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Yield and catch changes in a Mediterranean small tuna trap: a warming change effect?

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Abstract

Since the 17th century, the Tonnarella of Camogli, a small tuna trap, has been used to catch pelagic fish along the western coast of the Portofino Promontory (Ligurian Sea, Northwestern Mediterranean). The availability of long-term datasets on fish yields (1950–1974 and 1996–2011), with information related to the seawater temperatures and the North Atlantic Oscillation (NAO), has allowed us to study the qualitative and quantitative changes in fish yields in the last decade and the possible relationships with the seasonal anomalies of temperature that have occurred in the Ligurian Sea. In 1950–1974, yields remained relatively constant over time (average of 35.6 ± 8.7 t·year^{-1}). From 1996 through 2011, yields were high (42.9 ± 15.9 t·year^{-1}) but inconsistent with strong annual variability in catches. The primary catches are *Seriola dumerili*, *Auxis rochei*, *Trachurus* spp. and *Sarda sarda*. Changes in species composition have occurred as well: *S. dumerili*, *Sardinella* sp. and *Belone belone* have appeared recently. Moreover, a significant decrease in the boreal scombroid (*Scomber scombrus*) and an increase of warm-temperate carangids and other typically Southern Mediterranean species such as *Coryphaena hippurus* and *Sphyraena viridensis*, appear to be linked to the warming of the surface water layer, particularly evident in the Ligurian Sea, for the last 10 years. The analysis of this kind of trend may be a powerful tool for assessing structural changes of the pelagic fish community in the Ligurian Sea (Northwestern Mediterranean).

Introduction

Substantial changes have occurred in the Mediterranean marine ecosystem during the last few decades (1980–2010). A significant warming of the western basin has been particularly evident (Marullo *et al.* 2007; Vargas-Yáñez *et al.* 2010) and a colonizing of thermophilic species has been a clear indicator of warming at the regional scale (Bianchi 2007). However, the evaluation of the effects of the global change is complicated by the fact that ecological information has been presented in different temporal and spatial scales. In addition, long-term datasets are unfortunately rare or difficult to locate. In this case, the popular knowledge (local ecological knowledge, LEK) could be useful and its importance has been highlighted recently as an alternative information source to evaluate possible changes in marine fish communities; datasets on fish catches may also provide useful information (Azzurro *et al.* 2011).

In the Mediterranean Sea, from the Middle Ages to the middle of the 20th century, the harvesting of pelagic fishes moving along the coast using large or small traps has been a thriving enterprise (Garcia Vargas & Florido del Corral 2010). However, in the last 50 years, fishing using these systems has collapsed throughout the region. Today, only a few large tuna traps remain in use in Portugal, Spain and Morocco in the Eastern Atlantic, and in Sardinia (Italy) in the whole Mediterranean (Addis *et al.* 2008; ICCAT 2011), and the use of smaller traps has essentially been discontinued.

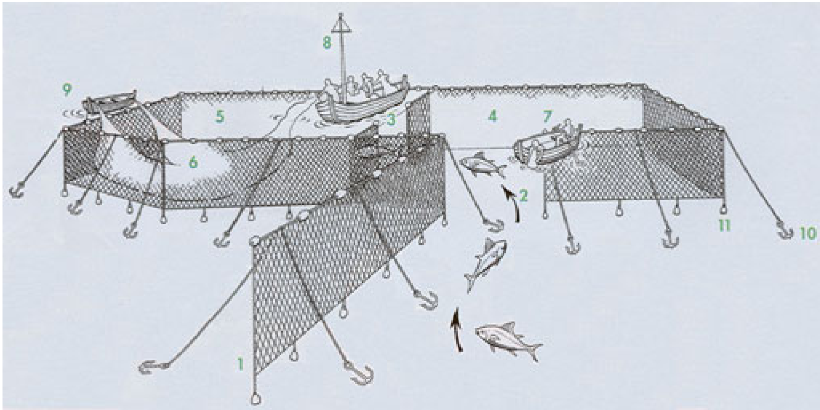

Fig. 1. The structure of the small static tuna trap, called 'the Tonnarella of Camogli' (modified from Mariotti 2007). Since 17th century, the Tonnarella is used to catch pelagic fish in the Ligurian Sea (northwestern Mediterranean): 1 barrage net or 'pedale' - 2 entrance – 3 secondary entrance – 4 collecting chamber – 5 death chamber or 'lea' – 6 hauling net – 7, 8, 9 fishermen boats – 10, 11 anchors.

Data from a small trap, called 'Tonnarella', used in the Portofino Marine Protected Area (Portofino MPA) in the Ligurian Sea (Northwestern Mediterranean Sea), seemed fit to identify catch trend and variability over time.

Information about the Tonnarella of Camogli originates from the 17th century (Cattaneo-Vietti & Bava 2009). Data on catches arise from the 19th century: Parona (1898) reported yields of 15–39 t·year^{-1} between 1890 and 1896. Catches mainly comprised bluefin tuna (*Thunnus thynnus*) and other smaller tunnids, mackerels (*Scomber* spp.) and swordfish (*Xiphias gladius*). It is likely that at the end of the 19th century, entire catches were not officially recorded, and the net system was smaller than it is today.

Prior to World War II (1940), the yields were particularly significant, although information on quantitative trends in this period is lacking. During 1937, a total harvest of 50.5 t was recorded in the Tonnarella log books, with bluefin tuna dominating the yields. Since the end of World War II, the Tonnarella has been used continuously, with brief interruptions.

Long-term data series are invaluable for evaluating short- and long-term changes in biodiversity, yield and fish composition, and predicting future scenarios.

The aim of this work was to test the hypothesis of possible relationships between the yields and fish composition from 1950 to 2011, also using a previous dataset (Balestra *et al.* 1976; Relini 2001), and to examine trends of seawater temperature and the North Atlantic Oscillation.

Material and Methods

The trap net and study area

The Tonnarella of Camogli (44°19′48′ N, 9°8′56′ E: WGS84; Fig. 1) is a small trap formed by a barrage net. The net, called 'pedale,' is 340 m long and is set perpendicular to the coastline, near the locality of Punta Chiappa (Ligurian Sea; Fig. 2a), whereas the two rectangular collecting chambers (including the 'death chamber', locally called 'lea') are approximately 100 m long and 10 m wide. The mesh size of the barrage is 60 cm, and that of the collecting net 40 cm. The 'death chamber' net has a mesh size of 1 cm.

The entire net, excluding the 'death chamber' is handmade every year using coconut ropes. The 'death chamber' is a nylon net that is colored with a chemical dye to make it less visible; fouling organisms quickly cover the coconut ropes of the barrage and collecting chamber. From April to September, fishermen haul the net three times per day: before dawn, in the late morning and in the afternoon.

The Tonnarella of Camogli is placed in the center of a complex oceanographic system. The Portofino Promontory lies within the Ligurian current that moves from east to west as part of the general cyclonic circulation of the Mediterranean Sea (Astraldi & Manzella 1983; Gasparini *et al.* 1999). The very narrow continental shelf, together with the Portofino Promontory itself, extending into the sea for more than 4 km with a roughly quadrangular shape, produces a 'tunnel effect' in the coastal current which significantly increases the hydrodynamics of the area and causes a well defined clockwise gyre in front of the town of Camogli (Doglioli *et al.* 2004). According to local fishermen, pelagic fish schools follow this small littoral clockwise gyre, turn around, bypass Recco and Camogli, and return towards Punta Chiappa (Fig. 2b). As the barrage net intercepts their route, fishes follow this net, arriving finally in the 'death chamber'.

Fishery dataset and environmental variables

All variables and datasets used are listed in Table 1. Since 1950, data on catches and species composition have been recorded daily in a logbook by the fishermen, who are familiar with the species identification. From 2000, this information has been verified by the presence of observers

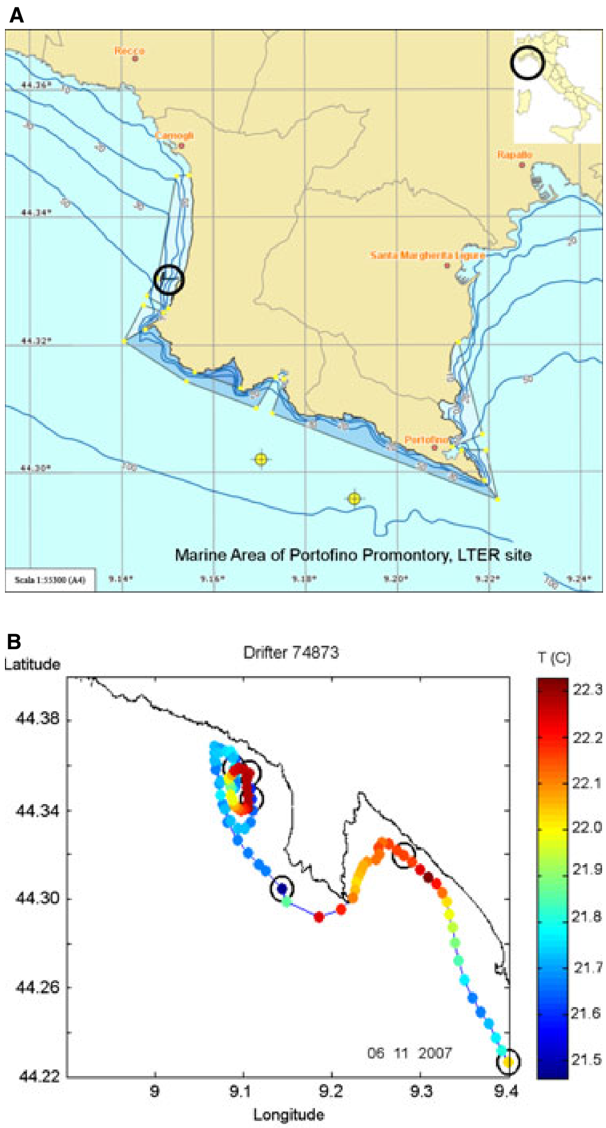

Fig. 2. Location of the trap net and hydrological features of the area. (A) Eastern Ligurian Sea. The small tuna trap is located close the town of Camogli along the western side of the Portofino Promontory (http://portofino.macisteweb.com); (B) The track of an in-shore drifter placed along the eastern Ligurian coast showing the clockwise gyre present in front of the town of Camogli (from Locritani *et al.* 2011 modified).

onboard the fishing vessels. This daily logging has allowed a detailed dataset to be created.

The time series of monthly offshore surface seawater temperature (SST) data from the Ligurian Sea from 1948 to 2009 were recorded by the U.S. National Oceanographic and Atmospheric Administration (NOAA 2011). The coastal seawater temperature in the Portofino MPA (LTER site Punta Faro station; 44°17′43′ N, 9°13′11′ E: WGS84) from surface to bottom (80 m depth) was recorded twice a month in 2000–2011 using a multiparametric CTD probe (Idronaut Ocean Seven 316 plus). CTD data were averaged for each meter and the monthly means were calculated.

Table 1. List of variables and data set used in analysis.

variable	unit	time range	reference
total yield/single species yield	t·kg^{-1}	1950–1974	Balestra *et al.* (1976)
total yield/single species yield	t·kg^{-1}	1996–2000	Relini (2001)
total yield/single species yield	t·kg^{-1}	2000–2011	this study
offshore sea surface temperature (SST)	°C	1950–2011	NOAA (2011)
coastal 0–50 m temperature (T)	°C	2000–2011	this study
coastal 0–50 m temperature anomaly (ᐞ T)	°C	2000–2011	this study
north Atlantic Oscillation (NAO index)	-	1950–2011	NOAA (2011)

The North Atlantic Oscillation (NAO index) was calculated from the monthly time series provided by the Climate Prediction Center (CPC) of the National Oceanic and Atmospheric Administration (NOAA 2011), available since 1950.

Data analyses

To test differences in the mean annual catches and SST among different periods, the non-parametric Kruskal–Wallis test was applied. Pearson's correlation analysis was performed to test the relationships between the various parameters. The data were not transformed.

An MDS analysis of the total annual catches (in kg) for a selected number of species of commercial interest (*Auxis rochei, Boops boops, Oblada melanura, Sarda sarda, Sarpa salpa, Scomber colias, Scomber scombrus, Scomberesox saurus, Trachurus* spp., *Seriola dumerili*) was performed to compare the historical data (1950–1974) with the recent catches (2000–2011); data were log-transformed prior to the analyses, and the Bray–Curtis similarity index was used.

Monthly SST data were de-trended from the seasonal component using a Loess decomposition (Zuur *et al.* 2007). Monthly and seasonal (JFM/AMJ/JAS/OND) anomalies of coastal seawater temperature (ᐞT) in the surface layer to 50 m were computed by removing the average seasonal mean based on the monthly means between 2000 and 2011, divided by the standard deviation.

The winter NAO index (December–March mean value) was used to determine the importance of winter meteorological and climatic conditions to determine the state of pelagic ecosystems in Northwestern Mediterranean Sea (Lloret *et al.* 2001; Bridges *et al.* 2009; García-Comas *et al.* 2011).

Data exploration and analysis were performed using the software packages PRIMER 6ß (Clarke & Warwick 1994), STATISTICA (Statsoft Inc.) and BRODGAR 2.5.1 (Highland Statistics Ltd. 2011).

Ethics statement

No laboratory or field experiments were performed during this study. The use of tuna nets was permitted within the Portofino MPA by national authorities.

Results

Quantitative trends and seawater temperature

The annual yields of the Tonnarella of Camogli have changed in the last few decades (1950–2011) (Fig. 3). In 1950–1974, they remained relatively constant over time, with an average of 35.6 ± 8.7 t·year^{-1} (Balestra *et al.* 1976), whereas at the end of the last century (1996–2000), the catch increased to 52.0 ± 13.0 t·year^{-1} (Relini 2001). Subsequently, in 2000–2011, the total catch yields remained high (43.56 ± 16.32 t·year^{-1}) but were inconsistent; *e.g.* the yield decreased to 15 t·year^{-1} in 2009 and then suddenly increased to 50 t·year^{-1} in the next year. Generally, the total catch yields show a decreasing trend and differ significantly [Kruskal–Wallis test; H (2, n = 41) = 8.37, P = 0.0152].

Migratory fishes move closer to the coast in late spring: in 2000–2011, catches in April, May and June represent 80–98% of the total annual catches, with the exception of 2011 (87% in July because of large catches of bullet tuna and little tunny; Table 2).

In 2000–2011, a significant increase in the average monthly temperature of the water column relative to previous decades was recorded in the coastal waters off Portofino (Ruggieri *et al.* 2006; Cattaneo-Vietti *et al.* 2010), consistent with the offshore SST trend in the Ligurian Sea (Fig. 4). Anomalies in coastal seawater temperature were recorded despite the general warming trend (Fig. 5). High positive anomalies occurred from winter to summer 2001, from autumn 2006 to spring 2007, and in spring 2009; in contrast, the winters and springs of 2004, 2006 and 2010 were colder than the decade mean. The Tonnarella catches within this period reflect these anomalies: the highest levels of yields generally follow winters and springs with seawater temperatures colder than the decadal average (Fig. 6).

Species composition and changes in the catches

Catches from Tonnarella of Camogli have included 30 species of fish, with 15 different species making up the majority of the yield (Table 3).

Since 2000, the main catches are the amberjack (*Seriola dumerili*), small scombroids such as the bullet tuna (*Auxis rochei*), and the Atlantic bonito (*Sarda sarda*). This last shows strong inter-annual fluctuations, as do the Atlantic chub mackerel (*Scomber colias*) and the Atlantic and

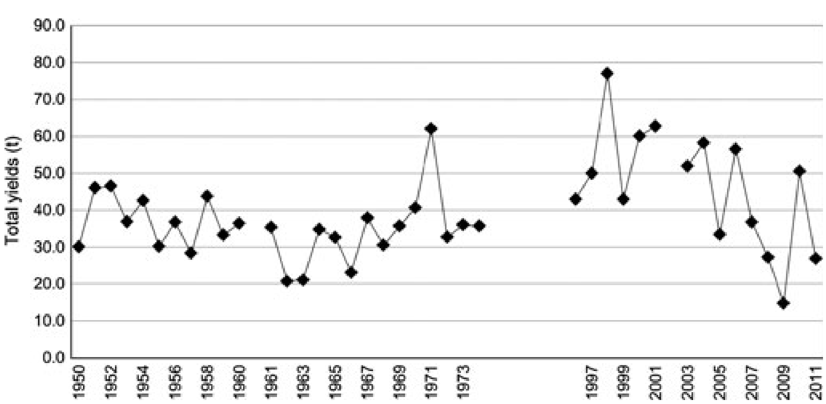

Fig. 3. General trend in the total yields (t/year) from 1950 to 2011.

Table 2. Yields in the first months (April-June) of trap activity respect to total catches (tonnes and percentages on the total yield).

		2000	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011
April–June	t	53.22	59.89	44.17	57.02	30.05	52.22	33.07	25.26	11.78	43.06	17.64
April–June	%	88.6	95.5	85.0	97.9	89.9	92.3	89.8	92.5	80.4	85.3	65.5

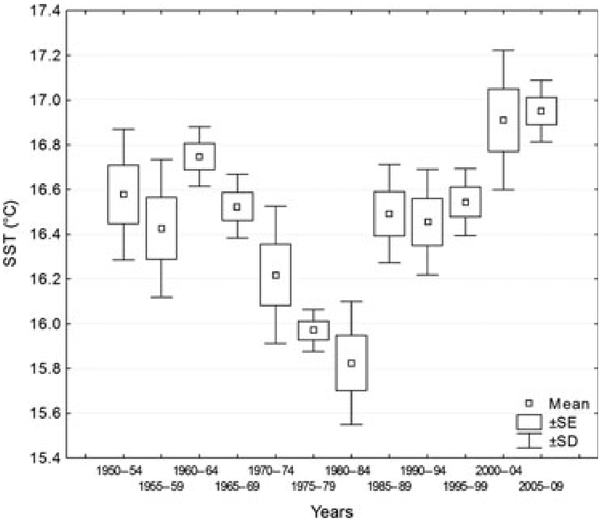

Fig. 4. SST trend in the Ligurian Sea for the last six decades. The annual mean temperature values, pooled together for 5 years, differ significantly (Kruskall-Wallis test; H (11, n = 60) = 40.71; P < 0.001).

Mediterranean horse mackerels (*Trachurus trachurus* and *Trachurus mediterraneus*, respectively). The saddle seabream (*Oblada melanura*), the bogue (*Boops boops*) and the salema *(Sarpa salpa)* are quantitatively relevant but economically less important.

Changes in species composition were evident within the multi-year dataset. Certain species have been periodically substituted by others, some have completely disappeared, and others appeared more frequently in the last few years (1996–2011).

Scombroids, such as the Atlantic mackerel (*Scomber scombrus*) and bullet tuna, have shown a decreasing trend, with the exception of the Atlantic chub mackerel and Atlantic bonito (Fig. 7). The Atlantic saury (*Scomberesox saurus*), once common, has not been present among catches since early 2000 (only a few individuals of <5 kg have been caught in 2007, 2008 and 2009) and has been substituted by the garfish (*Belone belone*). Moreover, the bluefin tuna (*Thunnus thynnus*) has been almost absent in the log books in recent years: in fact its presence in the Ligurian Sea is generally below the legal limits and the individuals are released when caught. Thus, the weight of bluefin tuna in the statistics for the past 50 years appears to be negligible. In addition, bogue and saddled seabream appear to have decreased in the last few years (2000–2011). Salema and little tunny, *Euthynnus alletteratus*, show high variability. Finally, the amberjack *Seriola dumerili*, the round sardinella (*Sardinella* sp.), the dolphinfish (*Coryphaena hippurus*) and the Eastern Atlantic barracuda (*Sphyraena viridensis*) appeared more frequently in the log books of the Tonnarella in these last years (1996–2011).

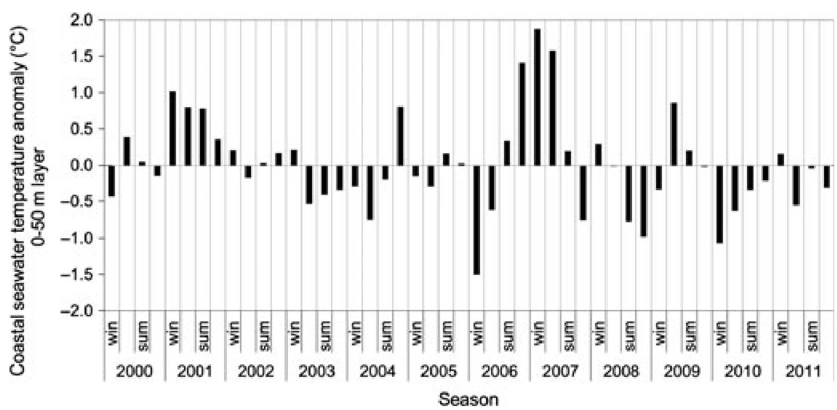

Fig. 5. Seasonal coastal seawater temperature (°C) anomalies within the LTER Portofino site from surface to 50 m (see Materials and Methods).

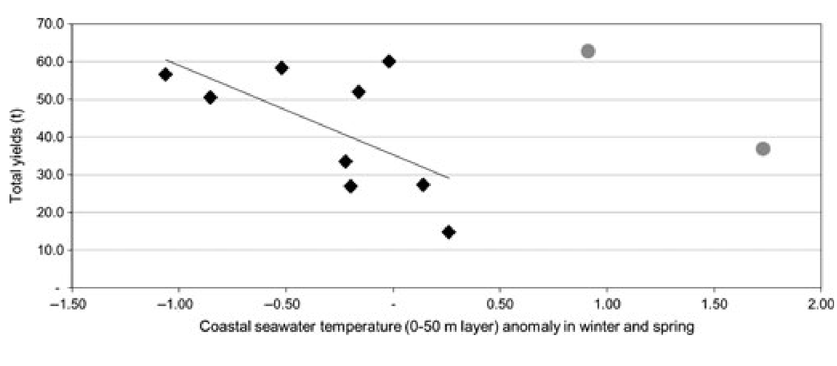

Fig. 6. Annual total yields relative to the average coastal seawater temperature anomaly in winter and spring. There is a direct relation between annual total yields and average winter and spring D T anomaly (n = 9; r = −0.632; P = 0.05; excluding 2001 and 2007, grey square).

Table 3. Multi-annual yield composition regarding the most important commercial species. In 'others' all the species, quantitatively less important, were grouped. They are: *Mugil cephalus, Liza aurata, Dentex dentex, Diplodus argus, D. puntazzo, Sparus aurata, Spicara smaris, S. maena, Lichia amia, Trachinotus ovatus, Thunnus thynnus, T. alalunga, Xiphias glaudius*.

		1950–1954 Balestra *et al.* (1976)	1955–1959 Balestra *et al.* (1976)	1960–1964 Balestra *et al.* (1976)	1965–1969 Balestra *et al.* (1976)	1970–1974 Balestra *et al.* (1976)	1996–2000 Relini (2001)	2000–2005 This study	2006–2011 This study
Auxis rochei	avg (t)	21.39	11.15	7.03	4.69	4.12	9.50	8.13	4.18
Belone belone	avg (t)							0.47	0.99
Boops boops	avg (t)	4.02	2.96	1.08	1.40	2.92	4.00	3.42	1.64
Coryphaena hippurus	avg (t)							0.12	0.11
Euthynnus alletteratus	avg (t)							0.72	0.49
Oblada melanura	avg (t)	0.02	0.35	0.46	1.41	1.40		0.59	0.38
Sarda sarda	avg (t)	2.56	9.14	2.59	3.93	2.91	2.90	4.37	5.50
Sardinella sp.	avg (t)							0.23	0.43
Sarpa salpa	avg (t)	0.71	1.37	3.06	8.66	14.16	1.50	0.99	0.26
Scomber colias	avg (t)	2.49	2.21	3.22	0.41	2.56	2.40	4.50	7.71
Scomber scombrus	avg (t)	0.38	0.81	1.44	0.16	0.47	0.20	0.04	0.00
Scomberesox saurus	avg (t)	1.33	3.27	2.55	3.35	1.51	6.00	0.13	0.06
Seriola dumerili	avg (t)						9.00	9.72	5.12
Sphyraena viridensis	avg (t)							0.13	0.32
Trachurus spp.	avg (t)	3.47	2.12	5.53	1.66	7.05	12.00	17.24	6.78
Others	avg (t)	3.92	1.89	2.19	2.81	3.38	4.50	2.70	1.50
Total catches	avg (t)	40.43	34.49	29.71	32.02	41.46	52.00	53.28	35.47
	SD	6.92	6.09	8.04	5.67	11.85	13.04	11.79	15.76

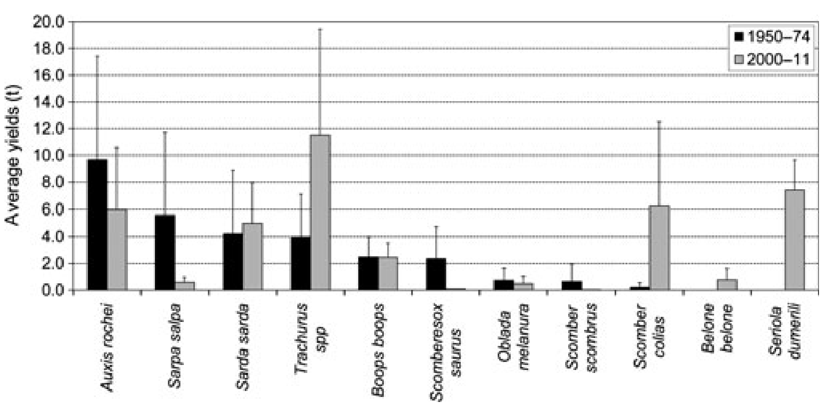

Fig. 7. Average yields (t/year) of the main species during the periods 1950–74 and 2000–2011. Bars denote the standard deviations.

These changes in species composition are highlighted by the MDS analysis (Fig. 8) comparing the annual catches of the primary species from 1950 to 1974 to catches in recent years. The catches from 2000 to 2011 group together and differ significantly from the other years (as shown by the superimposed complete linkage cluster).

Bycatch

Throughout the history of its use, the Tonnarella of Camogli has often enabled the collection of data and information on occasional and unusual captures (Table 4). At the end of the 19th century, bluefin tuna were not rare in catches, although they were never abundant: generally, these were

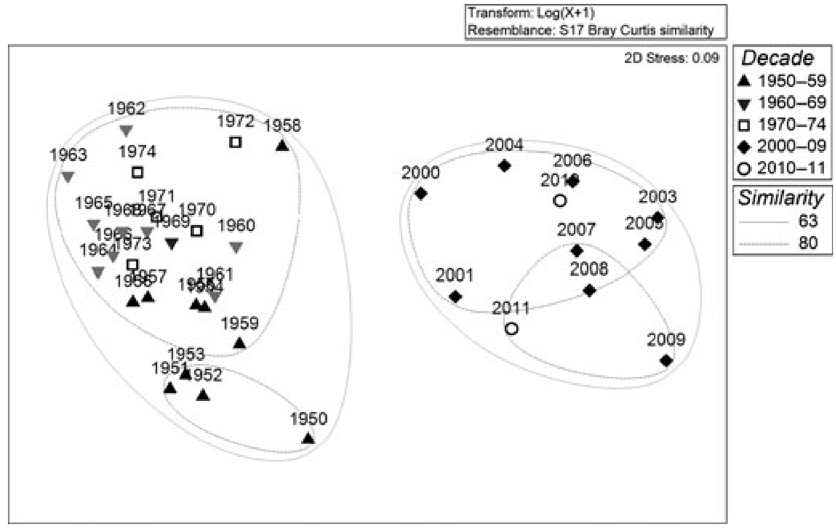

Fig. 8. MDS analysis of the annual yields of the main commercial species.

Table 4. Main unusual or rare captures in the last 60 years in the Tonnarella of Camogli.

species	remarks	references
Heptranchias perlo	Only once	Boero & Carli (1979)
Echinorhinus brucus	Only twice	Boero & Carli (1979)
Odontaspis ferox	Very rare	Boero & Carli (1979)
Alopias vulpinus	Occasional, every year	Cattaneo-Vietti & Bava (2009)
Cetorhinus maximus	Occasional, every year, released alive	Cattaneo-Vietti & Bava (2009)
Carcharodon carcharias	Only once	Tortonese (1965)
Isurus oxyrinchus	Rare	Boero & Carli (1979); M. Vacchi, personal communication
Lamna nasus	Only once	Boero & Carli (1979)
Mustelus spp	Rare in the last few decades (1990–2010)	Relini (2001); M. Vacchi, personal communication
Prionace glauca	Very rare	Boero & Carli (1979)
Galeorhinus galeus	Only once	Boero & Carli (1979)
Sphyrna mokarran	Only once	Boero & Carli (1977)
Sphyrna zygaena	Very rare	Boero & Carli (1979); fishermen's obs.
Raja asterias	Very rare	Boero & Carli (1979)
Dasyatis pastinaca	Rare in the last few decades (1990–2010)	Boero & Carli (1979); fishermen's obs.
Pteroplatytrygon violacea	Rare	Boero & Carli (1979)
Myliobatis aquila	Rare	Boero & Carli (1979)
Mobula mobular	Occasional in the last years (2000–2012)	Crovari (1970); fishermen's obs.
Makaira índica	Only once	Orsi-Relini & Costa (1986)
Tetrapturus albidus	Only once	Tortonese (1970)
Mola mola	Always very frequent, released alive	Cattaneo-Vietti & Bava (2009)
Caretta caretta	Occasional, released alive	Cattaneo-Vietti & Bava (2009)
Dermochelys coriacea	Very rare, released alive	Tortonese (1965); fishermen's obs.

small individuals or larger ones at the end of their reproductive period (locally called 'tonni di ritorno'). Even in the early 20th century, the catch of bluefin was sporadic. In 1913 and 1914, only 200 and 100 individuals were caught, respectively, and these fishes were generally 20–30 kg each (Parona 1919). Today, the bluefin tuna is rare.

The sunfish (*Mola mola*) is one of the most frequently caught fish, although it is no longer marketed and consequently it does not appear in the commercial datasets. Generally its size is small or medium, and does not exceed 30 kg. They are generally released alive.

Among other large pelagic predators, sharks are common catches and were frequently observed until the 1980s (Cattaneo-Vietti & Bava 2009). Thereafter, the trend in shark catches shows a clear decline during the last few decades (1970–2010) zero to five specimens per year (Fig. 9). Among sharks, the basking (*Cetorhinus maximus*) and thresher (*Alopias vulpinus*) sharks are the

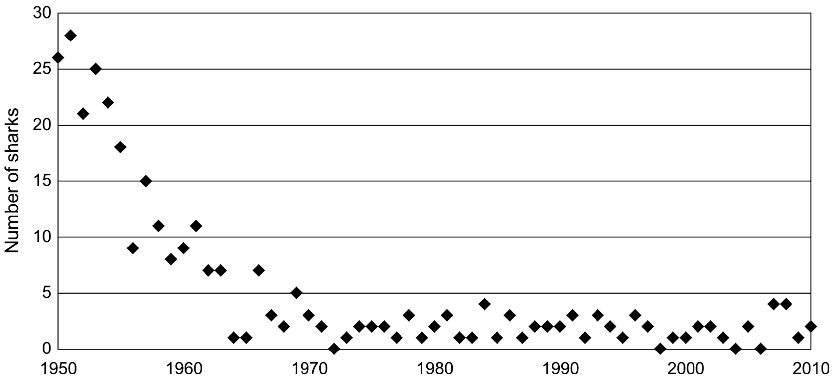

Fig. 9. Number of sharks caught in the tuna net of Camogli (modified from Boero & Carli 1979).

most frequently caught. Tortonese (1965) recorded the catch of a great white shark (*Carcharodon carcharias*) of 1500 kg in May 1954, and Boero & Carli (1977) reported the first catch of a great hammerhead shark (*Sphyrna mokarran*) in the Mediterranean Sea in 1969. Among batoids, catches of the devil fish, *Mobula mobular*, were recorded to be sporadic and occurred mainly in the last four decades: two individuals were caught in 1970, July of 2007, July of 2009 and in June of 2010, and three individuals were caught in 2011.

Finally, a 500-kg leatherback turtle (*Dermochelys coriacea*) was recorded in 1945, and another two individuals were caught in September 2006 and in 2007.

Discussion

The multi-year analysis of data from fisherman log books from the Tonnarella of Camogli shows high variability in both the quantity and the species composition: similar changes have also been recorded in other areas of the Mediterranean Sea. Sabatés *et al.* (2006) noted a significant increase of *Sardinella* sp. in relation to the increase in SST, whereas Azzurro *et al.* (2011) reported a decrease in Atlantic mackerel and Atlantic saury. The Eastern Atlantic barracuda has recently established consistent and permanent populations in the Ligurian Sea (Lejeusne *et al.* 2010), and the capture of individuals 6–8 kg in weight is not uncommon (up to approximately 10 kg·day^{-1}). The same trends have been recorded by Azzurro *et al.* (2011) in the Southern Tyrrhenian Sea and Adriatic Sea.

The disappearance of large pelagic species merits a separate mention. Currently, sharks have become increasingly rare due to the general decline of these species (Ferretti *et al.* 2008); noise disturbance caused by nautical traffic surrounding the Portofino Promontory during the summer may be a primary cause of the decline. The most common species of elasmobranchs accidentally caught in the Tonnarella of Camogli are the same as those that have been reported in the Sardinian tuna traps for the last 30 years (Storai *et al.* 2011). Although the number of specimens was not high, the information gathered from the Tonnarella data are interesting because several species (*Cetorhinus maximus, Mobula mobular* and *Dermochelys coriacea*) are considered rare and vulnerable to fisheries (Barcelona and Bern Conventions).

Understanding the causes of the Tonnarella yield fluctuations is difficult because there are many variables (natural and human) that influence the timing of the occurrence of migrant species within the Ligurian Sea. However, we can assume certain relationships.

The first assumption is a seasonal effect: fishes move closer to the coast in late spring and fishermen report that, in general, the majority of catches occur during the first months of their activity. For example, the horse mackerel appears until May–June, whereas the Atlantic saury is present later, in August–September. Large amberjacks disappear at the end of July, although younger individuals may be common in September.

The lunar cycle also influences fishing. During the full moon in June, there is a sudden decrease in the number of bullet tuna, followed by a long period of low abundance, and almost all of the catches of horse mackerel show a significant decrease during the new moons of May and August (Boero *et al.* 1980). For certain species, the influence of the nycthemeral cycle is clear. For example, almost the entire horse mackerel catch occurs before dawn, and most of the catches of bullet tuna and Atlantic bonitos occur in the late morning. Finally, a rough sea during a phase change of the moon or during the approach of fish towards the coast can jeopardize fishing for the entire month. According to the fishermen, many species are more frequently caught during sudden changes in the weather.

Apart from these general considerations, within the last few decades (1996–2010) there have been large unprecedented changes in species compositions, with a decrease in the abundance of certain scombroids (mackerels and bullet tuna) and an increase of carangids (horse mackerels, amberjack) and other typical southern-water fishes, such as the dolphinfish and the Eastern Atlantic barracuda.

These changes could be related to meteorological and climatic changes.

The NAO index is often used as a tool for summarizing the meteorological and climatic variables that influence changes in the marine ecosystem in the North Atlantic or the North Sea (Reid *et al.* 2001; Halliday & Pinhorn 2009). In the Mediterranean Sea, Lloret *et al.* (2001) highlighted the indirect influence of winter NAO index variations on the spatial and temporal dynamics of some commercial fish populations. In the Ligurian Sea, swordfish showed an inverse relationship with the winter NAO index for 1990–2006 (Orsi Relini *et al.* 2008, 2010), but Bridges *et al.* (2009) indicated, for the Mediterranean bluefin tuna, a positive correlation with the winter NAO index, but only after a time lag of 2 years. Conversely, Ravier & Fromentin (2004) did not reveal any clear relationship between catches and the NAO. All these considerations suggest that the NAO influences the marine biological dynamics in a complex manner.

Tentatively, we have tried to relate the winter NAO index with the total catches of the Tonnarella of Camogli during 1950–1974 and 2000–2011. No relationship was found with time lag 0. Conversely, considering the catches of the single species and different time lags, significant relationships were found (Table 5). These probably depend on the different characteristics of each species' life span. For example, *Auxis rochei*, *Boops boops* and *Trachurus* spp. (nearly 50% of the total catches) show a positive relationship with the winter NAO 4 years before. Confirming this result, most of the bullet tuna caught in the Ligurian Sea belonged to age >4 (Palandri *et al.* 2009). Other species, with different life cycles, show relationships with different time lags and some of them are opposite to the winter NAO index (Table 5).

Another step was carried out using only, as explanatory variable, the sea temperature measured in the last decade, the warmest since the 1950s. Temperature has a more direct effect than NAO index on fish dynamics (Ravier & Fromentin 2004). Migratory behavior and gonad maturation rate of bluefin tuna seem to be influenced by the increasing of SST in the Mediterranean Sea (Addis *et al.* 2008).

In 2000–2011, the Ligurian Sea showed very uneven temperature trends: hot summers have followed very cold winters or vice versa. This climatic unpredictability may have affected, positively or negatively, the biological cycles of some species and consequently their abundance. The analyses of the Tonnarella dataset in this period show, in general, that the highest levels of yield occurred when winter and spring coastal seawater temperature was colder than the decadal average. In fact, in the Mediterranean Sea, an increase in ecosystem productivity has commonly been recorded after colder winters or intense water column mixing in winter (Duarte *et al.* 1999; Marty & Chiavérini 2010) when the passage of energy to higher levels of the food web is enhanced due to an increase in zooplankton biomass (García-Comas *et al.* 2011). However, prolonged positive seawater temperature anomalies in winter–spring (*e.g.* 2007) can favor warm-water species, thereby partially balancing the decline of other species.

As said, the largest catches were made during the late spring and prior to the summer heat, but temperature anomalies can influence the timing of the presence of a particular species along the coast. In a normal situation (after a cold winter) most of the catches occur in May and June (*e.g.* year 2004, Fig. 10a), whereas after a particularly mild winter, the catches shift in the first months of the trap activity (*e.g.* year 2007, Fig. 10b) and the fishing season is shortened, as observed by Addis *et al.* (2008) for bluefin tuna in Sardinia traps.

Analysing single species (the most abundant commercial ones) and coastal temperature anomalies at different time scales (the period in which the trap is active and also the previous months), we observed significant relationships for only a few of them (Table 6). The round sardinella is negatively related to the March T anomaly and the Eastern Atlantic barracuda is positively related to the April T anomaly. It follows that successful fishing of these species is related to thermal events immediately before the start of the trap activity. Conversely, the Atlantic bonito and the dolphinfish are influenced not only by

Table 5. Maximum correlation between winter NAO (at different time lag) and yields of single species.

fishes	years	winter NAO time lag	n	r	P	relationship
Auxis rochei	1950–1974; 2000–2011	−4	32	0.349	<0.05	Positive
Boops boops	1950–1974; 2000–2011	−4	32	0.383	<0.05	Positive
Trachurus spp.	1950–1974; 2000–2011	−4	32	0.447	<0.01	Positive
Scomber colias	1950–1974; 2000–2011	−3	33	0.533	<0.001	Positive
Sarpa salpa	1950–1974; 2000–2011	−2	34	0.447	<0.01	Negative
Oblada melanura	1950–1974; 2000–2011	−2	34	0.373	<0.05	Negative
Scomberesox saurus	1950–1974; 2000–2011	−1	35	0.475	<0.01	Negative

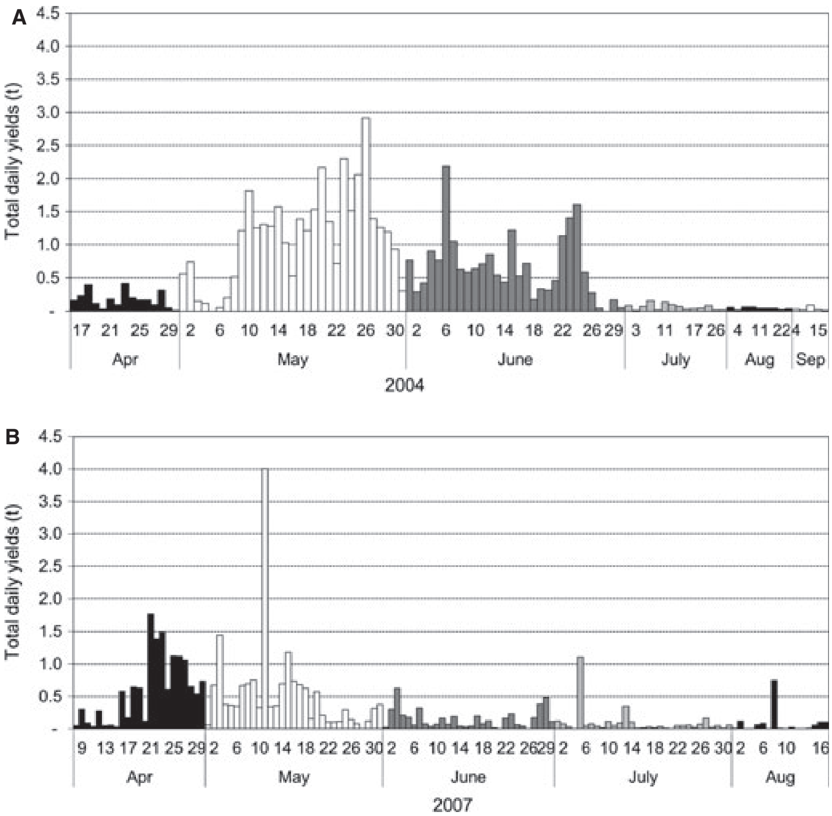

Fig. 10. Shift in daily yields in two different years. (A) daily yields (t) in 2004 (cold winter and spring); (B) daily yields (t) in 2007 (warm winter and spring).

Table 6. Correlation between temperature (at different time scale) and yields of some important commercial species.

fishes	fishes	years	explanatory variables	n	r	P	relationship
A	*Sardinella* sp.	2000–2011	▵ T March	11	−0.617	<0.05	Negative
B	*Sphyraena viridensis*	2000–2011	▵ T April	11	0.584	<0.05	Positive
C	*Coryphaena hippurus*	2000–2011	▵ T winter–spring–summer	11	0.623	<0.05	Positive
	Sarda sarda	2000–2011	▵ T winter–spring–summer	11	0.649	<0.05	Positive

temperature before the start of the trap activity, but also by temperature during the fishing period: the higher the temperature, the greater the yield.

Conclusion

The local ecological knowledge (Azzurro *et al.* 2011) obtained from the log books of the Tonnarella of Camogli is of great scientific interest because it allows us to evaluate the changes of the commercial fish community in the Ligurian Sea and its possible 'meridionalization'. Analysing the Tonnarella of Camogli dataset, we observed significant differences in the yields. A general increase has been observed since the end of the 1990s, although this period has been marked by a high inter-annual variability. In addition, there is a clear influence of seawater temperature on the quantity and quality of the yields, further supported by the recent increase in the abundance of warm-water species such as the amberjack (*Seriola dumerili*), dolphinfish (*Coryphaena hippurus*) and Eastern Atlantic barracuda (*Sphyraena viridensis*), and a decrease in boreal species. The relationship between yields and the winter NAO index is less clear and more data are probably required.

These datasets are a powerful tool for assessing structural changes of the commercial pelagic fish in the Ligurian Sea. Today, the Tonnarella of Camogli is at risk because it is no longer economically viable: if this fishing method collapses in the near future, we will lose not only an important traditional fishing system, but also an important long-term dataset on the biology and ecology of the pelagic fish community in the Ligurian Sea. For this reason, this site (Marine Area of Portofino Promontory, site no. 15) belongs to the Italian Long-Term

Ecosystem Research Network (LTER, Italy) whose mission is 'to track and understand the effects of global, regional and local changes on socio-ecological systems and their feedbacks to the environment and society'.

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