Effects of artisanal fisheries on the scorpaenids (*Scorpaena* spp.) reproduction in the marine protected area of Cap de Creus (NW Mediterranean)

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Abstract

Rockfish species are considered important to the ecology of rocky-reef communities which constitute a key habitat in many coastal marine protected areas (MPAs). These species, which are commercially valuable for artisanal fisheries in the Mediterranean, display particular biological traits that could render them vulnerable to fishing. In this study we monitored the artisanal fisheries of scorpaenids (*Scorpaena* spp) in the MPA of Cap de Creus (northwestern Mediterranean) in order to estimate the status of their populations, to link captures with the reproduction of these species, and to evaluate the potential impact that artisanal fishing may have on them. Data from onboard sampling with artisanal fishermen and from fisheries statistics (total landings) were used. Total landings and catch per unit of effort (CPUE) follow a clearly seasonal cycle, with a prominent peak during the summer months coinciding with their spawning season, which may be due to mating behavior prior to fertilization. Although maximum sizes are bigger inside the MPA than in non-protected areas situated close by, a significant percentage of individuals caught inside the MPA are below their size at sexual maturity. Although rockfish seem to be favored by the partial protection of the MPA, the allowed artisanal fisheries are probably impacting the reproduction of these species.

Keywords: Scorpaenidae, fisheries, reproduction, MPA, Mediterranean

1. INTRODUCTION

Rockfish species (*Scorpaena* spp) inhabit rocky areas and *Posidonia oceanica* meadows (Harmelin-Vivien et al., 1989), and are considered important to the ecology of rocky-reef communities of tropical and temperate seas throughout the world (Russell, 1983; La Mesa et al., 2005). Since these habitats are well represented in many marine protected areas (MPAs) of the Mediterranean, rockfish populations may be considered good indicators of the status of these marine reserves. In this sense, *S. porcus* has been suggested as a "biomonitor" species to perform monitoring studies, because of the pattern of its responses to pollution at different levels of organization (Oven et al., 2000).

Rockfish are valuable target species for artisanal fisheries operating in northwestern Mediterranean MPAs with rocky habitats, e.g. Port Cros (Cadiou et al., 2009), as well as in other rocky coastal areas around the Mediterranean (see Reglero and Morales-Nin, 2008; Battaglia et al., 2010; Matic-Skoko et al., 2011). However, little is known about the impact of artisanal fishing on rockfish populations. Stewart and Hughes (2010) and Mason (1998) revealed the long history of depletion that many species of the family Scorpaenidae have suffered, with population resilience declining due to the removal of larger and older fish (Leaman and Beamish, 1984). Moreover, the negative anthropogenic impact on the reproductive potential of scorpaenids caused by pollution has been demonstrated for *S. porcus* (Oven et al., 2000).

The main objectives of this study are to evaluate the status of the scorpaenids (*Scorpaena* spp.) in a Mediterranean MPA (Cap de Creus) and the potential impact artisanal fishing may have on the reproduction of these species. Reproduction data on scorpaenids in the area nearby Cap de Creus is combined with catch data from an onboard sampling taken from artisanal fishing vessels to analyze whether there are relationships between them. Our hypothesis is that the complex reproductive characteristics of scorpaenids render them vulnerable to artisanal fishing in

Mediterranean rocky coastal areas, where these fisheries are often considered not to jeopardize coastal resources (see e.g. Cadiou et al., 2009). Because trawling is usually prohibited inside the Mediterranean MPAs (Abdulla et al., 2008), artisanal fishing remains the only extractive practice impinging on scorpaenids in these areas.

2. MATERIAL AND METHODS

2.1. Study site

The MPA of Cap de Creus was created in 1998 and is situated in the northwestern Mediterranean, comprising part of the rocky coast of the eastern Pyrenees in Catalonia (Spain). Its 3056 ha of sea show different levels of protection (partial reserve, integral reserve and park zone), as seen in Figure 1. Trawling and purse-seining are prohibited everywhere in the MPA while recreational and artisanal fishing are only allowed in the park zones and the partial reserves.

One of the most prominent features of the fisheries in this area is their diversity in terms of the types of fishing gear, fishing sites, caught species and seasons of fishing (Gómez et al., 2006; Lloret et al., 2010). This is due to the Cap de Creus being a complex zone from a biological and environmental point of view, with different kinds of communities and habitats, and varying oceanographic and climatological situations.

2.2. Collection of data

Because landings statistics and bottom trawl survey data are inaccurate for the evaluation of scorpionfish in Mediterranean coastal waters (SGMED-STECF, 2011), onboard sampling with artisanal fishers was carried out from January 2008 to December 2010. The sampling scheme had two components. On one hand, three observers interviewed the artisanal fishermen and conducted an on-board inspection for data. On the other, a fisher self-sampling program was established in which three

artisanal fishers were trained, equipped and paid to provide information about their own fishery, including length-frequency measurements. Recent studies have highlighted the ability of fishers to report catches in a manner that is consistent with other fishery-dependent data sources when there is incentive to do so, supporting the use of self-sampling programs developed in many parts of the world as sources for catch documentation and tools for fishery management (Roman et al., 2011). In our case study, the fishery observer data were used as a secondary source for validation of data gathered by the fishers. When observers where on board, they controlled how fishers identified and measured the fish and gathered data on effort in search of inconsistencies.

Sampling was scheduled for at least four days per month in 2008 and 2009, and two days per month in 2010 in the natural park and partial reserve zones. No sampling was conducted in the integral reserve. Days and fishing gears were chosen at random. From this sampling scheme, a total of 382 fishing sets (i.e., fishing samples that represented an individual fishing gear) were obtained (71% carried out by the observers and 29% by the fishers). In order to obtain comprehensive information on rockfish species caught in the park, this study considered trammel nets, which constitute the most frequently used fishing gear in the MPA (43% of the total fishing sets), and which are responsible for nearly all (97%) scorpaenids caught (Lloret et al., 2011). Since trammel nets were set at depths of between 5 and 100 meters (average depth 30 meters), they caught the most coastal scorpaenid species: *Scorpaena porcus* (Linnaeus, 1758), *S. notata* (Rafinesque, 1810) and *S. scrofa* (Linnaeus, 1758). During the sampling on board fishing vessels, the sizes of all individuals were measured using a fish measuring board. The observers were on board and inspected catches as they were pulled onto the boat, as did the fishers on their own. Fishers were interviewed and a sampling report was completed to include the date and time that the gear was set or cast and when it was removed, and the depth and the length of each net that was cast (the height of the trammel nets varied little, from 1.3 to 1.7 meters). The weight of the

113 catch was calculated using the length frequencies derived from the sizes measured
114 and the species' weight–length relationships available from Froese and Pauly (2011).
115 With the information on fishing times and the total net length, the fishing effort was
116 calculated, which in turn is required to calculate the catch per unit effort (CPUE) in
117 number and weight. Therefore, CPUEs were used as indicators of the abundance or
118 biomass of the scorpaenids extracted in each sample.
119
120 Furthermore, time series of monthly landings of rockfish species (all three species
121 together) caught by the artisanal fishers from Port de la Selva and Roses in the waters
122 inside Cap de Creus were available for the period 1988-2009 (Department of
123 Agriculture and Fisheries of the Government of Catalonia). Time series of landings
124 were described by calculating the seasonal component and the trend by means of
125 multiple moving averages using the ForeTESS time series statistical package (Prat et
126 al., 2001). This software is based on ARIMA (autoregressive-integrated-moving-
127 average) models (Box and Jenkins, 1976). While the seasonal component shows the
128 spectral peaks at seasonal frequencies (i.e., the seasonal value of a given month is the
129 percentage above/below the annual mean), the trend represents the smoothed
130 evolution of the series. The mean seasonal pattern (percentage below/above the
131 annual mean landings) of total landings in Port de la Selva and Roses harbors was
132 computed from the seasonal landing values of the full time series of landings of
133 rockfish (1989-2010).
134
135
136 **3. RESULTS AND DISCUSSION**
137
138 **3.1. Seasonality of landings**
139 *S. scrofa* is the most frequently caught scorpaenid species in the MPA, followed by *S.*
140 *porcus* and *S. notata* (Table 1). Altogether these three species represent about 25% of

the total catch made by trammel nets in the MPA of Cap de Creus in terms of abundance, and 20% in terms of biomass.

Catch per unit of effort (CPUE) of the three rockfish species within the MPA follow a clearly seasonal cycle, with a prominent peak during the summer months (Figure 2). The very low scorpaenid total landings during winter is due to the reduction of the trammel net fishing effort. Nevertheless, when the fishing effort is taken into account, low CPUE values are also obtained in this season.

The seasonal pattern of landings has also been described for *S. scrofa* in the Aeolian Islands (Battaglia et al., 2010), where the main landings are also obtained during summer. *S. scrofa, S. porcus*, and *S. notata* spawn during this season (Bradai and Bouain, 1991; Bilgin and Celik, 2009; Muñoz et al., 2005; respectively), and some captured females were observed to be actively spawning, i.e., showing large amounts of gelatinous substance spilling from their urogenital papilla (Figure 3A).

These results suggest that high CPUE and landing values during summer season may be due to mating behavior prior to fertilization. Scorpaenids show an intermediate reproductive strategy between the simplest oviparity and the development of internal fertilization (Muñoz et al., 2002a). Gametes are still released towards the external medium, but both sexes develop mechanisms to facilitate the fertilization of the eggs. The ovarian stroma of *S. scrofa, S. porcus*, and *S. notata* is located in the center of the gonad and the developing oocytes are connected to it by peduncles and extend out into the surrounding lumen. This type of organization seems to be related to the production of the gelatinous matrix (Koya et al., 1995) detected in some captures, and which keep the spawn together by surrounding the expelled eggs (Muñoz et al., 2005). Likewise, it should be noted that males also have unusual features in relation to their reproductive traits. Spermatogenesis is quite similar in most of the teleosts it has been described in: the male germinal epithelium is normally composed of spermatocytes that

are formed when a single clone of primary spermatogonia is enclosed by Sertoli cells. The germ cells develop synchronously inside these cysts and, at the end of the process, the cysts open and the spermatozoa are released into the lobular lumen. Spermatogenesis of *S. scrofa*, *S. porcus*, and *S. notata*, however, does not follow this well-known pattern (Muñoz et al., 2002b; Sàbat et al., 2009). In these species, spermatocysts open and release developing germ cells into the lobular lumen before they become spermatozoa (Figure 3B), thus implying the simultaneous existence in the seminal fluid of spermatocytes, spermatids and spermatozoa. This kind of spermatogenesis is called semicystic (Mattei et al., 1993) and, in addition to the cited scorpaenids, it has been described in very few fish species: in some Bleniidae (Lahnsteiner and Patzner, 1990; Lahnsteiner et al., 1990), *Opistognathus whitehurstii* (Manni and Rasotto, 1997), *Lepadogaster lepadogaster* (Mattei and Mattei, 1978), *Ophidion* sp. (Mattei et al.,1993; Hernández et al., 2005) and in *Lophiomus setigerus* (Yoneda et al., 1998a). It is noteworthy that these species in which semicystic spermatogenesis has been observed exhibit similarities in their spawning. Gobiesocidae, Bleniidae, and Opistognathidae release their eggs in groups within secretions (Potts, 1984; Robins and Ray, 1986). In the same way, *Ophidion marginatum*, *Lophiomus setigerus*, and cited species of the genus *Scorpaena* lay eggs within a floating gelatinous mass (Fahay, 1992; Yoneda et al., 1998b; Muñoz et al., 2002a; respectively). Taken together, all these findings suggest that semicystic spermatogenesis may in some way be related to the secretion of abundant thick seminal fluid, the function of which is to keep the spermatozoa together, and in this way facilitate fertilization of the whole egg mass. Perhaps spermatocytes and spermatids present in the seminal fluid act similarly to the parasperm in some cottoid fishes (see review of Hayakawa, 2007) exhibiting an “antidispersive” role that contributes to reducing the lateral dispersion of the semen during ejaculation.

196 Therefore, in these species, the release of grouped spermatozoa seems to be
197 achieved through the abundant, viscous seminal fluid which includes spermatozoa
198 together with other developmental sperm cells. This would favor the joint fertilization of
199 the whole egg mass encased by the female in a gelatinous matrix, thereby reducing the
200 need for the female to produce numerous eggs, which would explain the relatively low
201 fecundity of the species when compared with other scorpaeniformes (Muñoz et al.,
202 2005). Observation of pairs of rockfish during spawning season (Figure 3C) seems to
203 support this hypothesis (Muñoz, 2010).
204 Because of this, during this season rockfish probably become more active or expand
205 their area of activity to find a partner, becoming more accessible to fisheries (i.e., the
206 catchability increases). In this way the mating behavior of rockfish constitutes a
207 complex reproductive strategy that increase the vulnerability of these species, since
208 spawning behavior can be easily disrupted during or after fishing, as was noted for
209 other fish species by Rowe and Hutchings (2003).
210

211 **3.2. Size of individuals**

212 The average size in the trammel net catches within the MPA and their range of sizes as
213 well as those captured in non-protected areas situated close by are shown in Table 2.
214 The average size in the catch of scorpionfishes inside the MPA was always greater
215 than their size at sexual maturity. However, despite the limitations of the sampling
216 scheme of our study (e.g., both sexes are considered together) and those of the
217 existing literature (e.g., only the minimum SL of maturation in the case of *S. scrofa* is
218 known), it is noteworthy that around 24% and 44% of *S. porcus* and *S. notata*,
219 respectively, captured within MPA, had a smaller size than their size at sexual maturity.
220

221 On the other hand, the presence of actively spawning *S. scrofa* specimens in the rocky
222 areas of the MPA of Cap de Creus, and their absence from catches in the nearby
223 trawlable areas during the spawning season both by artisanal and by trawling fisheries

(Sàbat, 2005) as well as from the trawlable zones of other areas in the Mediterranean (Siblot-Boutaflika, 1976; Bradai and Bouain, 1991) suggest that the reproductive red scorpionfish are solely found in rocky areas such as those of the MPA of Cap de Creus, where they can find a spawning refuge. These areas thus constitute an essential fish habitat for the reproduction of *S. scrofa*.

Apart from the complex reproduction, scorpaenids show other biological traits such as limited mobility and slow growth that may make them particularly vulnerable to exploitation (Harmelin, 1987; Reñones et al., 2001). In this sense, although our data about the size of captured specimens in close-by non-protected areas is from some years before (Muñoz, 2000; Sàbat, 2005), it should be noted that maximum obtained sizes are much bigger inside the MPA than in those areas (Fig. 1; Table 2). The largest individuals, which should be those with the highest reproductive potential, are currently not very abundant inside the MPA but are more abundant than in non-protected areas. The slow growth rates and high longevity of scorpaenids (up to 30 years in some species; Ragonese et al., 2003) together with the fact that the MPA of Cap de Creus was established 13 years ago, imply that the reserve effect for large individuals will not become totally apparent until the future. In fact, although the role of MPA in the protection of fishery resources has been corroborated by several studies, Claudet et al. (2008) point out that re-stocking exploited populations generally requires between 10-20 years in the Mediterranean. It should be considered that in the MPA of Torre Guaceto (southern Adriatic Sea), catches of *S. scrofa* inside the protected area first declined after a fishing ban was implemented, but soon after catches inside the MPA were twice the catches obtained outside (Guidetti et al., 2010). Similarly, Reñones et al. (2001) showed a progressive recovery of the population of *S. scrofa* after the Columbretes Islands MPA (western Mediterranean) was established.

3.3. Management considerations

252 Scorpionfishes are not only relevant for fisheries, but also considered important to the
253 ecology of coastal rocky-reef communities (Russell, 1983; la Mesa et al., 2005).
254 Because of this, monitoring and management of their populations has to be carefully
255 carried out. The evaluation of the status of coastal resources is not only important to
256 small-scale fisheries, which constitute around 80% of the Mediterranean fleet, but also
257 as indicators of environmental health status of coastal rocky-reef ecosystems and of
258 protection effects.
259 The implementation of specific measures to safeguard populations of coastal rockfish
260 species, such as limiting or banning their capture through seasonal closures during the
261 spawning season (summer), and the establishment of a minimum landing size
262 (currently lacking), should be promoted. For instance, in the case of *S. porcus*, Bilgin
263 and Celik (2009) suggest a minimum fishing size of at least 18 cm TL. Furthermore, at
264 a broader spatial scale, coastal scorpaenids that show complex reproductive traits,
265 slow growth and long life span, should be considered to be listed under international or
266 national species-at-risk legislation. This would facilitate the designation of specific
267 regulations or actions—such as those proposed previously—to help prevent these
268 species from becoming endangered. Finally, there is a need to follow the research on
269 spatial and temporal scales of reproduction of rockfish, as well as the monitoring of
270 their stocks in Mediterranean rocky areas, particularly in MPAs. Owing to the lack or
271 the poor quality of small-scale fishing landings and the inefficiency of bottom trawl
272 surveys to catch coastal species such as scorpionfish in many Mediterranean areas
273 (SGMED-STECF, 2011), surveys onboard artisanal fishers could provide good data to
274 evaluate coastal species. Whenever surveys on board artisanal vessels become
275 difficult or impossible due to security reasons or limited space on board, sampling on
276 the deck during landing operations, or independent (experimental) small-scale surveys,
277 could be valid alternatives.
278
279 **3.4. Conclusions**

Although the protective measures of the MPA of Cap de Creus are favoring rockfish populations, because specimens attain larger sizes and actively spawn within the protected area, artisanal fisheries are probably impacting the reproduction of rockfish in the MPA. The catchability of scorpaenids increases during their spawning season, which is probably linked to their mating behavior prior to fertilization. A significant percentage of individuals caught inside the MPA are below the size at sexual maturity, and big spawners are scarce. Monitoring and management of rockfish species should be improved

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REFERENCES

Abdulla, A., Gomei, M., Maison, M., Piante, C., 2008. Status of Marine Protected Areas in the Mediterranean Sea. IUCN-WWF Report, Spain, 152 pp.

Battaglia, P., Romeo, T., Consoli, P., Scotti, G., Andaloro, F., 2010. Characterization of the artisanal fishery and its socio-economic aspects in the central Mediterranean Sea (Aeolian Islands, Italy). Fish. Res. 102, 87-97.

Box, G.E.P., Jenkins, G.M., 1976. Time Series Analysis: Forecasting and Control. Prentice Hall, Inc., New York. 575 pp.

308 Bradai, M.N., Bouain, A., 1991. Reproduction de *Scorpaena porcus* (Linne, 1758) et
309 de *Scorpaena scrofa* (Linne, 1758) du Golfe de Gabes. Oebalia XVII, 167-180.
310 Bilgin, S., Celik, E.S., 2009. Age, growth and reproduction of the Black scorpionfish,
311 *Scorpaena porcus* (Pisces, Scorpaenidae), on the Black Sea coast of Turkey. Appl.
312 Ichth. 25 (1), 55-60.
313 Cadiou, G., Boudouresque, C.F., Bonhome, P., Le Diréach, L., 2009. The management
314 of artisanal fishing within the Marine Protected Area of Port-Cros National Park
315 (northwest Mediterranean Sea): a sucess story? ICES J. Mar. Sci. 66 (1), 41-49.
316 Claudet, J., Osenberg, C.W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J.A.,
317 Pérez-Ruzafa, A., Badalamenti, F., Bayle-Sempere, J., Brito, A., Bulleri, F., Culioli,
318 J.M., Dimench, M., Falcón, J.M., Guala, I., Milazzo, M., Sánchez-Meca, J., Somerfield,
319 P.J., Stobart, B., Vandeperre, F., Valle, C., Planes, S., 2008. Marine reserves: size and
320 age do matter. Ecol. Lett. 11 (5), 481-489.
321 Fahay, M.P., 1992. Development and distribution og cusk eel eggs and larvae in the
322 Middle Atlantic Bight with a description of *Ophidion robinsi* n. sp. (Teleostei:
323 Ophidiidae). Copeia 3, 799–819**.**
324 Froese, F., Pauly, D., 2011. Fishbase. Accessed 23 March 2011. www.fishbase.org
325 Gómez, S., Lloret J., Riera V., Demestre, M., 2006. The decline of the artisanal
326 fisheries in Mediterranean coastal areas: the case of Cap de Creus (Cape Creus).
327 Coast. Manage. 34, 217-232.
328 Guidetti, P., Bussotti, S., Pizzolante, F., Ciccolella, A., 2010. Assessing the potential of
329 an artisanal fishing co-management in the Marine Protected Area of Torre Guaceto
330 (southern Adriatic Sea, SE italy). Fish. Res. 101, 180-187.
331 Harmelin, J.G.,1987. Structure and variability of the ichthyofauna in a Mediterranean
332 protected rocky area (national Park of Port-Cros, France). Mar. Ecol. –P. S. Z. N. I 8,
333 263-284.

334 Harmelin-Vivien, M-L-., Kaim-Malka, R.A., Ledoyer, M., Jacob-Abraham, S.S., 1989.
335 Food partitioning among scorpaenid fishes in Mediterranean seagrass beds. J. Fish
336 Biol. 34, 715-734.
337 Hayakawa, Y., 2007. Parasperm: morphological and functional studies on nonfertile
338 sperm. Ichthyol. Res. 54, 111-130.
339 Hernández, M.R., Sàbat, M., Muñoz, M., Casadevall, M., 2005. Semicystic
340 spermatogenesis and reproductive strategy in *Ophidion barbatum* (Pisces, Ophidiidae).
341 Acta Zool. –Stockholm 86, 295-300.
342 Koya, Y., Hamatsu, T., Matsubara, T., 1995. Annual reproductive cycle and spawning
343 characteristics of the female kichiji rockfish, *Sebastolobus macrochir*. Fish. Sci. 61,
344 203-208.
345 Lahnsteiner, F., Patzner, R.A., 1990. Spermiogenesis and structure of mature
346 spermatozoa in bleniid fishes (Pisces, Bleniidae). J. Submicr. Cytol. Path. 22, 565–576.
347
348 Lahnsteiner, F., Richtarski, U., Patzner, R.A., 1990. Functions of the testicular gland in
349 two bleniid fishes, *Salaria (= Blennius) pavo* and *Lipophrys (= Blennius) dalmatinus*
350 (Blenniidae, Teleostei) as revealed by electron microscopy and enzyme histochemistry.
351 J. Fish Biol. 37, 85–97.
352 La Mesa, M., La Mesa, G., Micalizzi, M., 2005. Age and growth of Madeira
353 scorpionfish, *Scorpaena maderensis* Valenciennes, 1833, in the central mediterranean.
354 Fish. Res. 74, 265-272.
355 Leaman, B.M., Beamish, R.J., 1984. Ecological and management implications of
356 longevity in some Northeast pacific groundfishes. Int. North Pac. Fish. Com. Bull. 42,
357 85-97.
358 Lloret, J., Muñoz, M., Casadevall, M., 2010. Monitoring of artisanal fisheries in Cape
359 Creus. Report MedPAN project.

360 Manni, L., Rasotto, M.B., 1997. Ultrastructure and histochemistry of the testicular
361 efferent duct system and spermiogenesis in *Opistognathus whitehurstii* (Teleostei,
362 Trachinoidei). Zoomorphol. 117, 93–102.
363 Mason, J.E., 1998. Declining rockfish lenghts in the Monterey bay, California,
364 recreational fishery, 1959-94. Mar. Fish. Rev. 60, 15-28.
365 Mattei, C., Mattei, X., 1978. La spermiogenèse d'un poisson téléostéen (*Lepadogaster*
366 *lepadogaster*). II. Le spermatozoïde. Biol. Cellulaire 32, 267–274.
367 Mattei, X., Siau, Y., Thiaw, O.T., Thiam, D., 1993. Peculiarities in the organization of
368 testis of *Ophidion* sp. (Pisces, Teleostei). Evidence for two types of spermatogenesis in
369 teleost fish. J. Fish Biol. 43, 931–937.
370 Matic-Skoko, S., Staglicic, S., Pallaoro, A., Kraljevi M., Dulcic, C., Tutman, P.,
371 Dragicevi, B., 2011. Effectiveness of conventional management in Mediterranean type
372 artisanal fisheries. Estuar. Coast Shelf S. 91, 314-324.
373 Muñoz, M., 2000. Biologia de la reproducció d'alguns escorpeniformes del Mediterrani
374 occidental (Pisces: Teleostei). PhD Thesis. Universitat de Girona, Spain. 311 pp.
375 Muñoz, M., Casadevall, M., Bonet, S., 2002a. The ovarian morphology of *Scorpaena*
376 *notata* shows a specialized mode of oviparity. J. Fish Biol. 61, 877-887.
377 Muñoz, M., Casadevall, M., Bonet, S., 2002b. Testicular structure and semicystic
378 spermatogenesis in a specialized ovuliparous species: *Scorpaena notata* (Pisces,
379 Scorpaenidae). Acta Zool. –Stockholm 83, 213-219.
380 Muñoz, M., Sàbat, M., Vila, S., Casadevall, M., 2005. Annual reproductive cycle and
381 fecundity of *Scorpaena notata* (Teleostei: Scorpaenidae). Sci. Mar. 69, 555-562.
382 Muñoz, M., 2010. Reproduction in Scorpaeniformes, in: Cole, K.S. (Ed.), Reproduction
383 and Sexuality in Marine Fishes. Patterns and Processes. University of California
384 Press, California, pp. 65-89.
385 Ordines, F., Quetglas, A., Massutí, E., J. Moranta., 2009. Habitat preferences and life
386 history of the red scorpion fish, *Scorpaena notata*, in the Mediterranean. Estuar. Coast
387 Shelf S. 85, 537-546.

388 Oven, L.S., Rudneva, I.I., Shevshenko, N.F., 2000. Responses of *Scorpaena porcus*
389 (Scorpaenidae) to anthropogenic impact. J. Ichthyol. 40, 70-73.
390 Potts, G.W., 1984. Parental behaviour in temperate marine teleosts with special
391 reference to the development of nest structures, in: Potts, G.W., Wootton, R.J. (Eds.),
392 Fish Reproduction: Strategies and Tactics. Academic Press, London, pp. 223–244.
393 Prat, A., Catot, J.M., Sole, I., 2001. Fore Tess. Polytechnical University of Catalonia,
394 Dpts. Of Statistics, High School of Engineering, Barcelona.
395 Ragonese, S., Gancitano, S., Norrito, G., Rizzo, P., Bono, G., 2003. Life history traits
396 of the slender rockfish, *Scorpaena elongata* Cadenat, 1943 (Pisces, Scorpaenidae), of
397 the trait os Sicily (Mediterranean Sea). Biol. Mar. Medit. 10, 223-232.
398 Reglero, P., Morales-Nin, B., 2008. Relationship between fist sale price, body size and
399 total catch of trammelnet target species in Majorca (NW Mediterranean). Fish. Res. 92,
400 102-106.
401 Reñones, O., Quetglas, A., Goñi, R., 2001. Effects of fishing restrictions on the
402 abundance, size structure and mortality rate of a Western Mediterranean population of
403 *Scorpaena scrofa* (Linnaeus, 1758). Rapp. Comm. Int. Mer Médit. 36, 316.
404 Robins, C.R., Ray, G.C., 1986. Atlantic Coast Fishes. Houghton Nifflin Company,
405 New York.
406 Roman, S., Jacobson, N., Cadrin, S.X., 2011. Asessing the reliability of fisher self-
407 sampling programs. N. Am. J. Fish. Manage. 31(1), 165-175.
408 Rowe, S., Hutchings, J.A., 2003. Mating systems and the conservation of
409 commercially exploited marine fish. Trends Ecol. Evol. 18, 567-572.
410 Russell, B.C., 1983. The food and feeding habits of rocky reef fish of northeastern
411 New-Zealand. New Zeal. J. Mar. Fresh. 17, 121-145.
412 Sàbat, M., 2005. L'oviparisme en la família Scorpaenidae (Pisces: Scorpaeniformes).
413 PhD Thesis. Universitat de Girona, Spain. 216 pp.

414 Sàbat, M., Lo Nostro, F., Casadevall, M., Muñoz, M., 2009. A light and electron
415 microscopic study on the organization of the testis and the semicystic spermatogenesis
416 of the genus *Scorpaena* (Teleostei, Scorpaenidae). J. Morphol. 270, 662-672.
417 Siblot-Boutaflika, D., 1976. Contribution à l'étude des Scorpaenidés de la région
418 d'Alger. PhD Thesis. Université Aix-Marseille, France. 173 pp.
419 SGMED-STECF (2011). Assessment of Mediterranean Sea stocks - part 1 (STECF-11-
420 08) Report. 258 pp.
421 Stewart, J., Hughes, J.M., 2010. Life-history traits of the southern hemisphere eastern
422 red scorpionfish, Scorpaena cardinalis (Scorpaenidae: Scorpaeninae). Mar.
423 Freshwater Res. 61, 1290-1297.
424 Yoneda, M., Tokimura, M., Fujita, H., Takeshita, N., Takeshita, K., Matsuyama, M.,
425 Matsuura, S., 1998a. Reproductive cycle and sexual maturity of the anglerfish
426 *Lophiomus setigerus* in the East China Sea with a note on specialized
427 spermatogenesis. J. Fish Biol. 53, 164–178.
428 Yoneda, M., Tokimura, M., Fujita, H., Takeshita, N., Takeshita, K., Matsuyama, M.,
429 Matsuura, S., 1998b. Ovarian structure and batch fecundity in *Lophiomus setigerus* . J.
430 Fish Biol. 52, 94–106.
431
432

FIGURE CAPTIONS

Figure 1. Location of the Marine Protected Area of Cap de Creus, showing the different levels of protection (IR = integral reserve; PR = partial reserve; P = park zone). The map in the upper left corner shows the location of the MPA (thick line).

Figure 2. Catch per unit of effort (CPUE) of *S. scrofa, S. porcus* and *S. notata* caught by trammel nets in the MPA of Cap de Creus, 2008-2010. The upper panel shows the mean seasonal pattern (% below / above the annual mean landings) of total landings in Port de la Selva and Roses harbors, 1989-2010.

Figure 3. A. Actively spawning specimen of *S. scrofa*. The arrow shows the gelatinous matrix with embedded eggs. **B.** Histological section of a testicular lobule of *S. notata.* S = Sertoli cell, Sc = spermatocytes, Sd = spermatids, Sz = spermatozoa. **C.** Pair of *S. notata* underwater (photo courtesy of Carles Roqué).

Table

	n	%	TW	%
Scorpaena scrofa	779	47	472	79
Scorpaena porcus	630	38	99	17
Scorpaena notata	240	15	26	4
TOTAL	1649	100	597	100

Table 1. Catches of Scorpaenids in the MPA of Cap de Creus. n = number of individuals, TW = total weight (in kg).

Table

	MPA of Cap de Creus		non MPA		
	Average size TL ± SD	**Range of sizes**	**Average size SL ± SD**	**Range of sizes**	**Sexual maturity size (♂ - ♀)**
S. scrofa	32.4 ± 5.6	10 – 52 TL	21.2 ± 7.9	11.6 – 48.7 SL	12.4 – 14.3 TL
S. porcus	21.0 ± 4.4	10 – 37 TL	14.6 ± 3.1	10.6 – 27.8 SL	16.7 – 17.5 TL
S. notata	11.9 ± 3.8	04 – 19 TL	11.5 ± 1.6	07.1 – 16.7 SL	08.8 – 09.2 TL

Table 2. Size of captured Scorpaenids in the MPA of Cap de Creus and in non-protected trawlable adjacent areas, outside the MPA. SD = standard deviation; SL = standard length (in cm); TL = total length (in cm). Average and range of sizes outside of the MPA were obtained from Sàbat (2005) for *Scorpaena scrofa* and *S. porcus*; and from Muñoz (2000) for *S. notata.* Sexual maturity sizes are from Bradai and Bouain (1991), Bilgin and Celik (2009), and Ordines et al. (2009), respectively.

Figure
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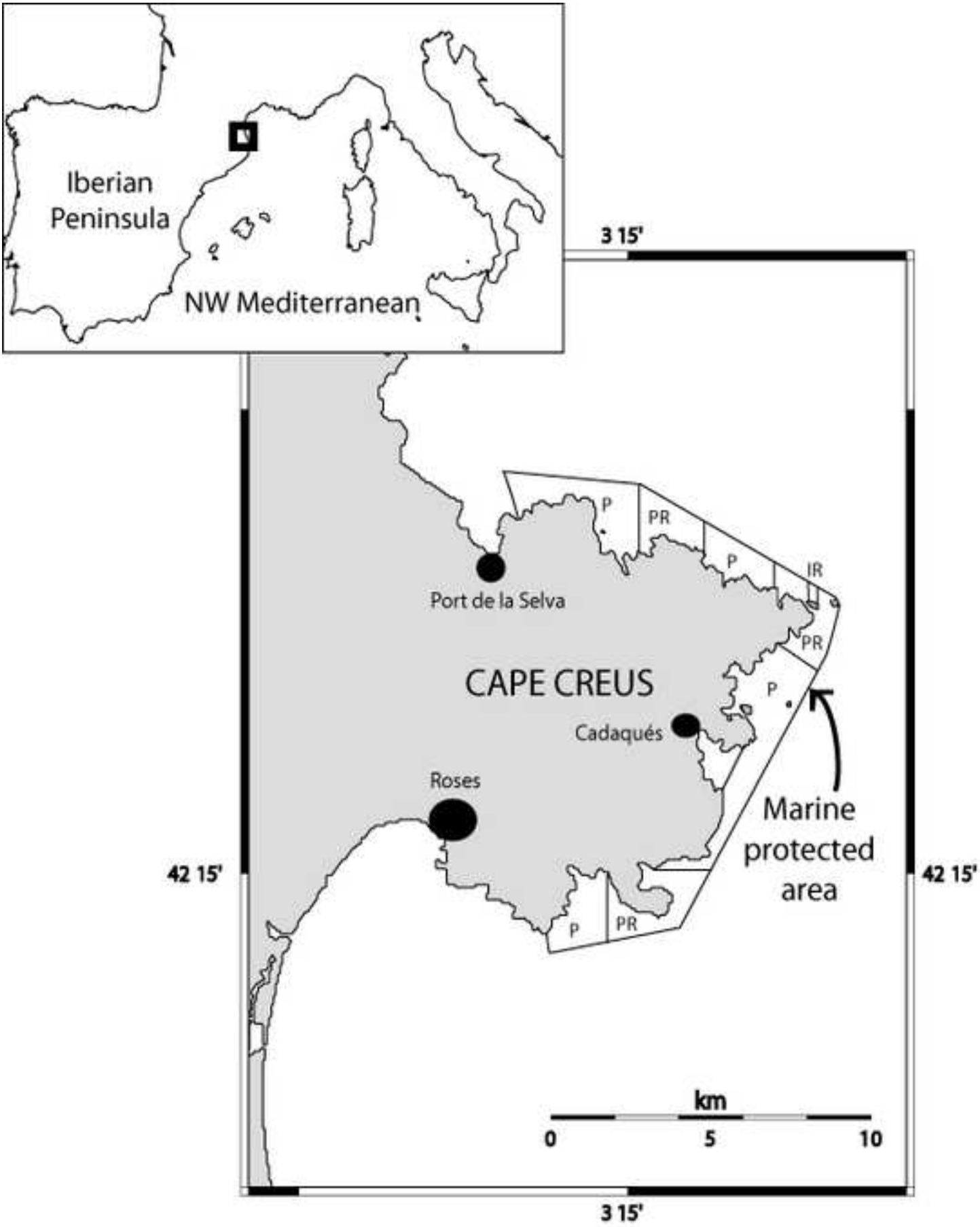
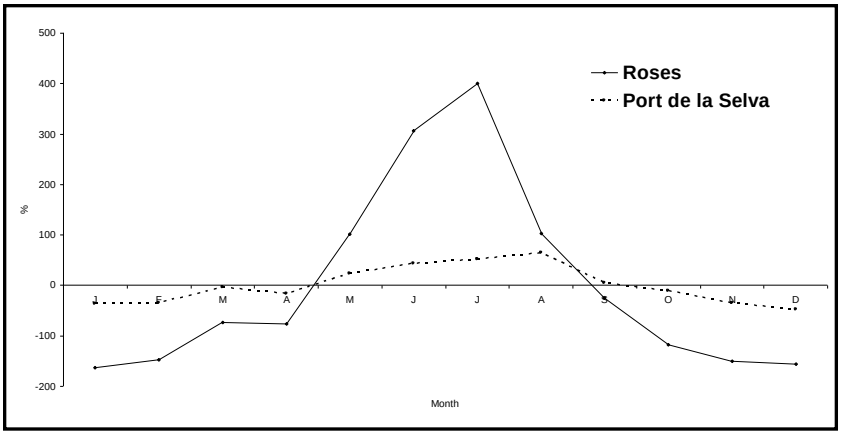
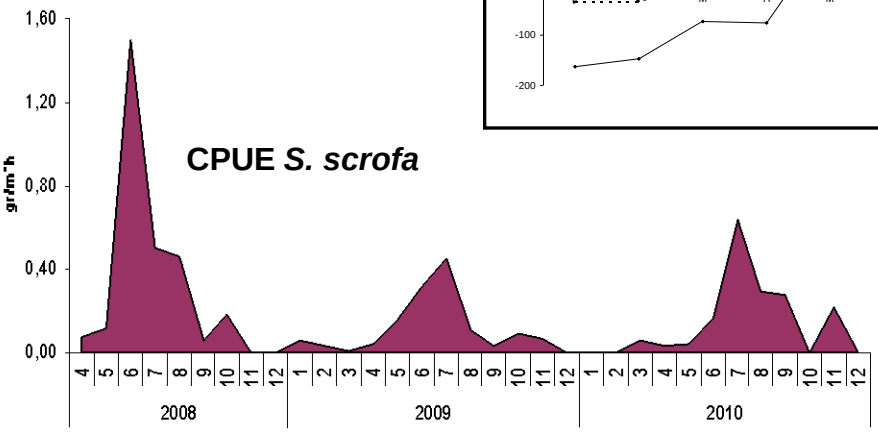
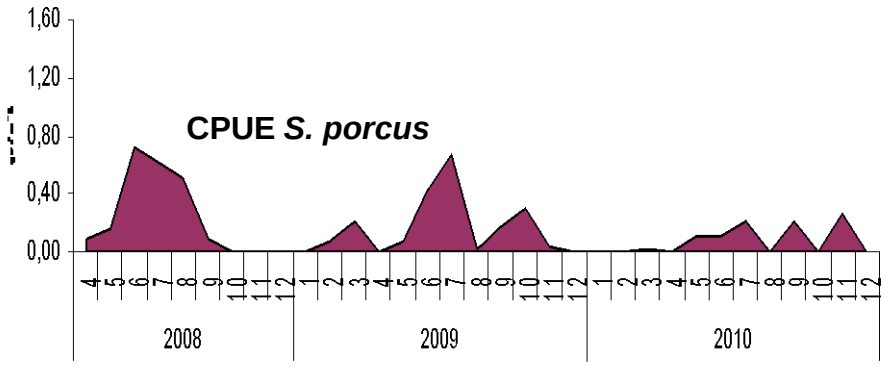
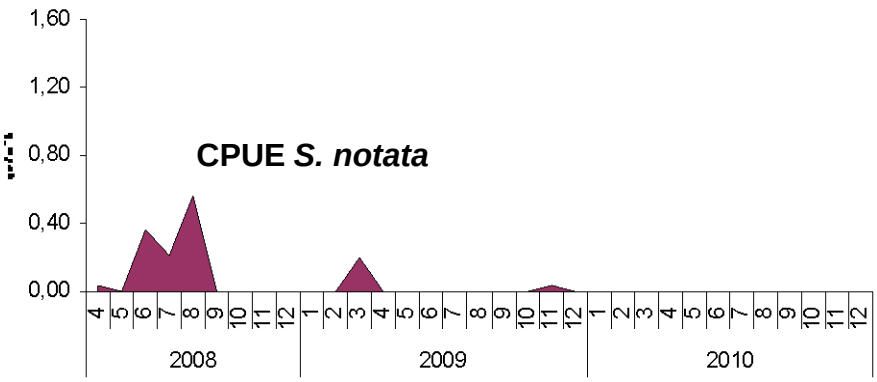


Figure


Roses
Port de la Selva
%
Month
J
F
M
A
M
J
J
A
S
O
N
D


CPUE S. scrofa
gr/km*h
2008
2009
2010


CPUE S. porcus
2008
2009
2010


CPUE S. notata
2008
2009
2010

Figure