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ASSESSMENT OF THE MEDITERRANEAN SWORDFISH BASED ON THE ITALIAN HARPOON FISHERY DATA

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Abstract

The Mediterranean Sea has a millenarian history of exploitation. Today most of its stocks are overexploited with large predators at extremely low levels of population abundance. For the Mediterranean swordfish (*Xiphias gladius*), historical and recent status of population abundance are quite uncertain due to the lack of standardized fishery data. Catch statistics are available from few countries despite the species is targeted by a large international long-line fleet. In the Strait of Messina, swordfish is also target of a traditional small-scale harpoon fishery whose catch and effort data are available since 1976 in a systematic fashion. By using generalized linear models (GLM) and their extensions, we analyzed catches registered in harpoon fishers' logbooks to detect long-term trends of swordfish population abundance. Data were available in different formats, from daily catches with information on fishing position, date, time, fishing vessel, to aggregated annual landings. Accordingly, we carried out multiple analyses with different probabilistic strategies within the GLM framework. Both aggregated and more detailed data were able to show a significant decline of swordfish in the last 30 years. Nonetheless, there is evidence of a recent recovery. We will discuss causes and implications of the observed patterns, and the importance of small-scale fisheries to detect dynamics of fish populations in the absence of conventional data.

Introduction

The Mediterranean Sea has a millenarian history of exploitation. Today most of its stocks are overex-ploited with large predators at extremely low levels of population abundance (Tudela *et al*., 2005; Ferretti *et al*., 2008). Swordfish, *Xiphias gladius* (Linnaeus 1758), is a large pelagic predator characteristic of oceanic waters, occasionally found close to the coasts. It is a migratory fish with a worldwide distribution in tropical, subtropical and temperate oceans, including the Mediterranean Sea (Palko *et al*., 1981). Here the species is represented by a single population distinct from those of the of Atlantic Ocean (De Metrio *et al*., 1989; Kotulas *et al*., 1995; Di Natale *at al*., 1996; Tserpes and Tsmenides, 1995; Pujolar *et al*., 2002; Canese *et al*., 2007) with a little genetic exchange (Magoulas *et al*., 1993; Kotoulas *et al*., 1995; Alvarado Bremer *et al*., 1999).

In the Mediterranean sea swordfish has been object of target fishing at least since Roman time. Today it is being targeted all over the basin by a large international fleet, mainly with long-lines (47% of the total catch, ICCAT, 2004) and driftnets (ICCAT, 2007), though the latter has been banned by the European community in 2002 for its high impact on by-catch species (Silvani *et al*., 1999; Rogan and Mackey, 2007). The biggest producers of swordfish (1997-2001) are Italy (44%), Morocco (23%), Greece (10%), and Spain (9%). Catch and effort statistics are uncertain, being available from few countries and very discontinuous in time and space. There is a large portion of unknown catch by illegal and unregulated fisheries that makes conventional stock assessment hard to carry out.

Official data show an increasing trend of landings from 4000 tonnes in 1976 to 20000 t in 1988, followed by a slight decline in the last decade (fluctuating around 12000-16000 tonnes), along with a sharp decline in mean size of fish (Rey *et al*., 1987; Di Natale *et al*., 1996; Tserpes and Tsimenides, 1995).

Fishery independent data are rare, local and mostly recent with a restricted breath in time span (Damalas *et al*., 2007). It is hard to investigate pattern of population abundance from these few scattered and restricted windows of information. The outburst of catches of the 70s and the 80s, followed by subsequent decline, and the mean size decrease of fish may be a classical example of boom and burst of fisheries, where rapid development in fleet distribution and fishing efficiency caused increasing production, then followed by declining catches due to the overexploitation of the resource (Hilborn and Walters, 1997). However, without detailed information on catch and effort competing hypotheses cannot be discarded.

In the Strait of Messina, swordfish is target of a traditional small-scale harpoon fishery whose catch and effort data are available since 1976 in a systematic fashion. This represents a unique source of information that may help to explain patterns in population abundance of showdfish in the last decades. By using generalized linear models (GLM) and their extensions, we analyzed CPUE of this fishery from data either newly extracted from fisher logbook, published in previous literature (Di Natale *et al*., 2005) or monitored through observer program in the area.

Swordfish in the Strait of Messina

The Strait of Messina acts as a barrier, between the Ionian Sea and Tyrrhenian Sea. These have different physical, chemical and biological features (De Domenico, 1987) also characterised by diversified bottoms and systems of currents (Griffa *et al*., 1986; De Domenico 1987; Di Sarra *et al*., 1987; Sapia and Salusti, 1987; Nicolò and Salusti, 1991; Brandt *et al*., 1997; Santoro *et al*., 2002). For its geographical conformation the strait is an area characterized by strong tidal currents (Azzaro *et al*., 2004) triggering up-welling phenomena often rich in nutrients, zooplankton and other nekton populations (Guglielmo, 1969; 1976; Genovese *et al*., 1971; Guglielmo *et al.*, 1973; Scotto di Carlo *et al*., 1982; Zagami *et al*., 1996). Here swordfish is able to swim toward the surface and to concentrate in zones where food is abundant along frontal zones where currents or water masses intersect creating turbulence and sharp gradients of sea surface temperature (SST) and salinity (Sakagawa, 1989).

The seasonal presence of swordfish in the Strait and surrounding areas (May to August) seems related to reproduction (Romeo *et al*., 2008). In facts, the southern Tyrrhenian Sea has been recognized as a breeding area (Cavaliere, 1963,1964; Cavallaro *et al*., 1991). At the end of the summer, swordfish move away toward the Ligurian sea (Canese *et al*., 2007) recognized as a feeding area of the species (Orsi Relini *et al*., 2003; Canese *et al*., 2007).

Swordfish shows a well defined diving behaviour. It swims for the majority of daytime deeper than 200 m and raises at the surface (between 0 m and 10 m) after sunset (Clarke, 1986; Bello, 1991; Peristeraki *et al*., 2005; Canese *et al.* 2007; Romeo *et al*., 2008). However, during the day this pattern is sometimes interrupted by fast surfacing events when the fish moves from elevated depths (400-500 m) to the surface in just a few minutes. Then it swims superficially for about an hour before diveing again to deep waters (Canese *et al*., 2007). Through years, harpoon fishers learned such behaviour. They chase the species during its seasonal movements and exploit the moment these fishes surface during daytime (Cavaliere,1963; Romeo unpublished data).

Local Harpoon fishing

The Strait of Messina's harpoon fishery is composed by a total of 16 boats, 8 operating in Sicily and 8 in Calabria. A typical fishing boat is called "passerella", a vessel of about 16 meters long (about 300 HP and 14 GT) with a tall sighting platform on the vessel's mast (25 m above the sea level) where the boat is piloted and fish are sighted, and a plank 20-24 m long extending from the bow for the harpooning operations (bridge).

Fishing operations are carried out during the day starting at about 7 a.m till 6 p.m at the latest depending on the abundance of sightings. Since 1902 the local Harbour office of the coast guard regulates this activity. The boats fish into assigned sectors of about 1 km^2 named "poste". 8 fishing sectors divide the coast between Messina and Torre Faro where seven sicilian boats and a calabrian one operate (fig. 1).

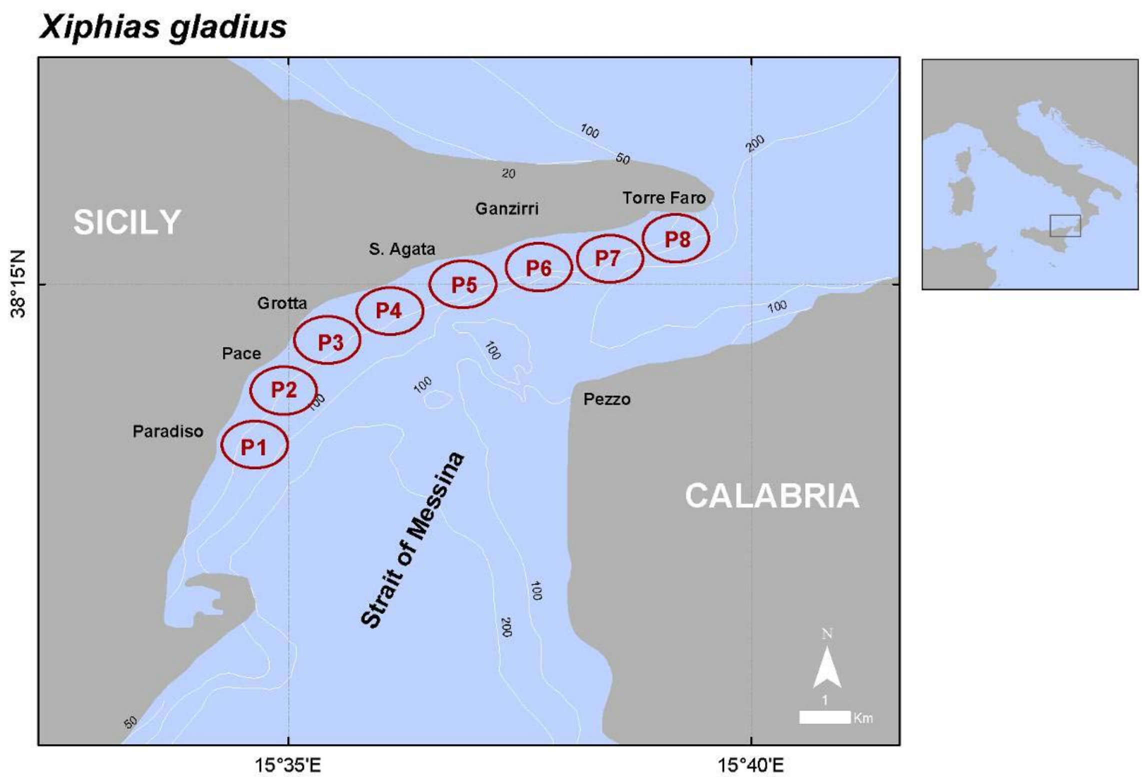

Fig. 1 Location of sector (poste) in the Strait of Messina for harpoon swordfish fishery.

Although the entire fishing area is quite small, fishers believe that the likelihood of catching a swordfish differs from a fishing sector to another. Therefore all vessels participate to a system of sector rotation that proceeds from south to north allowing each vessel to change sector every day. At the beginning of the fishing season, the coast guard assigns the initial fishing spots by means of a draw. A similar system exist in the Calabrese side. As the Sicilan side is

thought to be more suitable for this kind of fishing, Calabrian boats are allowed in turns to access one rotating Sicilian spot. Therefore every day there is a Sicilian boat left from the 8 rotating fishing spots, which either browses the remaining part of the straits, a condition called "Errante", or go fishing to an area of the strait they call "Taglio", an occasional temporary oceanographic front produced by tidal currents.
Fishing consists of browsing the assigned fishing spot in search of surfacing swordfish. Usually there are 3-4 crew members plus the skipper in the sighting platform.
When a swordfish is sighted they advise the harpooner who immediately moves to the bridge tip attempting to spear the fish. The harpoon fishery developed several gear improvements over years. There was a drastic change during the sixties when the old traditional technique, characterized by fixed sighting stations and auxiliary rowing boats for harpooning the fish, was replaced by the fleet of the actual motor boats (Cavaliere, 1963,1964; Sisci, 2005). Eventually these went through further developments such as the increase in boat length, increase in the observing tower height, increase in the bridge length, mostly devoted to increase the likelihood of sighting the fish and navigation speed. However during the last 30 year there was no further development but the introduction of sunglasses with polarized lenses during the 80s that facilitated the observation of sea surface by fishers (personal communication).

Material and methods

- **Data**

We analysed three dataset: a dataset reporting catch data (weight and number) of *X. gladius* for the sample vessel from 1981 today; a dataset reporting data, weight (kg), name of boat, locations of each boat (posta or out) for each swordfish catch from 2003 to 2007 and a dataset reporting published catches, relative to the log-book of another fishing vessel (Ciano) from 1976 to 2003 (Di Natale *et al.*, 2005).

Data on historical swordfish distribution were retrieved from interview with fishers (eight sicilian boat owners of age between 45 and 75). We collected information on fishing activity; changes in its technology, trend of catch and target species. Catch data were collected from logbooks of one boat (vessel “Peppe”), for the period 1981-2007. These were registers of sells where small swordfish were aggregated as cumulative number and weight, and large swordfish were detailed to the single catch.
From 2003 to 2007 we monitored “Peppe” with on-board observers. Information on fishing area and catches (number and weight for each swordfish) were collected for the whole period.
Data for the other Sicilian boats were collected through interviews (period 2003-2004), and through an observer at landing recording catches and relative sector (2005 to 2007).
For the analyses when a boat fished outside the assigned fishing locations (poste), the area was reported as "out". Fishing locations were reported from the 1st of June, when the rotation begins.

- **Analysis**

To model catches over time we used Generalized Linear Models (GLMs). For the catch series coming from fishers logbooks (vessel “Peppe” and “Ciano”) we assumed that the number of swordfish caught in each fishing trip followed a Poisson distribution

$$f(x_i) = \mu^{x_i} e^{-\mu} \big/ x_i! \quad x_i = 0,1,2,\ldots \tag{1}$$

with the mean μ linked to the linear predictor by a logarithmic function. For Peppe’s logbook data the model specification was the following,

$$log(\mu_{ij})=\alpha+y_i\beta+m_j\beta_2 \quad (2)$$

where μ is the expected number of swordfish taken in year (y_i) and month (m_j). α, β and β_2 are estimates for the intercept, year effect and month effect respectively. For "Ciano", data were more aggregated. We had the number of fish taken each year and the relative number of fishing days, Therefore we modeled catches as a function of year with fishing days treated as an offset variable,

$$log(\mu_i)=\alpha+y_i\beta+log(d_i) \quad (3)$$

- *Biomass*

To model the expected swordfish biomass caught each fishing day we used a delta-Gamma model (Dick, 2004). First we modeled the number of positive catch over time as a function of year and month. We assumed that the likelihood of catching a swordfish in a given fishing day followed a Bernoulli distribution where $pr(Y_i=1)=\pi_i$; and the probability of catching no fish is $pr(Y_i=0)=1-\pi_i$;. We investigated the relationship between the response probability $\pi=\pi(x)$ and the explanatory variables by fitting a GLM with binomial distribution. The linear predictor η is linked to the probability π by a logit function

$$\eta = \log(\pi / 1 - \pi) = \exp(X\beta) \quad (4)$$

$$E(\pi_i) = \frac{\exp(X\beta)}{1 + \exp(X\beta)} \quad (5)$$

where X is the matrix of covariates (variables) and β is the vector of parameter estimates.
Then we modeled the biomass of fish caught each day with a GLM with gamma distribution by using only positive records

$$f(y) = \frac{1}{\Gamma(\nu)y}\left(\frac{y\nu}{\mu}\right)^{\nu} \exp\left(-\frac{y\nu}{\mu}\right) \quad (6)$$

where ν is the scale parameter. The general model structure was

$$log(\mu_i)=\alpha+XB \quad (7)$$

where μ_i is the expected value of swordfish biomass in fishing trips that have registered at least one catch, X the matrix of covariates affecting the variability of μ_i, B the vector of their, relative parameters. The expected biomass of swordfish per day will be given by the product of the inverse functions of the binomial and gamma model linear predictors

$$E[\mu_{delta}]=p*\mu_{gamma} \quad (8)$$

We removed two days when no boats landed any fish. Finally, we modeled catches (in numbers) obtained by the entire fishing fleet for the period 2003-2007 in the portion of the Strait divided in "poste". We estimated the year effect of the variability of catches, controlling for the effect of fishing sector, boat (as fixed and random effect), lunar phase, and month. We assumed that the mean number of catch per day registered by each boat followed a Poisson distribution and that it was linked to the linear predictor η by a logarithmic function as in equation 7. Each year have been standardized by taking into account the fishing boat and the number of fishing days per month plugged in the model as offset variable.

Results

Row data displayed an increasing trend in mean number of catch per day over time, with a maximum peak in 1997 and a minimum in 1986 (fig. 2). From 25 years of catches registered in the logbook of "Peppe" it is evident an increasing trend of catches in abundance, and a similar though more buffered pattern for weight. The mean size of fish, obtained by dividing the cumulative weight caught each day by the number of specimens caught, showed an opposite trend, declining over the entire time period with a minimum registered in 1998 (23 kg). Since 2004 we observed an increase in size with an average weight of about 50 kg. When catches registered their maximum expected number, the mean size of fish was minimum.

Models suggested an overall increase in catches of about 4.36 times since 1981. It is possible to detect a differential rate of increase between two phases when the boat Peppe changed its fishing crew.

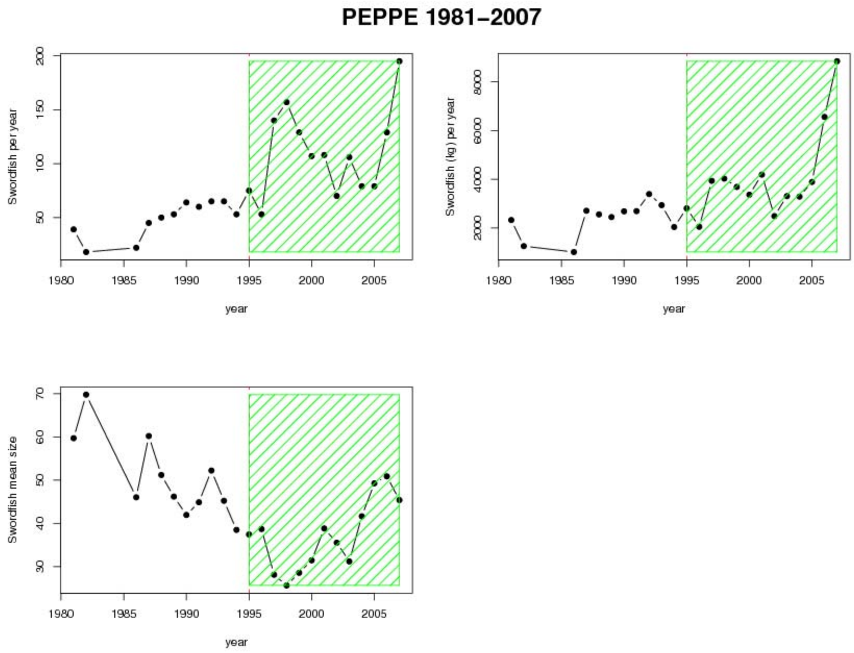

Fig. 2: Number, biomass and mean size of swordfish registered in "Peppe's" logbook. The green shaded area represents the time period when the vessel has been managed by the current crew

The increasing trend is weaker in phase 1 rather than phase 2, which also caught more fish per day. Even though we applied a model predicting a constant change of catch rate over time, it is evident a flexion point correspondent to 1998 when the expected number of catch per year declined to a minimum of 0.6 in 2002.The expected biomass of swordfish per day show an increasing trend over time (table 1). Even here it is possible to detect two phases: an initial phase of gradually increasing catches before 1998, and a following period where CPUEs show an initial decline and an abrupt reversing trend after 2002 (fig.3).

Table 1. Output of the Binomial model for the analysis of biomass.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-126.53	12.48	-10.14	0.00
year	0.06	0.01	10.12	0.00
August	-0.54	0.28	-1.92	0.06
July	0.01	0.27	0.03	0.98
June	-0.10	0.27	-0.37	0.71
May	-0.15	0.28	-0.54	0.59
September	0.45	0.40	1.12	0.26

The same trend it is reported for mean size of swordfish (fig. 4). Trends projected from the boat Ciano and Peppe differ substantially. CPUE of swordfish registered an instantaneous rate of change of 0.057 (CI: 0.05, 0.063; ProbChiSq= <0.001), while those of Ciano declined by an IRC of -0.026 (CI: -0.033, 0.02; ProbChiSq = <0.001). Although Ciano was recorded in our dataset, its occurrence was occasional and further comparisons of its catches with the other vessels could not be made.

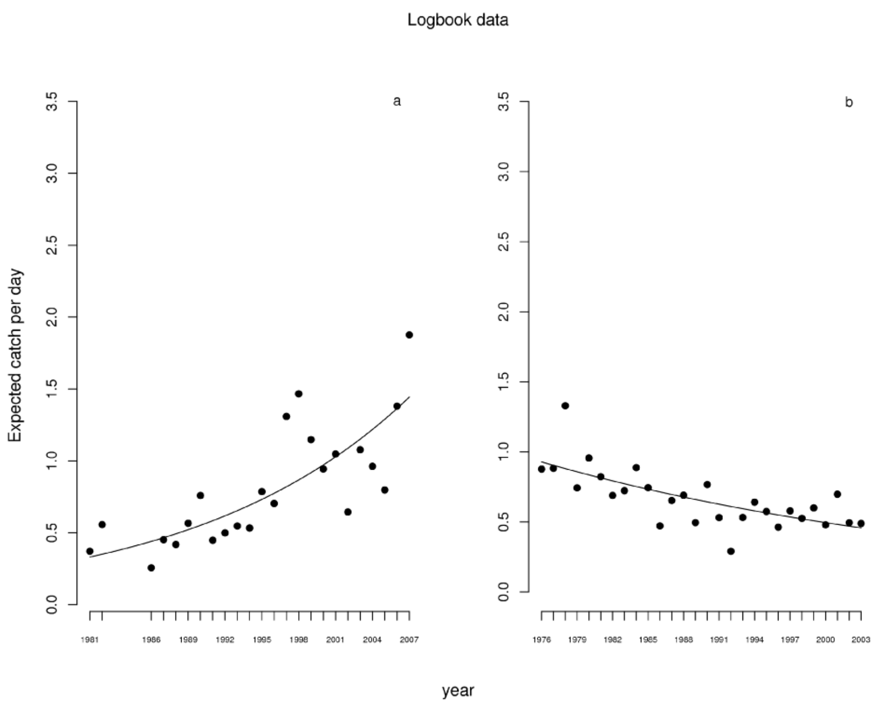

Fig. 3: Trends in abundance (expected number of per day) of swordfish registered by the fishing vessel "Peppe" (a) and "Ciano" (b). Dots are standardized catch obtained by fitting the model with year as factor (and month held fixed, July, for "Peppe's" data). The superimposed line is the trend by fitting the model with year as continuous

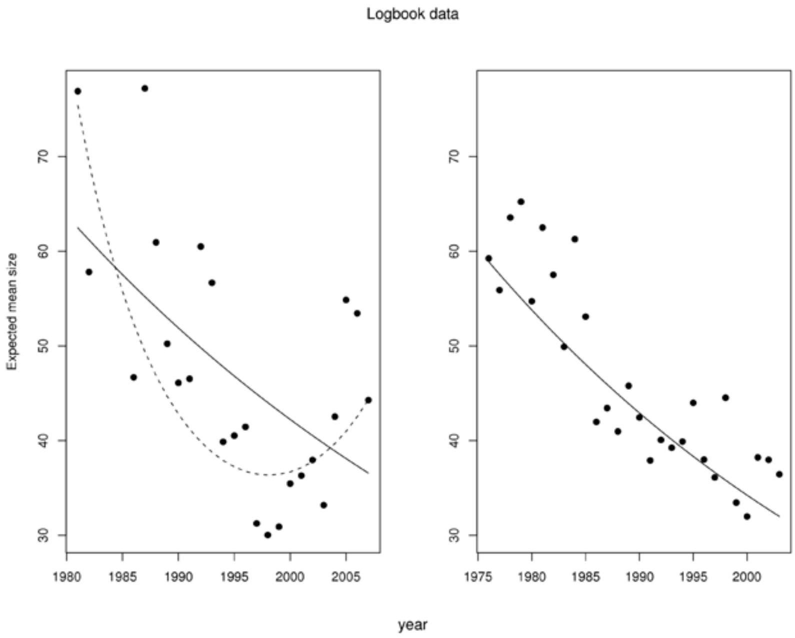

Fig. 4: Trends in biomass (expected mean size) of swordfish registered by the fishing vessel "Peppe" (a) and "Ciano" (b). The dotted line represents a local polynomial regression line fitted to the data.

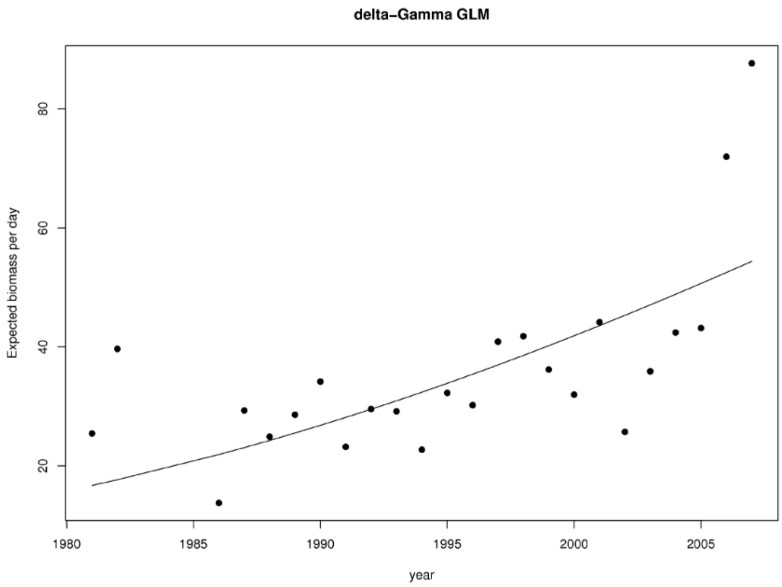

Fig 5: Expected biomass of swordfish per day. Dots represent standardized catch with year fitted as factor; the superimposed line represents the trend in catch rate given by the same model with year fitted as continuous variable

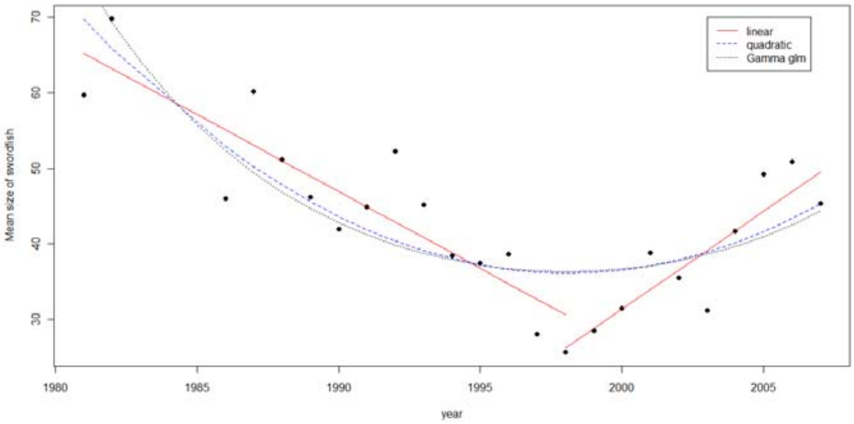

Fig. 6: Trends in mean size of swordfish registered by the vessel "Peppe". They are showed the result of a liner (red), quadratic and generalized linear model fitted to the aggregated data (mean size averaged across year regressed over years)

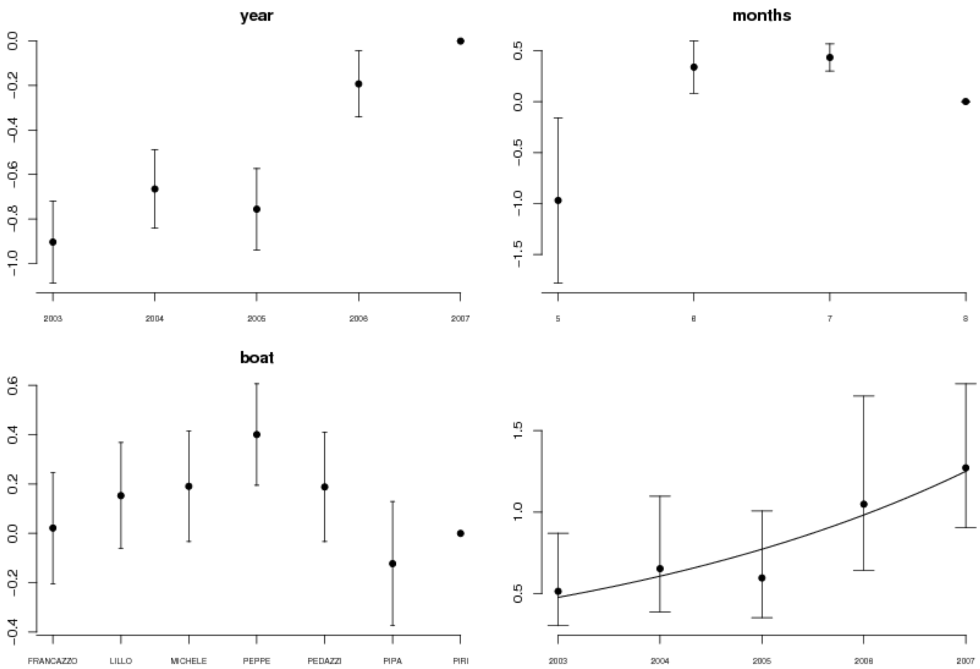

Fig. 7. Model output for the GLM applied to the whole fishing fleet data. Quadrants 1to 3 show parameter estimates and 95% confidence intervals for each covariate. Quadrant 4 shows the standardizecd CPUEs and relative confidence intervals over time. The overimposed line have been drawn by using the parameter estimate of the year effect fitted as continuous variable.

For both "Peppe" and "Ciano" mean size declined significantly over time, IRC of -0.02 (CI: -0.029, -0.012) and -0.023 (CI: -0.027, 0.018) respectively. However for "Peppe" it is evident a flexion point correspondent to 1998 when the trend is reversed. This can be observed in fig. 4,5 and 6. To Peppe's data, we fitted three model to detect this trend, a piecewise regression with a breakpoint in 1998, a quadratic linear model and a quadratic GLM with Gamma distribution to the whole series. Models are all significant but the best fit is given by the piecewise regression. This may suggest a non natural driver influencing the catches.

From 2003 to 2007 swordfish CPUE had an instantaneous rate of change of 0.24 (CI: 0.2, 0.28, Pr Chisq <0.0001). Catches showed a significant seasonality with July and June being the months with the highest likelihood to obtain a catch. As well, catch rate differed across boats (fig. 7; table 2) with Peppe being the fishing fleet with the highest catchability.

Table 2. Model output relative to the whole fleet data.

Parameter	Level1	DF	Estimate	StdErr	LowerWaldCL	UpperWaldCL	ChiSq	ProbChiSq
Intercept		1	-0.59	0.11	-0.80	-0.38	30.39	<.0001
year	2003	1	-0.90	0.09	-1.09	-0.72	92.04	<.0001
year	2004	1	-0.66	0.09	-0.84	-0.49	54.29	<.0001
year	2005	1	-0.76	0.09	-0.94	-0.57	65.60	<.0001
year	2006	1	-0.19	0.08	-0.34	-0.04	6.44	0.0112
year	2007	0	0.00	0.00	0.00	0.00		
months	5	1	-0.97	0.41	-1.78	-0.16	5.50	0.0190
months	6	1	0.34	0.13	0.08	0.59	6.69	0.0097
months	7	1	0.43	0.07	0.30	0.57	39.80	<.0001
months	8	0	0.00	0.00	0.00	0.00		
boat	FRANCAZZO	1	0.02	0.12	-0.20	0.25	0.04	0.8498
boat	LILLO	1	0.15	0.11	-0.06	0.37	1.96	0.1618
boat	MICHELE	1	0.19	0.11	-0.03	0.41	2.79	0.0950
boat	PEPPE	1	0.40	0.11	0.19	0.61	14.50	0.0001
boat	PEDAZZI	1	0.19	0.11	-0.03	0.41	2.77	0.0961
boat	PIPA	1	-0.12	0.13	-0.37	0.13	0.91	0.3395
boat	PIRI	0	0.00	0.00	0.00	0.00		
Scale		0	1.00	0.00	1.00	1.00	_	_

Discussion

The Mediterranean swordfish population has a widespread distribution. Our data are limited to a small area between the southern Tyrrhenian and Ionian sea. However, we aimed to make inference on long-term trends of swordfish population abundance by using a valuable probing activity. The harpoon fishery in the Strait of Messina provided historical data on swordfish abundance with a time span unusual for the Mediterranean sea. Average swordfish size declined over time. Trends in mean size of fish can better explain the fishing pressure on the resources rather than catch rates. Size is a more sensitive indicator of swordfish stock status. Data reported in the eastern Mediterranean sea underline a similar pattern (Damalas *et al.*, 2007) even if related to a shorter time series and a different gear. In the Ionian sea, from 1978 to 1997, De Metrio *et al.* (1999) showed a decline in average individual weight from 50 to 10 kg. Our results may suggest a strong density dependent effect where recruitment could have been enhanced by population decline. During this period the presence of other predators as sharks have dramatically declined (Ferretti *et al.* 2008). This may have contributed to increase the juvenile survival of swordfish.

During the decade 1990-2000, swordfish exploitation by driftnets peaked. In this period, fishing fleets from African countries developed as well (Tudela *et al.*, 2005). As large size fish were scarce, harpoon fishers caught as many fish as they could, including juveniles, spearfish and bluefin tuna. Even though juveniles have a low commercial value, a greater number of little fish could compensate for the loss of revenue given by the scarcity of adults. Recently (2004-2007), the increasing abundance of big-sized fish modified the habits of harpoon fishers again. Even if present in the area, juveniles were not caught any more (pers. comm. Romeo).

The seasonal effect of swordfish catches it was also reported for fish caught by longline in the eastern Mediterranean sea (Damalas *et al.*, 2007). Stergiou *et al.*, (2003) studying swordfish monthly landings in the eastern Mediterranean, ascribe the major summer peak to the higher

fishing activity in this season for the better weather conditions. For harpoon fishing, weather is a limiting factor, and in this area adult swordfish disappear after the summer. Only juveniles are caught by longline, as by catch of albacore (*Thunnus alalunga*) fishing (Andaloro, 2006). The difference in number of fish caught for each boat can be related to the the skipper's and crew's experience as well as the number of fishers in the sighting platform. This is a factor already described by several authors (Broadhrust and Hazin, 2001; Stone and Dixon, 2001; Tserpes and Peristeraki, 2003; Bigelow *et al*., 2006), that became more evident for this fishing activity. Despite our results are still preliminary, it is emblematic the difference we observed in the catch trends of "Peppe" and "Ciano" where similar gear and methods, fishing in the same area produced catch trends of opposite direction.
Resolutions adopted by the European Community, the General Fisheries Commission for the Mediterranean (GFCM) and ICCAT (ban of driftnet, technical modification of the longline fishing gears to reduce the catch of juveniles, minimum size of catch), could have promoted the increase in size of swordfish that we observed from 2004 to the present day (Reg, UE 1238/98; ICCAT 2007). Even if there are several factor that may influence swordfish catch, its distribution and abundance (Carey and Robinson, 1981; Di Natale and Mangano, 1995; Draganik and Cholyst, 1987; Sakagawa, 1989; Podestà *et al*., 1993; Holts *et al*., 1994; Bigelow *et al*., 1999; Sedberry and Loefer, 2001; Seki *et al*., 2002; Fritsches *et al*., 2005), fishing pressure is the major responsible for the detected pattern of change in size. Considering the Strait of Messina as an obligatory transit of swordfish during its reproductive period, analysis of harpoon catch data could represent a good indicator of the swordfish stock status. The present study is preliminary and further direction has to addressed to data standardization in order to validate a method to detect resources status of swordfish stock in the Mediterranean sea by analysis of harpoon fishery.

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