale fishing gear (*aparelho de carteiras*, an artisanal fishing gear baited with cockles and pots) is used to catch the purple dye murex (Carneiro *et al.*, 2006).

On the Catalan coast (NW Mediterranean), the purple dye murex is exploited by bottom trawling and two small-scale fishing gear, a boat dredge (locally called *rastell*) and a trammel net. The fishing activity is carried out near the port base five days a week. The catch is freshly commercialized daily upon the arrival of the vessels to the port base. Early in the afternoon, the auction for small-scale fishing (boat dredge and trammel net) takes place, followed by bottom trawling.

Because of the wide continental shelf in the area of the Ebro Delta (Fig. 1), bottom trawlers are allowed to fish from 3 nautical miles from the coast, that is, at a depth of less than the 50-m isobath. The use of boat

dredges has markedly decreased in the last thirty years, from approximately 60 boat dredgers in the early nineties operating on the central and southern Catalan coast (Leonart, 1990; Martín *et al.*, 1995) to 21 in 2023, which operate exclusively in the Ebro Delta. At present, fishing with boat dredge is managed through a management plan (Generalitat de Catalunya, 2020), which limits its use to the fishing port of La Ràpita and to 21 authorized vessels (up to 14 gross registered tonnes and vessel horsepower up to 110 kW or 150 HP) at a minimum distance from the coast of 0.3 nm. One vessel can use two dredges simultaneously, each 2-m wide. The boat dredge fishing days are reported monthly to the administration, and no other gear different from the boat dredge can be used simultaneously. A minimum landing size (MLS) was set for purple dye murex at a shell width of 25 mm (55 mm shell length, SL). A two-month ban in July and August is implemented for bottom trawling and boat dredging. Trammel nets can be used five days a week, all year round. The established MLS on the Catalan coast (25 mm shell width) is the same as that on the Andalusian coast (Junta de Andalucía, 2020) but smaller than the MLS on the southern coast of Portugal (6.5 mm SL; DGRM, 2025). No minimum conservation reference size has been set for the purple dye murex at the European Union or Mediterranean level.

This study focused on the trend of the purple dye murex fishery on the Catalan coast over the past two decades and on the current status of the exploited population. To this end, data on landings, landings per unit of effort and income from the different fleets involved in this fishery were analysed; their corresponding fishing grounds were



**Fig. 1:** Study area: the Catalan coast and the Delta of Ebro River. The enlarged panel shows the spatial distribution of purple dye murex landings in 2023 (kg/km<sup>2</sup>) produced by bottom trawlers and boat dredgers with base in La Ràpita fishing port. The fishing grounds where each fleet operates are clearly identified. Trammel netters are set in the Alfacs Bay, their fishing ground is shown qualitatively.

defined; the exploited population was characterized; and the dependence of each fleet on this resource was established. Hypotheses on whether the decline in fishing yield was concomitant with a decrease in the extent of the species fishing grounds or species abundance were explored. Finally, the current status of the exploited population was assessed.

## Materials and Methods

### Study area

The Catalan coast, approximately 550-km long, is characterized to the north by a narrow continental shelf incised by several submarine canyons that widen to the southern part the Ebro River Delta. This study focused on the purple dye murex fishery in the area of the Ebro River Delta because a large proportion of the annual landings on the Catalan coast originate from this area. In addition, the use of a boat dredge, designed specifically for the catch of this species, is currently allowed exclusively in the Ebro Delta under certain conditions, as explained above (Generalitat de Catalunya 2020). Sampling was conducted at the fishing port of La Ràpita. The study area included the Bay of Alfacos in the southern part of the delta near La Ràpita, where trammel nets are set, and the boat dredge and bottom trawl fishing grounds where purple dye murex is caught (Fig. 1). The Alfacos Bay is a semiconfined mass of sea water with a surface area of 49 km<sup>2</sup> and an average depth of approximately 3 m, with silty, muddy and sandy sediments (Garcés *et al.*, 1999). Out of the bay, the sediment becomes progressively finer with depth, with medium and fine sands at the shoreline down to a depth of 5–6 m (Guillén & Palanques, 1997). The transition from nearshore sand to prodeltaic mud occurs across a narrow zone of sandy mud. This zone is located at a water depth of approximately 6 m (Díaz *et al.*, 1996).

### Fisheries data

Data on daily landings by species and vessel, revenue from first sale at the auction, and fishing effort (fishing days with reported purple dye murex landings) along the Catalan coast over the period 2002–2023 were provided by ICATMAR (Institut Català de Recerca per a la Governança del Mar; [www.icatmar.cat](http://www.icatmar.cat)). The catch per unit of effort (CPUE) was calculated as kg/day/vessel. Purple dye murex discards by bottom trawl are negligible (Blanco *et al.*, 2023), and small-sized individuals from small-scale fishing that are not commercialized are to be returned alive to the sea when the catch is to be sorted for the auction. The mortality of these individuals is assumed to be very low or nil, given the reported high survival of the species (Vasconcelos *et al.*, 2012a; Pérez-Mayol *et al.*, 2025).

Bottom trawlers are equipped with a vessel monitoring system (VMS) that allows for accurate positions of the vessels to be tracked and their activity to be monitored.

Boat dredgers use the Automatic Identification System (AIS). The position of trammel netters targeting purple dye murex was determined through interviews with fishers. The fishing grounds corresponding to bottom trawl and boat dredge fishing were characterized by combining the activity of the vessels in 2023 with the reported purple dye murex catch by vessel on a daily basis. VMS data were provided by the Spanish Fisheries Secretariat of the Spanish Government, and AIS data were obtained from Puertos del Estado (<http://www.puertos.es>), with prior authorization.

VMS and AIS data do not indicate whether the vessels are fishing, steaming or inactive. To filter the fishing activity of bottom trawlers, a speed filter between 1.5 and 4.8 knots, which was based on the trawlers' speed spectrum in the area, was applied, following methodologies described in previous studies (Bueno-Pardo *et al.*, 2017; Lee *et al.*, 2010; Russo *et al.*, 2014). This selection included the speed range for bottom trawling while excluding steaming and inactive moments. Once the fishing VMS data were obtained, we calculated the fishing time per day and vessel (fishing trip) and homogeneously associated the purple dye murex daily catch with the VMS fishing points corresponding to the same trip. Finally, we aggregated the fishing points and their associated variables in a 1×1 km<sup>2</sup> grid. A similar procedure was followed for AIS data from a boat dredge. In this case, on the basis of the speed spectrum of the boat dredgers, a filter between 4.0 and 7.5 knots was applied, and the no-take-zone positions (Fig. 1) were removed. For the speed spectra, only the fishing days with reported purple dye murex landings were considered. The fishing grounds corresponding to trammel nets were determined qualitatively on the basis of the fishers' indications. This methodology allowed for determination of the spatial distribution of the *B. brandaris* catch in 2023 (kg/km<sup>2</sup>) by fishing gear.

By combining the spatial distribution of the bottom trawl and boat dredge purple dye catches with their corresponding fishing times applied to each cell during two periods (October 2016 to September 2017 and 2023), changes in the purple dye murex biomass CPUE index, calculated as kg per fishing hour (kg/h), were assessed. The period from October 2016 to September 2017 was chosen for comparison because of AIS data availability from a previous study on this fishery (Marco-Herrero *et al.*, 2017). The distribution of the species in the study area was assumed to correspond to the extent of the fishing grounds and was calculated for the two periods.

### Biological sampling

Monthly sampling was conducted at La Ràpita in 2023 from January to December to determine the size structure exploited by each gear. The purple dye murex is marketed in red, yellow and black bags, which broadly correspond to three commercial categories (small–medium, medium–large, and large individuals). These categories apply to bottom trawl, boat dredge and trammel nets. A total of 58 monthly samples (27 bottom trawl, 22 beam

trawl and 9 trammel net samples) were collected at the auction site. The number of samples differed among the gear types because the three commercial categories do not appear all months in the catch of the three gear types and because of the use of each gear varied throughout the year. A small difference was observed (1%) between the landings registered by the fleet and those registered by the fleet and commercial categories, possibly because a small amount of catches was commercialized without assigned categories. The samples were subsequently examined in the laboratory. The following measurements were obtained: shell length (SL), shell width (SW) and shell length without siphon (SLWS), using a digital calliper (precision of 0.01 mm), as well as the total weight (TW) to the nearest 0.001 g.

The annual length frequency distributions (LFDs) by gear and commercial category were generated by combining the monthly LFDs by gear and commercial category from the sampling at the auction and the corresponding monthly landings (tonnes) by gear and commercial category from the fishing statistics provided by the Fishers Association of La Ràpita. The total annual LFD by gear was obtained by merging the corresponding annual LFDs by commercial category, and finally, the overall annual LFD was obtained by merging the annual LFDs of the three types of fishing gear. The LFDs are expressed in numbers (thousands). The length–weight relationship ( $TW=a*SLWS^b$ ,  $a=0.0002$  and  $b=3.036$ ) used to express the landing weights into numbers was calculated from the individuals sampled at La Ràpita and examined in the laboratory.

### **Economic dependence**

For each fleet, economic dependence was defined as the proportion between the value of purple dye landings and the value of total landings from the first sale at the auction. The contribution of each fleet to the exploitation of purple dye murex was defined as the proportion of landings by fleet in relation to the total purple dye murex landings (Carvalho *et al.*, 2017; Daurès *et al.*, 2009). These two indicators were calculated for 2023.

### **Assessment**

The purple dye murex stock was assessed using CMSY software (CMSY\_2019\_9f. R; Froese *et al.*, 2019). CMSY uses a Monte-Carlo method that estimates fishery reference points (MSY (maximum sustainable yield),  $F_{MSY}$  (fishing mortality at MSY), and  $B_{MSY}$  (biomass at MSY)) as well as relative stock size ( $B/B_{MSY}$ ) and exploitation ( $F/F_{MSY}$ ) from catch data, a prior for resilience or productivity ( $r$ ), and broad priors for the ratio of biomass to unfished biomass ( $B/B_0$ ) at the beginning, intermediate year and end of the time series. Part of the CMSY package is an advanced Bayesian state-space implementation of the Schaefer surplus production model (BSM). The parameter settings were selected on the basis

of Froese *et al.* (2019). The following settings were used in the final run: catch data and CPUE (catch/day/vessel) at La Ràpita over the period 2000–2023; prior initial relative biomass = 0.2–0.6 (medium depletion); prior intermediate relative biomass = 0.01–0.4 (strong depletion) in 2014; prior final relative biomass = 0.01–0.2 (very strong depletion); and prior range for  $r$  = 0.2–0.8 (medium resilience based on fecundity).

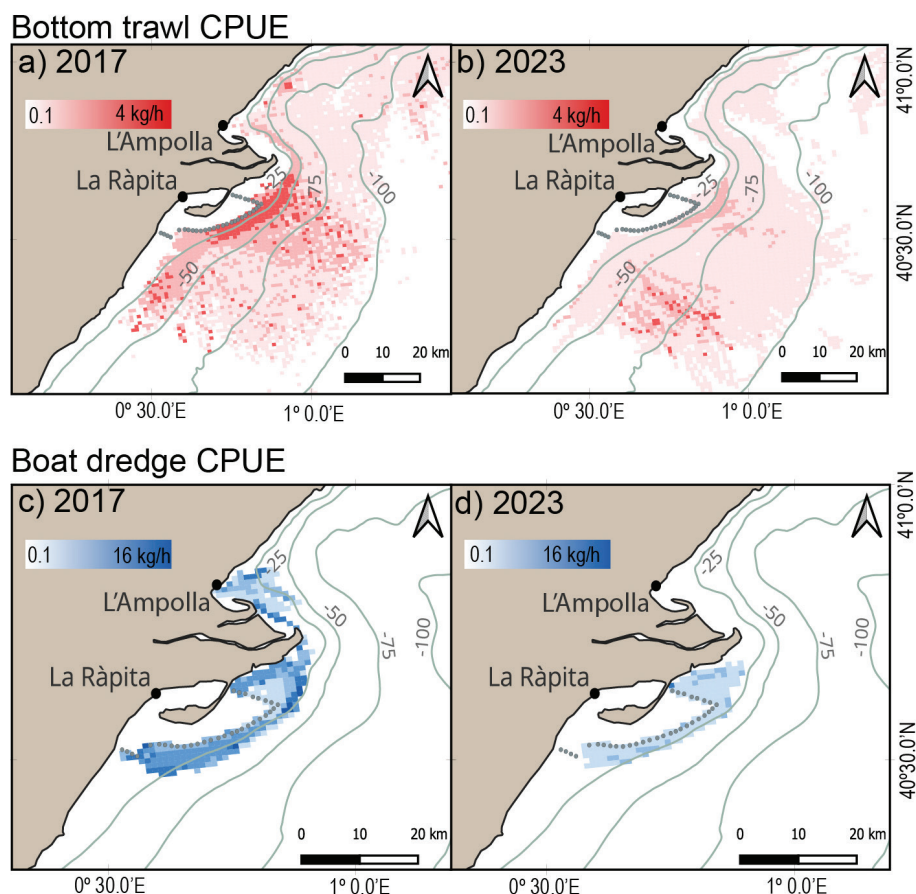
## **Results**

### **Purple dye murex fishing grounds in the Ebro River Delta**

The three types of fishing gear (bottom trawl, boat dredge and trammel net) involved in the purple dye murex fishery operate on different fishing grounds, with minimal overlap, at different depths. This implies that purple dye murex is fished throughout its bathymetric distribution. The spatial distribution of purple dye murex landings in 2023 at La Ràpita is shown in Figure 1. The most productive areas, i.e., the areas where higher amounts of biomass were extracted throughout the year, as well as the fishing grounds corresponding to each fishing gear, are clearly identified. Bottom trawl fishing grounds are located mainly at depths between 30 m (at least 3 nautical miles from the coast) and 50 m, although purple murex is also fished in a much larger area, down to approximately 80-m depth. Boat dredge fishing grounds are found in a narrow depth range, up to 25-m depth. Most of the catch was obtained in a well-defined area, near the small peninsula at the southern end of the Ebro Delta, the so-called *Punta de la Banyà* (horn tip). Trammel nets are set in the very shallow waters of Alfacs Bay.

### **Purple dye murex biomass and extension of the bottom trawl and boat dredge fishing grounds**

The biomass of purple dye murex displayed a marked decrease in the last six years (between October 2016 and September 2017 and in 2023), as shown by the CPUE (kg/h) maps (Fig. 2). Purple dye murex is a bycatch species for bottom trawl. Accordingly, the species catch was scattered across the shelf. In 2016–2017, the higher CPUE values were concentrated in the shallower waters where this fleet is allowed to fish, three nm from the coast, at approximately 25–30-m depth (Fig. 2a). Nevertheless, in 2023, this area with relatively high hourly yields was no longer observed (Fig. 2b). With respect to the boat dredge, the purple dye murex is, in principle, the target species of this gear. The areas of higher CPUE identified in 2016–2017 (Fig. 2c), which were located at approximately 25-m depth and adjacent to those of higher bottom trawl CPUE, disappeared six years later (Fig. 2d). In addition, the boat dredging area where the fleet operated also decreased by 66%, from 472 km<sup>2</sup> to 159 km<sup>2</sup>. In 2023, fishing activity was not permitted in the area to the north of the river mouth. In 2016–2017, the boat dredge



**Fig. 2:** *Bolinus brandaris* biomass CPUE (catch per unit of effort) index calculated as kg per fishing hour (kg/h) in October 2016–September 2017 and in 2023, for bottom trawl (a and b) and boat dredge (c and d). The fishing hours in each 1 km<sup>2</sup> grid cell from vessels with purple dye murex catch has been used as unit of effort. In 2023 the fishing activity to the north of the river mouth was not permitted. Dots delimit a non-fishing area.

hourly yield was greater ( $2.86 \pm 2.24$  kg/h) when the area to the north of the river mouth was not included in the calculation ( $2.53 \pm 3.70$  kg/h, north area included), which indicates that the species abundance was greater in the southern part of the delta (Table 1).

Both the boat dredge and bottom trawl catch markedly decreased from October 2016–September 2017 to 2023, by 87% and 78%, respectively. The fishing intensity, that is, the effective fishing effort (fishing hours) per unit area, decreased differently, by 26% for boat dredging and 41% for bottom trawling (Table 1). The decline in the catch was more pronounced for boat dredges than for bottom trawls, although the decrease in fishing hours was greater

for bottom trawls and the purple dye murex is a bycatch species for this gear, while it is the target species for boat dredging. Accordingly, the decrease in the hourly yield was also more marked for boat dredging (69%) than for bottom trawling (40%; Table 1).

#### **Landings, CPUE and effort trends and economic dependence**

Purple dye murex is caught all along the Catalan coast, although fishing is concentrated in the area of the Ebro River Delta. During the past two decades, from

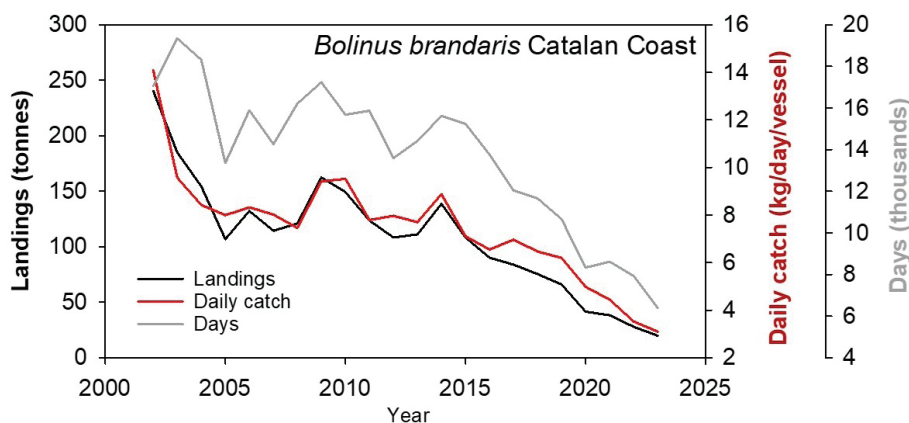
**Table 1.** Summary of the fishing activity carried out by bottom trawlers and boat dredgers with purple dye murex catch in October 2016 to September 2017 and in 2023.

	Boad dredge		Bottom trawl	
	2017	2023	2017	2023
Total kg	38881	5088	24226	5441
Total h	5897	4362	53461	31830
(kg/h)	$2.53 \pm 3.70$	$0.79 \pm 0.38$	$0.42 \pm 0.34$	$0.25 \pm 0.21$
(kg/h)*	$2.86 \pm 2.24$	-	-	-

\*area to the north of the river mouth excluded

2002 to 2023, a steady decreasing trend was observed in landings (92% reduction, from 240.5 to 19.8 t), the daily catch per vessel (78% reduction, from 14.1 to 3.1 kg/day/vessel) and fishing effort (fishing days with sale of purple dye murex at the auction; 63% reduction, from 17068 to 6400 days; Fig. 3). The annual catch and CPUE displayed similar significant decreasing trends ( $p < 0.001$ ). Notably, purple dye murex landings at La Ràpita represented a large proportion of the total landings along the Catalan coast throughout 2002–2023, approximately 60–70%

since 2009 (Table 2). The marked decreasing trend in landings observed since 2015 at this port was similar to that on the Catalan coast, i.e., by 82% and 84%, respectively, from 77.6 t in 2015 to 12.5 t in 2023 at La Ràpita and from 108.3 t in 2015 to 19.8 t in 2023 on the Catalan coast. The aforementioned sharp decline in landings also represented a strong decrease in revenue from first sale at the auction, by 90% over the period 2002–2023, from 2210.48 k€ to 226.1 k€. Conversely, the mean price at the auction increased from 9.2 €/kg in 2002 to 11.4 €/kg in



**Fig. 3:** *Bolinus brandaris* landings (left axis), daily catch per vessel (right axis) and fishing days (right axis) in the Catalan coast over the period 2002–2023.

**Table 2.** *Bolinus brandaris* landings (tonnes) in the Catalan coast and in La Ràpita fishing port in the period 2002–2023. Landings displayed a marked decreasing trend and La Ràpita landings represented a large amount of the annual landings in the Catalan coast.

Year	Catalan coast	La Ràpita	La Ràpita %
2002	240.5	125.9	52.4
2003	185.0	79.7	43.1
2004	154.4	65.3	42.3
2005	106.8	30.2	28.3
2006	132.3	62.7	47.4
2007	114.4	49.5	43.2
2008	120.9	67.0	55.4
2009	162.4	99.1	61.0
2010	149.3	104.2	69.8
2011	123.7	85.8	69.4
2012	108.3	77.5	71.5
2013	111.1	80.8	72.7
2014	138.6	106.3	76.7
2015	108.3	77.6	71.6
2016	90.1	63.8	70.7
2017	83.8	61.7	73.6
2018	75.4	51.4	68.3
2019	66.1	47.5	71.9
2020	41.5	26.5	63.8
2021	38.3	24.2	63.2
2022	27.9	18.8	67.2
2023	19.8	12.5	63.1

2023 (updated in constant 2023 values).

Most of the vessels (75) of the fishing fleet of La Ràpita, the main fishing port in the Ebro River Delta, reported purple dye murex landings: 38 bottom trawl trawlers, 13 boat dredgers and 24 trammel netters (Table 3). Purple dye landings in 2023 amounted to 12.5 tonnes (63% of the total landings on the Catalan coast; Table 2). Of these, 44% and 41% corresponded to bottom trawling and boat dredging, respectively, and 15% corresponded to trammel nets. The landings throughout the year did not display a defined seasonal pattern. The implementation of a temporal closure in July and August for bottom trawl and boat dredging explains the very low landings during these months, taken by trammel nets (Fig. 4).

The economic dependence of the fleets on purple dye murex and its contribution to total landings were investigated to determine which fleets might be vulnerable because of their dependence on the species as well as which

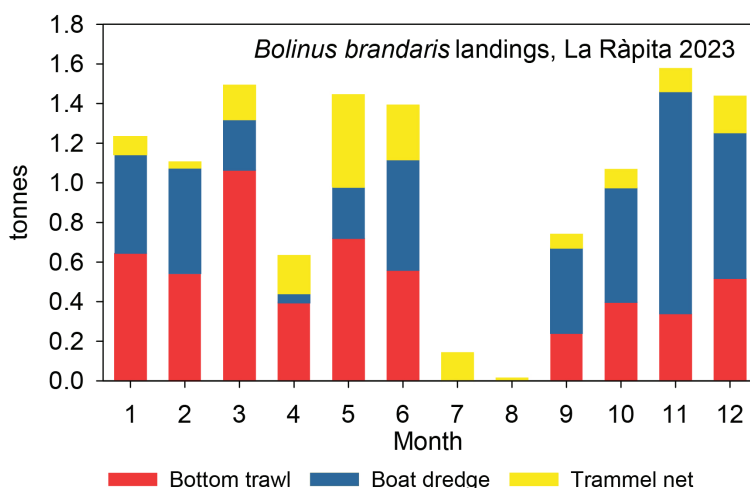
fleets might be more strongly affected by large removals. In all three fleets, the dependence was very low, both in terms of landings and revenue (Table 3). This was particularly remarkable in the case of boat dredges, since in principle, purple dye murex is the target species of this gear, where it represented 4.9% of landings and 3.5% of revenue. With respect to bottom trawl and beam trawl, these percentages were even lower, <1% for landings and <1.5% for revenue.

### Species composition of landings

The wide continental shelf of the delta results in a high species diversity of landings (Table 4). With respect to the fleets with reported purple dye murex landings, bottom trawl landings consisted of 128 species, many of which had very low landings. Two species that are char-

**Table 3.** La Ràpita 2023. Fishing fleets with reported landings of purple dye murex: number of vessels (in brackets number of vessels with no reported catch of purple dye murex); total and purple dye murex catch; total and purple dye murex revenue from first sale at the auction; mean price; purple dye murex percentage in the total landings and revenue of each fleet; and contribution of each fleet to the exploitation of purple dye murex, expressed as the proportion of the fleet landings in relation to the total purple dye murex landings.

	n vessels	All species	Landings (t)	Revenue (thousands €)	Mean price (€/kg)	Landings (%)	Revenue (%)	Contribution to exploitation (%)
Bottom trawl	38	all species	1449.713	7330.141				
	(4)	purple-dye murex	5.441	80.984	14.9	0.4	1.1	44
Boat dredge	13	all species	103.548	1200.862				
	(3)	purple-dye murex	5.088	41.571	8.2	4.9	3.5	41
Trammel net	24	all species	217.366	1622.274				
	(10)	purple-dye murex	1.909	13.030	6.8	0.9	0.8	15
Total	75	all species	1770.627	10153.278				
		purple-dye murex	12.438	135.585	10.9	0.7	1.3	



**Fig. 4:** *Bolinus brandaris*, La Ràpita 2023. Monthly catch by gear (bottom trawl, boat dredge and trammel net), in tonnes.

**Table 4.** Species composition of the landings, expressed in % of weight (tonnes) and revenue (thousands €) in La Ràpita in 2023, by fleet. The species with landings at least 1% of the annual total have been detailed. Only the vessels with reported purple dye murex landings have been considered.

<b>Bottom trawl</b>	<b>Landings (t)</b>	<b>Revenue (thousands €)</b>
<b>Total</b>	<b>1449.7</b>	<b>7330.1</b>
	%	%
<i>Squilla mantis</i>	15.3	13.0
<i>Mullus barbatus</i>	11.0	10.6
<i>Illex coindetii</i>	6.6	4.9
<i>Merluccius merluccius</i>	6.3	10.0
<i>Trachurus mediterraneus</i>	5.8	2.7
<i>Liocarcinus depurator</i>	4.4	2.5
<i>Citharus linguatula</i>	4.3	4.8
<i>Lophius boudegassa</i>	4.0	6.5
<i>Trisopterus minutus</i>	3.6	1.9
<i>Octopus vulgaris</i>	3.4	3.0
<i>Parapenaeus longirostris</i>	2.8	4.1
<i>Pagellus erythrinus</i>	2.8	0.8
<i>Scomber scombrus</i>	2.5	0.9
<i>Octopus vulgaris</i>	2.4	4.1
<i>Sepia officinalis</i>	2.4	3.1
<i>Lepidotrigla cavillone</i>	2.2	1.1
<i>Eutrigla gurnardus</i>	1.5	0.7
<i>Trachinus draco</i>	1.3	0.7
<i>Sparus aurata</i>	1.3	0.9
<i>Serranus hepatus</i>	1.2	0.6
<i>Penaeus kerathurus</i>	1.1	4.6
<i>Boops boops</i>	1.1	0.1
other species	12.9	18.5
<b>Boat dredge</b>	<b>Landings (t)</b>	<b>Revenue (thousands €)</b>
<b>Total</b>	<b>103.5</b>	<b>1200.9</b>
	%	%
<i>Penaeus kerathurus</i>	36.5	63.3
<i>Sepia officinalis</i>	22.0	15.0
<i>Squilla mantis</i>	10.3	4.2
<i>Acanthocardia tuberculata</i>	8.5	0.4
<i>Chamelea gallina</i>	5.4	3.0
<b><i>Bolinus brandaris</i></b>	<b>4.9</b>	<b>3.5</b>
<i>Octopus vulgaris</i>	3.7	2.7
<i>Solea solea</i>	3.6	6.6
<i>Callinectes sapidus</i>	3.3	0.1
other species	1.8	1.3
<b>Trammel net</b>	<b>Landings (t)</b>	<b>Revenue (thousands €)</b>
<b>Total</b>	<b>217.4</b>	<b>1622.3</b>
	%	%
<i>Callinectes sapidus</i>	23.0	12.3
<i>Sparus aurata</i>	21.1	32.7
<i>Diplodus annularis</i>	12.6	14.8
<i>Sepia officinalis</i>	6.4	2.0
<i>Solea solea</i>	2.9	9.3

Continued

Table 4 continued

Trammel net	Landings (t)	Revenue (thousands €)
Total	217.4	1622.3
	%	%
<i>Octopus vulgaris</i>	2.8	3.3
<i>Liza ramada</i>	2.7	0.7
<i>Liza aurata</i>	2.6	0.8
<i>Pomatomus saltator</i>	2.4	1.5
<i>Chelon labrosus</i>	1.9	0.8
<i>Mugil cephalus</i>	1.7	0.6
<i>Sarpa salpa</i>	1.6	0.4
<i>Lithognathus mormyrus</i>	1.3	1.0
<i>Raja asterias</i>	1.2	0.6
<i>Trachurus mediterraneus</i>	1.2	0.3
<i>Umbrina cirrosa</i>	1.1	1.0
<i>Dicentrarchus labrax</i>	1.1	2.8
<i>Synaptura lusitanica</i>	1.0	1.4
other species	11.5	13.8

acteristic of muddy bottoms and shallow waters, mantis shrimp (*Squilla mantis*) and red mullet (*Mullus barbatus*), represented 26% and 23% of the landings and revenue, respectively. Other species with landings >5% of the annual total were shortfin squid (*Illex coindetii*), European hake (*Merluccius merluccius*) and Mediterranean horse mackerel (*Trachurus mediterraneus*). Among the 31 species landed by boat dredge, two were identified as the main target species: caramote prawn (*Penaeus kerathurus*; 37% of the annual landings) and common cuttlefish (*Sepia officinalis*; 22% of annual landings). In addition, caramote prawn revenue alone represented 63% of the total. Other species with landings >5% of the annual total were mantis shrimp (*Squilla mantis*), rough cockle (*Acanthocardia tuberculata*) and striped venus (*Chamelea gallina*). With respect to trammel nets, three species comprised 57% of the annual landings: gilt-head bream (*Sparus aurata*; 21%), blue crab (*Callinectes sapidus*; 23%) and annular seabream (*Diplodus annularis*; 13%). Gilt-head bream revenue alone represented 33% of the annual total. In all the cases, purple dye murex represented a very low amount of the annual landings and revenue. In boat dredges, it represented 5% and <4% of the annual landings and revenue, respectively, and those for bottom trawl and trammel nets were even lower (Table 3). That is, the dependence on purple dye murex of the fleets that reported landings of this species was very low in 2023; only 13 boat dredgers out of the 21 with a licence to use this gear landed purple dye murex.

#### Length frequency distributions by gear and commercial category

Purple dye murex is marketed at the La Ràpita auction by commercial category (red, yellow and black) and fishing gear, and the importance of each category differs among the types of gear. The contribution of each gear

type to the 2023 annual landings (12.32 t) was 5.40 t from bottom trawling, 5.02 from boat dredging, and 1.89 t from trammel nets. Table 5 shows the composition of the landings, expressed in weight and numbers. The black category, which corresponds to the larger individuals, was fished by bottom trawl and was almost absent from the boat dredge and trammel net catches. Boat dredge landings consisted of red and yellow categories (small-medium and medium-large individuals), whereas trammel net landings, which were very low, comprised mainly yellow category (medium-large individuals). Although the weights of bottom trawl and boat dredging landings were similar, half of the annual landings in numbers (51%) corresponded to boat dredging, which explains the greater number of small individuals in the catch. With respect to the commercial category, the three gear types merged, the highest values in weight (42%) and number (41.8) corresponded to the yellow category.

A total of 5944 individuals were measured. The size range and individuals measured by gear type are presented in Table 6. The smallest size observed was 30.1 mm SL from boat dredging, and the largest was 92.1 mm SL from bottom trawling. The annual LFDs by gear and commercial category (Fig. 5) show that the size range by category was similar among gear types, despite the overlap among categories, mainly in the red and yellow categories. These LFD findings clearly show that large individuals were almost exclusively caught by bottom trawl nets and that the gear type contributing most to the catch of small individuals was the boat dredge.

As mentioned above, an MLS of 55 mm SL has been set. The species size at first maturity ( $L_{50}$ ) has been estimated at 51 mm SL in the study area (Mir-Arguimbau *et al.*, 2024). When these sizes were compared with the annual LFD of the total landings (bottom trawl, boat dredge and trammel net LFDs merged; Fig. 6), it became apparent that immature and below-MLS individuals constituted an important fraction of the annual landings (20% im-

**Table 5.** *Bolinus brandaris*, La Ràpita 2023. Landings by gear, expressed in weight (tonnes), number (thousands), and commercial category (red, yellow and black).

La Ràpita 2023	Landings (tonnes)			
	Red	Yellow	Black	Total
Bottom trawl	0.24	1.34	3.82	5.40
Boat dredge	2.15	2.68	0.20	5.02
Trammel net	0.74	1.10	0.05	1.89
Total				12.32

	Landings (thousands)			
	Red	Yellow	Black	Total
Bottom trawl	28.2	103.2	193.4	324.8
Boat dredge	313.3	239.3	11.7	564.3
Trammel net	90.6	117.1	2.8	210.4
Total				1099.6

	% weight	% numbers
	Bottom trawl	44
Boat dredge	41	51
Trammel net	15	19

	Landings (tonnes)	Landings (thousands)	% weight	% numbers
Red	3.13	432.1	25	39.3
Yellow	5.12	459.6	42	41.8
Black	4.07	207.9	33	18.9

**Table 6.** Summary of the *Bolinus brandaris* length frequency distributions sampling conducted in La Ràpita in 2023: number of individuals measured and corresponding size range by fishing gear (SL shell length, in mm).

	SL min	SL max	n measured
Bottom trawl	38.6	92.1	2668
Beam trawl	30.1	80.1	1681
Trammel net	39.2	77.8	1595

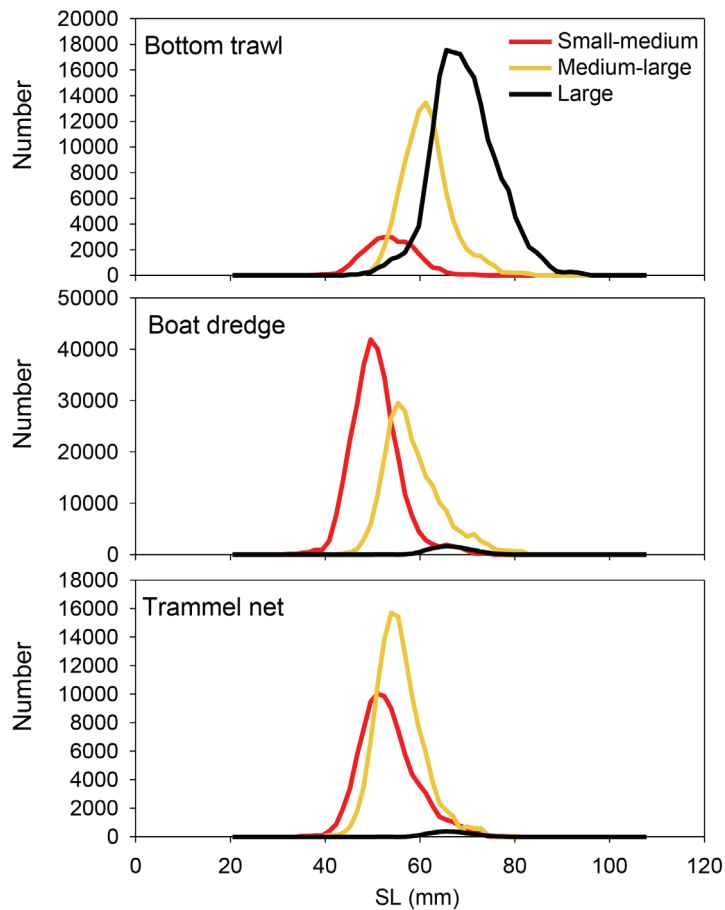
mature, 42% below the MLS; Table 7). The proportions of immature individuals and those below the MLS were very different depending on the gear. Most of the bottom trawl landings comprised mature (97%) and above-MLS individuals (92%). With respect to boat dredge and trammel nets, the presence of immature individuals (30% and 20%, respectively) and individuals below the MLS (58% and 53%, respectively) was similar, although trammel net landings were very low. Altogether, the length structure of landings indicates a non-sustainable exploitation of purple dye murex.

### Assessment

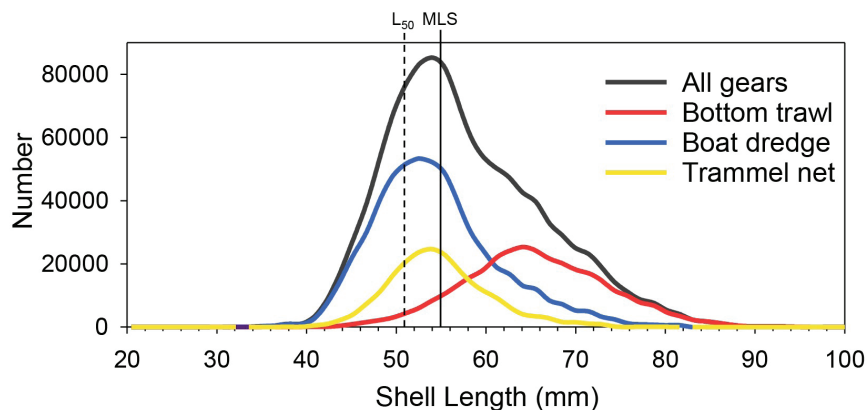
The CMSY assessment results (Table 8 and Figs. 7 and 8), which are based on BSM analysis, show that the

La Ràpita stock is overexploited at present (2023), with a very low level of biomass, and that overexploitation was already detected at the beginning of the analysed period (2000). Overexploitation highly increased from 2000 to 2023, especially in recent years. The highest  $F/F_{MSY}$  and lowest  $B/B_{MSY}$  ratios were achieved in 2023 (5.73 and 0.12, respectively). This retrospective analysis, which allowed for comparisons of the results when the last one, two or three years were omitted from the analysis, yielded consistent results. The trajectories of  $F/F_{MSY}$  and  $B/B_{MSY}$  were very similar in all the cases (Fig. 8).

The biomass corresponding to MSY is  $B_{MSY} = 0.5 \cdot B_0$ ; the biomass level below which recruitment is potentially reduced is  $B/B_{MSY} < 0.25$ ; and for stocks severely depleted, this ratio is  $B/B_{MSY} < 0.1$  (Froese *et al.*, 2017 and references therein). According to these biomass reference points, the stock of the purple dye murex in the Ebro Del-



**Fig. 5:** *Bolinus brandaris*, La Ràpita 2023. Annual length frequency distributions by gear (bottom trawl, boat dredge and trammel net) and commercial category, red (small-medium individuals), yellow (medium-large individuals), and black (large individuals).



**Fig. 6:** *Bolinus brandaris*, La Ràpita 2023. Annual length frequency distributions for bottom trawl, boat dredge and trammel net, and for the three gears combined. Vertical lines indicate the size at first maturity ( $L_{50}=51$  mm shell length) and the minimum landing size (MLS=55 mm shell length).

ta, whose biomass is very low ( $B_{2023}/B_{MSY} = 0.12$ ), is severely depleted, which substantially reduces recruitment; that is, the level of biomass would not be sufficient to ensure the replacement of the population.

## Discussion

The purple dye murex is a fishing resource that has been exploited for centuries in the Mediterranean. In the northwestern Mediterranean, on the Catalan coast, the

species was very common all along the coast and was frequent in the catches of the fishing fleet. Nevertheless, in recent years, especially the last two decades, catches have markedly decreased. Catches come from bottom trawls, boat dredges, and trammel nets. In both bottom trawl and trammel nets, *B. brandaris* has always been a bycatch species, but this is not the case for boat dredges, which are designed specifically for the catch of this species. Purple dye murex was the dominant species in the commercial catch of the boat dredge (up to 73%; Martín *et al.*, 1995), while at present, it represented just 5%.

**Table 7.** *Bolinus brandaris*, La Ràpita 2023. Presence in the landings of mature and immature individuals and of individuals above and below the minimum landing size, by gear (size at first maturity,  $L_{50}$ =51 mm shell length; MLS = 55 mm SL).

	Bottom trawl	Beam trawl	Trammel net	All gears
Landings (t)	5.40	5.02	1.89	12.32
Landings (thousands)	324.8	564.3	210.4	1099.6
$\geq 51$	316.3	396.3	167.7	880.4
$\leq 50$	8.5	168.0	42.7	219.3
$\geq 55$	297.6	239.0	98.7	635.3
$\leq 54$	27.2	325.3	111.8	464.3
	Bottom trawl	Beam trawl	Trammel net	All gears
% number	30	51	19	100
% mature	97	70	80	80
% immature	3	30	20	20
% $\geq$ MLS	92	42	47	58
% $\leq$ MLS	8	58	53	42

**Table 8.** *Bolinus brandaris*, La Ràpita 2023. Results for Management, based on BSM analysis (MSY and Biomass in tonnes).

$F_{MSY} = 0.046$ , 95% CL = 0.03 - 0.0705
MSY = 0.0992, 95% CL = 0.0753 - 0.131
$B_{MSY} = 0.514$ , 95% CL = 0.349 - 0.758
Biomass in last year = 0.0613, 2.5th perc = 0.0435, 97.5 perc = 0.0865
$B/B_{MSY}$ in last year = 0.119, 2.5th perc = 0.0845, 97.5 perc = 0.168
Fishing mortality in last year = 0.264, 2.5th perc = 0.187, 97.5 perc = 0.372
Exploitation $F/F_{MSY} = 5.73$ , 2.5th perc = 3.13, 97.5 perc = 10.4

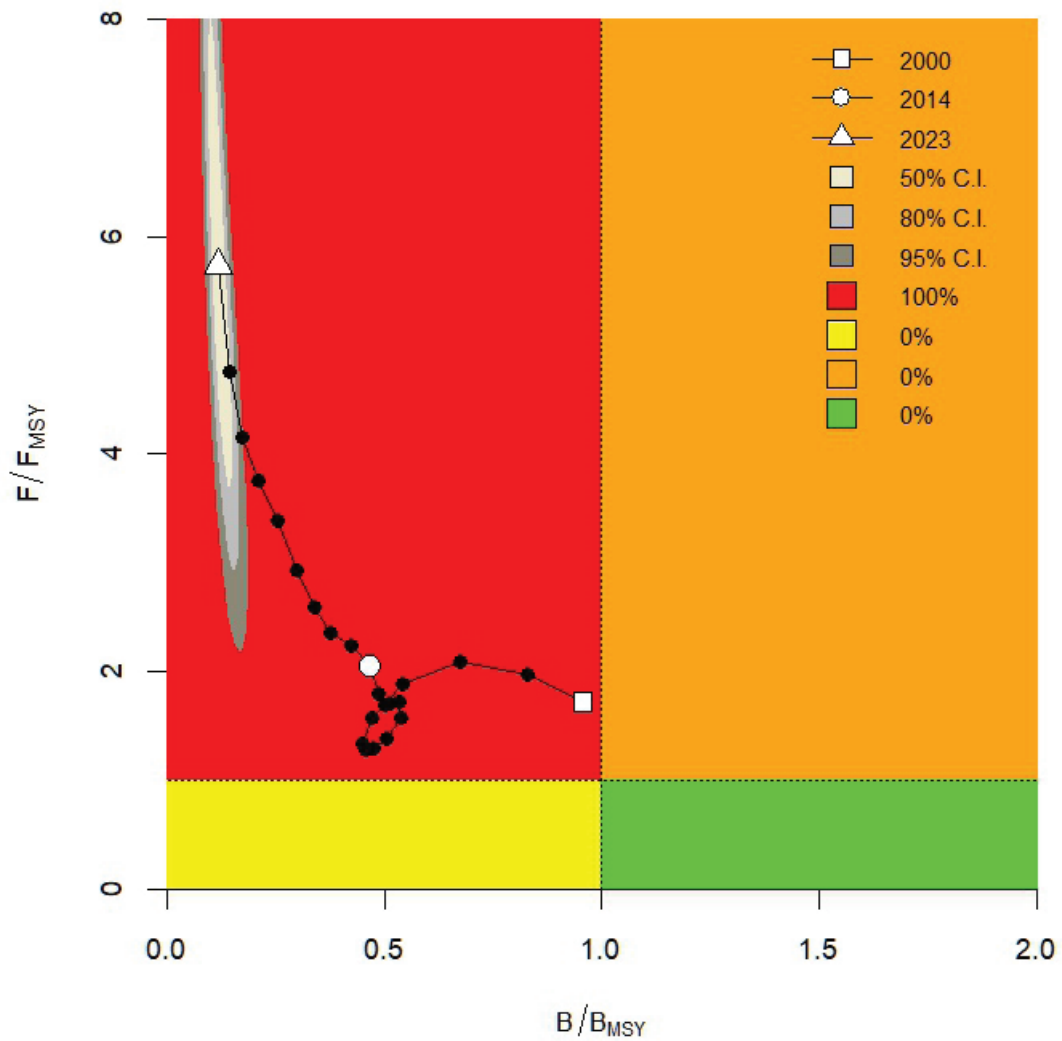
Herein, we describe several features that may explain the current poor status of the purple dye murex population in the Ebro River Delta.

Each of the three types of fishing gear for purple dye murex operates in well-defined fishing grounds, which are located at different depths, with practically no overlap among them (Fig. 1). This means that *B. brandaris* is fished in its entire bathymetric distribution. Furthermore, females concentrate when laying eggs, forming large masses of eggs. The presence of these masses of eggs has been observed recurrently in the trammel net catches during the spawning season of the species in May–June (J. M.-A., pers. obs.). These features of the purple dye fishery indeed indicate that the purple dye murex is under intense fishing pressure.

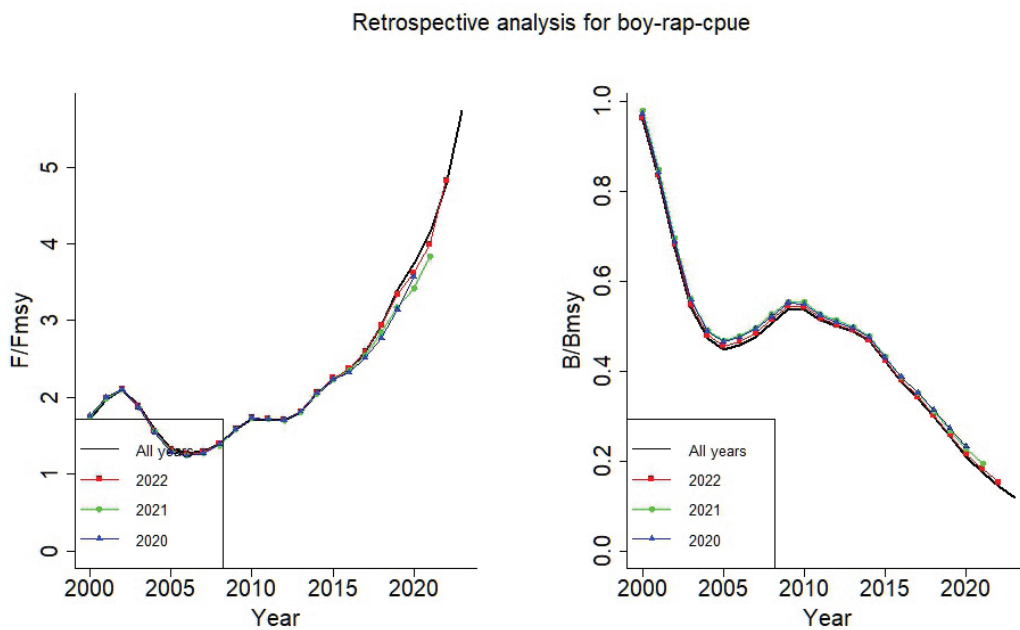
### Fishing grounds

A comparison between the extension of boat dredging fishing grounds in 2016–2017 and 2023 revealed that its

surface area was halved in only six years. In the case of bottom trawl, for which the purple dye murex is a bycatch species, that is, its fishing grounds are not determined by the distribution of a bycatch species, a clear decrease in the hourly yield was observed in the area adjacent to boat dredge fishing grounds, which corresponded to the higher yields in 2016–2017 (Fig. 2). Moreover, the purple dye murex biomass index, expressed as kg obtained per fishing hour, also decreased markedly for boat dredge and bottom trawl (Table 1), indicating that the observed decrease in the catch was a consequence of the decline in the resource. In this regard, it is worth noting that despite the purple dye murex being exploited by different fishing gear throughout its entire bathymetric distribution, that is, including bottoms where the larger individuals would be expected to be found, large individuals were scarce, and very large individuals were practically absent in the catches. Excessive truncation of a population's size structure is often identified as an important deleterious effect of exploitation. Most fisheries selectively remove larger, older individuals from the pristine stock, thus truncating



**Fig. 7:** *Bolinus brandaris*, La Ràpita. Kobe plot representing the time series of pressure ( $F/F_{MSY}$ ) on the Y-axis and state of the Biomass ( $B/B_{MSY}$ ) on the X-axis over the period 2000-2023.



**Fig. 8:** Retrospective analysis. Comparison of predictions for exploitation ( $F/F_{MSY}$ ) and relative stock size ( $B/B_{MSY}$ ) when the last 1-3 years are omitted from the analysis.

its natural pyramid of age classes and reducing its natural and characteristic longevity (Longhurst, 2002).

### ***Size structure of the population***

Age-truncated fish stocks are more variable over time and thus more susceptible to collapse than populations with more intact age structures are (e.g., Hixon *et al.*, 2014; Longhurst, 2002). Experimental fishing trials targeting a non-exploited purple dye murex population carried out to the north of the Catalan coast revealed a size structure ranging from 23 to 119 mm SL, with a mode at 70 mm SL (Mallol *et al.*, 2004). In our study, the mode of the overall LFD (Fig. 6, all gear combined) was much smaller (52–56 mm SL), whereas the individuals larger than 70 mm SL represented a small amount of the total (11%), which indicated truncation of the sizes of the exploited population in the Ebro Delta. On the Algarve coast, the annual LFD was similar to that on the Catalan coast (Vasconcelos *et al.*, 2008), with the mode peak at 55–59 mm SL, and >65 mm SL individuals represented approximately 18% of the total (21% on the Catalan coast). Considering the declining abundance of *B. brandaris* on the Algarve coast for more than a decade at the time of the study, a possible situation of overexploitation was suggested. In the southern Mediterranean, in the Gulf of Gabès, the mode peak of the purple dye murex LFD was also at 55–59 mm SL, with a wide range of sizes (22.4–97.0 mm SL; Elhansi *et al.*, 2017). According to Elhansi *et al.* (2017), the wide size ranges and large maximum sizes observed in the population indicate both renewal of the stock (presence of small individuals) and low intensity of exploitation (presence of large individuals). No further evidence was provided to support this conclusion. Nevertheless, it is well known that a change in the length at maturity is a potential indicator of exploited fish population (e.g., Marshall *et al.*, 2007), and the size at first maturity observed in that area (56.4 mm SL in females and 54.6 mm SL in males; Elhasni *et al.*, 2013) was greater than that on the Catalan coast (51 mm SL; Mir-Arguimbau *et al.*, 2024), which suggests a lower fishing pressure in the Gulf of Gabès at the time of the study than that on the Catalan coast in 2023.

### ***Landing trends and fishing gear in different Mediterranean areas***

A marked decrease in *B. brandaris* landings, by 40% according to FAO statistics, from 1712 t in 2019 to 1056 in 2022, has been observed in the Adriatic Sea in recent years, by far the area with the highest catches in the Mediterranean. Most of the catch (83%) comes from *rapido* trawl, which resembles a toothed beam-trawl and is considered one of the most impacting fisheries in the Mediterranean (Colloca *et al.*, 2017). The *rapido* trawl vessel length ranges from 9 to 30 m, with an engine power ranging from 60 to 1000 HP. Depending on its dimension, each vessel (64 active in 2018) can tow from 2 to 4 trawls, up

to 4-m wide, which slides on the seafloor aided by sleds. Other types of fishing gear that contribute to the purple dye murex catch in that area are bottom trawl (9%) and set netters (Masnadi *et al.*, 2020; Armelloni *et al.*, 2021). Nevertheless, a decline in landings has not been observed throughout the Mediterranean. In the Gulf of Lion (north-western Mediterranean), adjacent to the Catalan coast, the purple dye murex has been traditionally exploited using small-scale fishing gear and bottom trawling, similar to the purple dye fishing on the Catalan coast. Over the period 1973–1990, annual landings oscillated around 100 t (Campillo, 1993). More recently, landings displayed an increasing trend, from 114 t in 2014 to approximately 200 t over the period 2019–2022 (FAO statistics). Purple dye murex was caught with trammel nets (IFREMER 2019), dredges (*dragues à Murex*, 6 vessels in 2018, 9 m mean vessel length, active less than 5 months per year; IFREMER 2018) and bottom trawl. During the period of 2015–2017, bottom trawl landings represented approximately 50% of the annual landings (percentages estimated on the basis of the IFREMER 2018 and 2019 data and the GFCM data). It could be argued that the different trends of the purple dye murex fisheries in the Gulf of Lion and on the Catalan coast might be partially explained by the more intensive use of boat dredges in the latter area. Notably, in the early nineties, approximately 60 boat dredgers operated on the central and southern Catalan coast (Leonart, 1990), and twenty years later, 25 vessels used boat dredges in the area of the Ebro Delta (Marco-Herrero *et al.*, 2017). The management plan for boat dredgers limited the number of authorized vessels to 21 in this area (Generalitat de Catalunya, 2020). Nevertheless, some of the licences were not used in 2023 during the study year, which suggests that fishing with a boat dredge is no longer as profitable as it used to be years ago.

### ***Composition of the catch***

The dimensions of the boat dredging gear used on the Catalan coast are much smaller (two dredges used simultaneously, each 2-m wide; Generalitat de Catalunya, 2020) than those of the *rapido* trawl, but in any case, its impact on the sea bottom is high. The commercial catch represented approximately half of the total catch of experimental fishing carried out at La Ràpita (Marco-Herrero *et al.*, 2017). The discarded catch included invertebrates, such as ascidians, echinoderms, bryozoans, porifera and cnidaria, as well as animal and vegetal remains (e.g., empty shells, phanerogams, dead määrl), remains of human activity (e.g., plastic, textile, wood) and inorganic remains (e.g., stones). When the *B. brandaris* catches in La Ràpita in 2023 were considered in terms of the number and proportion of immature individuals (Table 7), exploitation with a boat dredge was the most detrimental for the resource, while the bottom trawl catch consisted of mature individuals. With respect to the use of trammel nets targeting the purple dye murex, it might seem that this fishing gear would not be as damaging for the species as a boat dredge, since despite the presence

of immature individuals in the catch, the catch was low (1.89 t; Table 7). Nevertheless, it is worth highlighting that masses of eggs in the catch were observed during the sampling in 2023, suggesting that fishers catch the females that concentrate to spawn. The capture of female aggregations of *B. brandaris* during collective spawning has also been described in Ria Formosa Lagoon (Vasconcelos *et al.*, 2008).

### ***Economic dependence of the fleets on purple dye murex***

*Bolinus brandaris* is a species appreciated by consumers. Nevertheless, the very low economic dependence on this species of fishers using the three types of fishing gear (bottom trawl, beam trawl and trammel net; Table 3) involved in purple dye fishery in the Ebro Delta is worthy of mention. Low dependence on both bottom trawl and trammel nets was expected since *B. brandaris* is a bycatch species for the former and because the catch of the latter is low. However, this was not the case for boat dredges, whose use is regulated by a specific management plan, with purple dye murex as the target species. A clear sign of the population decline in the Ebro Delta is that *B. brandaris* represented 73% of the commercial catch of boat dredges in the early 1990s (Martín *et al.*, 1995), whereas thirty years later, its catch was just 5% (Table 3).

### ***Assessment of the Ebro Delta population***

The methodology used in the assessment of the status of the purple dye murex stock in the Ebro Delta, CMSY (Froese *et al.*, 2019), has been previously applied to this species in the Adriatic Sea (central Mediterranean) over the period 1972–2018. According to the assessment, the purple dye murex stock indicated sustainable exploitation during the majority of the time series. However, it went into an overfishing status in the last years (Armelloni *et al.*, 2021). The abovementioned landings in the Adriatic decreased by 40% in the years following the assessment, from 2019 to 2022, which could be a result of the overfishing suggested in the assessment.

The results of the CMSY assessment of the Ebro Delta population revealed an overfishing status throughout the analysed period and a very poor status of the stock, despite the fact that fishing activity in the study area has steadily decreased, especially since 2015 (fishing days; Fig. 3). The current situation of the purple dye murex population might be the result of previous intense exploitation, and although at present the activity is much lower than it used to be, the stock does not show signs of recovery.

### ***Other factors affecting the population***

In addition to unsustainable fishing exploitation, other factors might have contributed to the current situation of the population of purple dye murex in the Ebro Delta. One

of them could be the prevalence of imposex, i.e., the masculinization of female sexual organs, which may sterilize females (Barreiro *et al.*, 2001). The incidence of imposex was very high in this population in 1999–2000 (99.67%; Ramón & Amor 2001). Nevertheless, with the implementation of the prohibition of organotin compounds on ships in 2003 (EC, 2003), a notable reduction in imposex among gastropods occurred in EU waters (Cacciatore *et al.*, 2018; El Ayari *et al.*, 2018). Furthermore, no evidence of imposex was detected in the individuals examined in the current study (pers. obs.). Therefore, imposex alone does not explain the population decrease.

Another factor to consider is parasitism, which may result in reduced reproductive activity or even castration. Prevalent parasitic castrators can substantially decrease host density (Lafferty & Kuris 2009). To the best of our knowledge, no information is available regarding purple dye murex parasites in the western Mediterranean. Larvae of *Sulcascaris sulcata* (Nematoda: Anisakidae) have been reported to infect purple dye murex in the Tyrrhenian Sea (Santoro *et al.*, 2022), although this nematode is not a castrator parasite. Nevertheless, during the laboratory examination of *B. brandaris*, signs of parasitic infection were observed, which is now under study. Thus, this possibility should not be excluded since infections by different parasites have been reported in the study area for other mollusc species, such as the noble pen shell (*Pinna nobilis*; Prado *et al.*, 2021), the Mediterranean mussel (*Mytilus galloprovincialis*; Carrasco *et al.*, 2007) or the Pacific oyster (*Crassostrea gigas*; Carrasco *et al.*, 2017).

Changes at the ecosystem level could also have contributed to the species decline. Boat dredge fishers have detected high densities of *Astropecten irregularis*, a predatory sea star that feeds on bivalves and gastropods (Baeta & Ramón, 2013). To the best of our knowledge, there are no data reporting an increase in *A. irregularis* density in the area. However, this observation suggests that a shift in predator roles may have occurred, potentially leading to cascading effects on the structure of the benthic communities. Similar situations have been described in northern Patagonia, where the Chilean abalone *Concholepas concholepas* has been replaced by the sea star *Cosmasterias lurida* (Hamame & Ortiz, 2022).

Another factor potentially affecting the species is the registered temperature increase in the area (<https://www.obsebre.es/es/es-datos-climaticos/es-temperatura-media>), as the purple dye murex inhabits very shallow waters. With the available information, this proposal remains speculative regarding, for instance, changes in species growth, natural mortality or reproduction linked to sea temperature warming. It remains also unknown the connectivity, if any, among different purple dye murex populations, as catches recorded all along the Spanish Mediterranean coast (Generalitat Valenciana 2025; ICATMAR 2024; IDAPES 2024), although at present generally low, or very low, might suggest.

### *About the management of gastropod fisheries*

Benthic, low-mobility species, such as gastropods, inhabiting coastal areas are very vulnerable to exploitation. The main challenge for managers is to identify and maintain crucial density-dependent population structures to foster resilience and the recovery of stocks facing collapse (Morris & Hernández-Flores, 2025). Despite the various management measures implemented (e.g., catch quotas, size and age limitations, temporal and spatial closures, gear restrictions), the overexploitation of gastropods has resulted in population declines globally (Stoner *et al.*, 2019). For instance, abalone (*Haliotis* spp.) landings worldwide decreased from almost 20000 t in the 1970s to only about 4500 t in 2020 (Cook, 2025). In Chile, a system of Territorial Users Rights for Fisheries (TURFs), has been recognized as one of the largest experiences of small-scale fisheries co-management at a global scale. The muricid *Concholepas concholepas*, locally known as *loco*, is a very valuable resource for the Chilean small-scale fishery. The iconic *loco* fishery began in the mid-60s and was under an open access regime until 1988. The general decrease in landings and the perception of overexploitation ultimately led the authorities to decree a total fishing ban from 1989 to 1992. TURFs were included in the management, and as of 2000, all commercialized *locos* must be obtained exclusively from TURF areas. This measure stabilized landings at the national level, at approximately 2600 annual tonnes from 1997 to 2021, although individual areas had extremely variable landings over time (Cerdeira & Stolz, 2022 and references therein; Sernapesca, 2023).

With respect to the purple dye murex fishery under study, despite the implementation of a management plan for boat dredges, the purple dye murex population clearly collapsed, indicating that the plan did not perform as expected. Since 2015, the Scientific, Technical and Economic Committee for Fisheries of the European Commission (STECF) has evaluated and reviewed this plan several times. Notably, in its plenary meeting in 2018 (STECF-PLN-18-01), regarding fishing effort, STECF concluded that the number of fishing days allocated to boat dredgers was likely to result in an increase in fishing pressure in the waters of La Ràpita, with unknown consequences for the target purple dye murex stock. The boat dredge management plan is currently under revision.

The target species of the boat dredge, as defined in the management plan in force (Generalitat de Catalunya 2020), are the purple dye murex and Venus clam (*Chamelea gallina*). Because of the low Venus clam density, its catch is prohibited until species recovery is demonstrated. In view of the purple dye murex situation and the ban on Venus clam fishing, it would seem advisable to reconsider the appropriateness of the use of boat dredges. Nevertheless, after a three-year closure, Venus clam abundance and biomass significantly increased, and the Venus clam bank reopened (STECF-PLN-2025-03). Altogether, it seems rather unlikely that such a recommendation would be implemented.

The beam trawl LFDs of the purple dye murex com-

mercial catch in 1995 and in 2023 are quite similar. This indicates that year after year, a substantial portion of the commercial catch from the beam trawl included immature and undersized individuals. No information is available on the size range exploited by bottom trawl and trammel nets in 1995, which would allow for comparison with the 2023 LFDs for all the gear types combined. Considering that trammel net catches were low and that immature and undersized individuals in the bottom trawl catch were absent, it could be hypothesized that a certain laxity in the implementation of the beam trawl regulations, which in 1995 included the same minimum landing size as that in 2023 (25 mm shell width; DOG, 1994), might have favoured the decline in the purple dye population.

Despite the different temporal and spatial management measures in force for the fleets involved in the exploitation of purple dye murex, in practice, the species is fished throughout the year to a greater or lesser extent. These combined measures do not allow for the species to experience a recovery period throughout the year, which would enhance growth or reproduction. Exploitation ranging from small individuals to adults, as well as year-round fishing of the species, will unavoidably lead to population depletion, as has been the case for the fishery under study.

### **Conclusions**

This research revealed features that indicate non-sustainable exploitation of purple dye murex, as indicated by the steady decrease in purple dye murex landings and in the daily catch per vessel in the last two decades, the presence of immature individuals despite the minimum landing size in force, the very small number of large individuals in the catch, and the reduction in surface and yield of the boat dredge and bottom trawl fishing grounds. The results of the assessment reveal a situation of overexploitation throughout the analysed period of 2000–2023.

The overexploitation status of the stock is a result of the combined effect of three types of fishing gear (bottom trawl, boat dredge, and trammel nets) involved in the purple dye murex fishery, which target the purple dye murex throughout its entire bathymetric distribution. Considering the presence of immature individuals in the catch, boat dredging is likely the most detrimental for the species, although the impact of trammel nets on *B. brandaris* reproduction cannot be ignored.

The dependence of the fleets on purple dye murex is very low in terms of both landings and revenue, even in the case of boat dredging gear, which is in principle designed to catch this species.

The purple dye murex population in the Ebro Delta is depleted. With the current very low level of biomass, recruitment will be substantially reduced; that is, the existing biomass is not sufficient to ensure the replacement of the population.

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