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RECONSTRUCTION OF MARINE FISHERIES CATCHES IN ARGENTINA (1950-2010)

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ABSTRACT

Argentina is a country with rich marine resources and an expansive continental shelf. The present paper reconstructs total marine fisheries removals in the Exclusive Economic Zone (EEZ) of Argentina from 1950 – 2010 by providing estimates of unreported components of fisheries catch in various sectors. The results indicate that reconstructed catch is 55% higher than FAO reported landings. Of the unreported component, unreported commercial landings accounted for 61.1%, discards accounted for 24.0%, recreational catch accounted for 14.7%, and catch in the subsistence sector was 0.2%. The recent declines in catch and the shift to species of lower trophic levels point to over-exploitation of Argentinean fisheries.

1 INTRODUCTION

Argentina is located at the southern tip of South America (Figure 1), extending between 22°S and 55°S; it has a continental shelf of 2,780,400 km². The Patagonian Large Marine Ecosystem (PLME) extends roughly over the entire continental shelf off southeast South America, from 23°S to 55°S, and contains the largest shelf in the southern hemisphere (Bisbal 1995). The confluence of the Brazil and Malvinas/Falklands currents at 39°S latitude provides warm, saline waters and rich nutrients from the sub-Antarctic area to Ecuador (Bakun 1993; Piola and Rivas 1997). Net primary productivity reaches high values near the Rio de la Plata estuary (which forms the border with Uruguay to the north), and in the southeastern Brazilian Bight (from Cabo Frio to the Cabo de Santa Marta Grande), of over 500 $mgC \cdot m^{-2} \cdot day^{-1}$, while primary productivity on the shelf south of 41°S is 150-250 $mgC \cdot m^{-2} \cdot day^{-1}$ (Bisbal 1995).

Figure 1. The continental shelf and Exclusive Economic Zone (EEZ; 1,530,500 km²) of Argentina.

Argentina covers much of South America, and is bordered on the north by Bolivia, Paraguay, Brazil, and Uruguay, in the southwest by Chile, and in the southeast by the Atlantic Ocean and the Atlantic waters of the Drake Passage. Argentina has a population of 40 million inhabitants, of which 66% are concentrated in four urban areas, i.e., Buenos Aires, Rosario, Cordoba, and Mendoza. Of the 23 provinces and the autonomous city of Buenos Aires, five have access to the sea, e.g., Buenos Aires, Río Negro, Chubut, Santa Cruz, and Tierra del Fuego.

The main feature of the shelf off Argentina is that it has gentle slopes and low relief; the soft sand bottom predominates in 65% of its surface, while rocky, hard bottoms are very limited in area. The productivity of the waters is supported by the presence of several oceanic fronts with high nutrient values that maintain various animal populations and their associated food webs.

1.1 Argentina's fisheries

The variety and abundance of marine species in Argentina varies with latitude, and the corresponding environment ranges from a typically tropical climate in the north to a sub-Antarctic climate in the south (FAO 1997; Rodríguez 1995). According to FishBase (www.fishbase.org), this region holds 334 species of marine finfishes, 119 deep-water species (Froese and Pauly 2014), in addition to various invertebrates. Commercially targeted fish species range from 60 to 70 species, including Argentine hake (*Merluccius hubbsi*), Patagonian grenadier (*Macroronus magellanicus*), whitemouth croaker (*Micropogonias furnieri*), stripped weakfish (*Cynoscion guatucupa*), Argentine anchovy (*Engraulis anchoita*), southern blue whiting (*Micromesistius australis*) and more than a dozen species of sharks and rays. Also, seven species of crustaceans are targeted, the most important of which are Argentine red shrimp (*Pleoticus muelleri*)
and southern king crab (*Lithodes santolla*), and ten species of mollusks, the most important of which are Argentine shortfin squid (*Ilex argentinus*) and Patagon.an scallop (*Zygochlamys patagonica*).

The exploitation of fisheries resources for commercial purposes began in 1978 when Argentinean, Japanese, and Polish fleets started fishing squid and previously unexploited demersal resources (FAO 1981). Fishing in Argentina, which takes place in FAO fishing areas 41, the Southwest Atlantic, and FAO fishing area 48, the Southern Atlantic, has in the past 15 years

yielded approximately 800,000 t·year^{-1}. In 2013, 14 fisheries accounted for 98% of landings, while 75% of landings were composed of four species: Argentine hake (mainly exploited near Uruguay in the Rio de la Plata estuary), Argentine shortfin squid, Argentine red shrimp, and Patagonian grenadier.

The Argentinean fleet consists between 800 to 1000 multipurpose vessels, whose activities vary depending on the season and year. In 2011, of the 896 vessels operating in Argentina, 420 of them were artisanal craft limited to bays and estuaries (i.e.,. *rada o ría y artesanales*), including 293 vessels that have only provincial license and operate within the 12 mile territorial sea; 121 were the far and near coastal fleet (*costeros cercanos y lejanos*); 139 belonged to the offshore fleet (*fresqueros de altura*), and 216 were freezer trawlers (*congeladores*). The freezer trawlers can in turn be broken down into demersal and pelagic trawlers (44), beam trawlers (*ramperos*; 79), longline (6), jiggers (84), and factory trawlers (3).

During the last four decades, Argentina's fishing industry has undergone significant structural changes, particularly attributable to changes in the composition of its fleet, the addition of new vessels and the use of new electronics. These changes led to a significant growth of the fleet's nominal and effective effort, and reported landings reached a peak of 1.3 million t in 1997. Much of Argentina's landings were generated by the freezer fleet, which by 2000, had grown to represent 70% of total landings.

From the early stage of the economic development of the Argentine fishery system (in the early-1960s to 1970s), the underlying market has been export-oriented. The aggregate economic value of the Argentine fisheries is in the order of 916 million USD; they generate an economic impact of 2.725 billion USD and an income effect to fishers and companies of 782 million USD (Dyck and Sumaila 2010), which in total represents about 3.4% of Argentina's GDP. Fishing also contributes about 13,500 direct jobs (54,000 including indirect jobs), as well as impact of the trade balance through exports..

1.2 Fisheries law and regulations

The Federal Fisheries Law 24.922 (LFP) and its Regulatory Decree 748/99 governs competition for fisheries resources between each legal community (federal and province) by setting limits on fishing. The provinces have jurisdiction over the living resources in the territorial waters adjacent to their coast up to a distance of 12 nm from shore, while the remaining areas within the EEZ are under the jurisdiction of the federal government of Argentina.

The enforcement authority of the Federal Fisheries Act 24.922 is the Undersecretary of Fisheries and Aquaculture (SSPyA), (under the Ministry of Agriculture, Livestock and Fisheries) which regulates fisheries operations, monitoring, and research. The SSPyA has the power to limit access to fishing in the case of over-exploitation, as well as regulate fishing for straddling stocks that migrate to areas outside of Argentina's EEZ.

Furthermore, the LFP created the Federal Fisheries Council (CFP) which engages in fisheries policy research and the national fisheries development plan, among other duties. The CFP consists of one representative from each coastal province, i.e., Buenos Aires, Río Negro, Chubut, Santa Cruz, and Tierra del Fuego, the Secretary of Fisheries (serving as chair), a representative of the Secretariat of Environment and Sustainable Development (SAyDS), a representative of the Ministry of Foreign Affairs, and two representatives of the National Executive. The CFP sets and regulates the catch quotas by species, vessel type, and fishing fleet. The allocation of catch shares is based on the amount of local labor employed, effective local investments, and the history of capture and processing. The CFP is advised by technical committees of the various fisheries, e.g., anchovy, crab, hake, and scallop, in which scientists and technicians, mainly of the National Institute for Fisheries Research and Development (INIDEP) and the provinces, are involved.

The Act states that INIDEP should "determine annually the maximum sustainable yield" of various species (Article 12, Law 24922) and recommend Biologically Acceptable Catch (CBA). From this information, the CFP sets the Total Allowable Catch (TAC) for each species. INIDEP predominantly uses two fishing vessels, the *Holmberg* and *Oca Balda*, for research on key fisheries data such as stock abundance, size structure, reproductive status, and in some cases by-catch of the target species. Additionally, they obtain fishing data from the onboard observer program (OAB) with regards to bycatch, discarding of target species, and mortality of chondrichthyans, seabirds, and marine mammals.

Regarding the Rio de la Plata region, Argentina and Uruguay have established a Common Fishing Zone (ZCP). The regulatory agencies in charge of this region are the Joint Technical Commission of Maritime Front (CTFM) in conjunction with the Administrative Commission of the Rio De La Plata (CARP). The setting of the TAC for those resources is done under the jurisdiction of the Treaty of Rio de la Plata and its Maritime Front. The CTFM is composed of INIDEP technicians and those of the National Directorate of Aquatic Resources (DINARA) of Uruguay.

The Coast Guard of Argentina (PNA) is dedicated to safeguarding navigation at sea, as well as protecting the marine environment within the EEZ of Argentina via the monitoring of maritime, river, and port areas. The National Health Service and Food Quality (SENASA) is the national health agency whose main purpose is to audit and certify the products and by-products of plant and animal origin, as well as their inputs. The aim is to prevent, eradicate, and control animal diseases, including those transmissible to humans, and to develop standards and monitors compliance, ensuring the implementation of the Argentine Food Code, *Código Alimentario Argentino* (CAA).

1.3 Commercial fisheries

As previously mentioned, Argentina's commercial fisheries catch between 60 and 70 different species of fish. Biological research on the main species of commercial fish in Argentina is well-developed, enabling the setting of biologically acceptable catch (CBA) for most species by INIDEP. A system of individual transferable catch quotas (ITQs) provided by Law 24.922 applies to five major fisheries: Patagonian grenadier, Argentine hake stock south of 41°S, southern blue whiting, Patagonian scallop, and Patagonian toothfish (*Dissostichus eleginoides*). Three fisheries are certified by the Marine Stewardship Council: scallop since 2004, anchovy north of 41°S since 2011, and Patagonian grenadier since 2012. Currently, there are two undergoing certifications for southern king crab and Patagonian toothfish.

Below, we describe the major commercial fisheries by species, organized by type, i.e., demersal, pelagic, cephalopods, crustaceans, and molluscs. In addition, we describe the current state of distant water foreign fleets (DWFF) and straddling stocks.

1.3.1 Demersal fisheries

Argentine hake (*Merluccius hubbsi*)

Argentine hake is a demersal and benthopelagic species distributed along the continental shelf off Argentina and Uruguay, occasionally reaching Brazilian waters (Aubone *et al.* 1997), and its e fishery is one of the most important demersal fisheries in Latin America (Villasante 2010). Due to its abundance, broad distribution, and the scale of landings, the fishery is a driver of fisheries sector development in Argentina (Bovarnick *et al.* 2010). The fishery involves over half of the Argentinean fishing fleet, generates about 12,000 direct jobs, and 40% of fisheries exports in recent years (Fundación Vida Silvestre Argentina 2008).

During the period 1987-1997, landings of Argentinean hake increased from 435,000 t to 645,000 t. In response to the growing risks of collapse, the Federal Fisheries Council reduced the total allowable catch to 189,000 t in 1999, compared to 298,000 t in the previous year. However, ineffective surveillance and control led to continued over-exploitation of the fishery (Goldeman *et al.* 1999), with recorded landings exceeding the TAC by 87% in 1999 and 93% in 2000. As a result, both the total biomass and landings continued to decline. Recent analysis of fishing capacity indicates overcapacity of 120% (Godelman 2004). At the same time, there has been an increase in discards, mainly juveniles, which represented between 11% and 24% of total landings during the period 1990-1997 (Dato *et al.* 2006). In economic terms, this represents annual losses in USD of 11-77 million (Villasante 2010).

For the purpose of management, the stock is divided into two regions, i.e., north of 41°S latitude and south of 41°S latitude. Hake is fished by 231 vessels (predominantly trawlers) in the northern management region and 335 vessels in the south management region; 38 boats in each jurisdiction are responsible for 50% of landings.

This fishery has high bycatch; in particular, common bycatch species include the smallnose fanskate (*Sympterygia bonaparte*i), plownose chimaera (*Callorhinchus callorynchus*) spiny dogfish (*Squalus acanthias*), which is considered vulnerable (VU) by the IUCN, tope shark (*Galeorhinus galeus*), also considered VU, narrownose smooth-hound (*Mustelus schmitti*), endangered (EN), and Patagonian skate (Bathyraja macloviana), near threatened (NT).

Patagonian grenadier (*Macroronus magellanicus*)
Patagonian grenadier is the most abundant fishery resource in the southern shelf and slope south of 45°S. It is highly migratory and trans-zonal, moving between Pacific waters and Atlantic waters as it migrates between Argentinean and Chilean shelves. Five ships are responsible for 50% of annual landings, while the remaining 127 of the vessels report the remaining landings.

In this fishery, bycatch of non-target species increases with latitude and is particularly high for in the region 59°W 43°S. Five retained species, i.e., Patagonian toothfish, tadpole codling (*Salilota australis)*, haddock, Argentine hake, and southern hake (*Merluccius australis*), generally represent in total about 10-12% of the catch. Discards of juvenile Patagonian grenadier are approximately 10% of the catch.

Southern blue whiting (*Micromesistius australis*)
Southern blue whiting are highly migratory species in the south of South America, with higher concentrations between Cape Horn and the Northeast of the Falklands, between the isobath of 100 m and the slope edge, shifting to the polar front in the summer months. All landings are performed by two vessels (trawlers). In waters off the Falkland Islands, overfishing of southern blue whiting has led to significant changes in the fish community.

1.3.2 Pelagic fisheries

Argentine anchovy (*Engraulis anchoita*)
The pelagic fishery of anchovy is located near the Mar del Plata platform. It is an under-exploited species and is commonly used for filleting and canning. The anchovy is fished by 86 boats, with 11 of them responsible for 50% of total landings. There is a protected area for reproduction which is closed to fishing within the Common Fishing Zone Argentinean-Uruguayan (ZCPAU). The fishery has several mechanisms for bycatch mitigation, although details on the species or quantity of bycatch are not available.

Anchovy is a very important element in the food web of the Argentinean marine ecosystem; it is estimated that between 2.4 and 6 million t are consumed by predators (20 species, of which the most important is hake). In particular the Magellanic penguin (*Spheniscus magellanicus*) consumes 2 million t on the Patagonian shelf during its reproductive season.

Chub mackerel (*Scomber japonicus*)
The winter fishery of mackerel takes place mainly in the El Rincon area (39°40'-41°'30'S) of the Argentine Sea (Perrotta *et al.* 2003) as mackerel migrate to shallow waters to spawn. It is a pelagic and semi-pelagic fish that inhabits the waters close to the bottom, and hence is predominantly caught by nets, although there is no available information on the benthic impact of this practice. Mackerel is targeted by 232 vessels, 13 of which catch approximately 50% of total landings. As for anchovy, bycatch mitigation methods are used, yet details on their effectiveness are not available.

1.3.3 Cephalopods

Patagonian shortfin squid (*Illex argentinus*)
One of the most important marine resources of Argentina is the Patagonian shortfin squid (*Illex argentinus*), a neritic-oceanic species that has been found from 54°S to 23°S off Argentina at bottom temperatures of 2.1-13.5°C, but mainly occurs between 4-12°C (Brunetti 1988). Its distribution is limited to the area of influence of the warm-cold waters of sub-Antarctic origin, particularly of the Falkland Current (Castellanos and Cazzaniga 1979; Roper *et al.* 1984), and it plays an important ecological role in the ecosystem (Rodhouse and Nigmatullin 1996).

The abundance of Argentine squid is difficult to estimate due to its short lifespan, complex population structure, and the high inter-annual variability in its population size from various environmental conditions (Basson *et al.* 1996). In 2002, the major commercially fished

population (the winter spawners) was estimated to number 1.3 billion individual squids. Brunetti (1988) distinguished three main spawning stocks in the southern range of the distribution of Patagonian shortfin squid, i.e., the summer-spawning stock (SSS), the south Patagonian stock (SPS) and the Bonaerensis-Northern Patagonian stock (BNS). The Patagonian shortfin squid has a life cycle of around one year (Brunetti *et al.* 1998) in which the biomass can vary greatly from year to year. The most commercially important population, the South Patagonian or winter-spawning stock, spawns and hatches between 28 and 38°S (Laptikhovsky *et al.* 2001). During the most vulnerable stage in its life cycle, the squid has an extensive distribution and migration, passing from the fisheries conservation zones of Argentina and the Falklands to the high seas (Barton *et al.* 2004). The diet of young and maturing Patagonian shortfin squids is mainly composed of crustaceans, while fish (mainly young hake), anchovy, lanternfishes (family Myctophidae), and squid, including Argentine shortfin squid, become more important for more mature species (Haimovici *et al.* 1998).

1.3.4 Crustaceans

Southern king crab (*Lithodes santolla*)
Crab is a benthic crustacean commonly caught by trap fishing, with little bycatch and no impact on the benthic fauna. It is located in national territorial waters near the Gulf of San Jorge and is a highly selective fishery that retains and processes only males with carapace length over 110 mm. Fishing takes place with traps, moored for four days between October and April. In the past, there have been conflicts between this fishery and vessels beam trawling for shrimp. Crab is fished by four vessels that are responsible for 90% of annual landings.

Argentine red shrimp (*Pleoticus muelleri*)
Argentine red shrimp is a migratory benthic crustacean that is mainly distributed in the Golf of San Jorge, which lies within the jurisdictions of the provinces of Chubut and Santa Cruz, and in waters under national jurisdiction. There is difficulty with this stock in linking the spawning biomass to the magnitude of subsequent recruitment, which results in an inability to generate quotas. Hence, the fishery operates under continuous monitoring of the resource and is closed when necessary to protect the spawning process and minimize overfishing during growth and recruitment; 236 vessels (trawlers) are involved in this fishery, of which 45 land 50% of the catch. Shrimp fishing trawlers have the sole authority to operate in areas of permanent closure for hake fishing.

The main impact of this fishery is through its bycatch, involving 80 species of fish, the most common of which being juvenile hake. According to the IUCN categories, nine species of bycatch in the shrimp fishery are either endangered (EN), e.g., tope shark, angular angel shark (*Squatina guggenheim*), and spotback skate (*Atlantoraja castelnaui*), or vulnerable (VU), e.g., yellownose skate (*Zearaja chilensis*), narrownose smooth-hound, and eyespot skate (*Atlantoraja cyclophora*). Other species caught as bycatch include haddock and hake. Red porgy is rarely captured, but as a result of their endangered status (EN), is important to monitor them as bycatch. The bycatch of invertebrates includes approximately 60 species including crustaceans, molluscs, and echinoderms.

1.3.5 Molluscs

Patagonian scallop (*Zygochlamys patagonica*)
Patagonian scallops settle on regions known to have high primary productivity. Four vessels target this resource utilized gear which drags along the ocean floor and hence results in high bycatch of between 80-90 different taxa, many of them juveniles. The maximum biomass of bycatch ranged on average between 43 and 61% of the total catch, depending on the region of fishing.

1.3.6 Distant water fishing fleets (DWFF)

The creation of Exclusive Economic Zones (EEZs) under the United Nations Convention on the Law of the Sea (UNCLOS) has dramatically changed the activity of the distant-water fishing fleets (DWFFs) (Pauly *et al.* 2002; Pauly and Maclean 2003). These fleets, aware of the difficulties related to new international fisheries regulations, began to develop strategies to access other countries' fishing grounds through public agreements or joint ventures (Kaczynski 1979; Kaczynski and Fluharty 2002; Alder and Sumaila 2004), often subsidized by national governments (Clark *et al.* 2005; Khan *et al.* 2006; Gelchu and Pauly 2007).

In Spain, for example, this joint venture strategy was used as a means to find new fishing grounds for the fleet, as established in the Spanish Act 147/1961 on Fleet Protection and Renewal. The Act, which was aimed at dealing with the severe depression of the construction and modernization of fishing vessel sector, resulted in a considerable increase of the freezer fishing fleet (González Laxe 1982). The Spanish fleet, mainly high seas freezer, became one of the most important foreign fleets operating on the high seas. It operated on an irregular basis between 1960 and 1983, and increased its fishing effort gradually until it reached its highest level in 1990 when the Namibian fishing ground, where it had operated, was closed. This change generated an increase in the number of Spanish vessels operating off Argentina and the Falklands by 50% (Portela *et al.* 1997; Portela *et al.* 2005). The fleet is comprised of around 40 vessels, together with another 20 and 100 Argentinean and Falklands, respectively, flagged vessels that operate under joint ventures.

The main distant-water fishing nations (DWFNs) around the world in the 1950-1994 period were Japan (21%) and the USSR (32%), which generated over 50% of the total catches, followed by Spain with 10% (Bonfil *et al.* 1998). Geographically, DWFFs cover the entire world from the Arctic to the Antarctic Ocean (Bonfil *et al.* 1998) and the Patagonian Shelf is not an exception (Villasante and Carballo Penela 2006). There is extensive bottom fishing by DWFNs in the Southwest Atlantic, most of which appears to be taking place within the EEZs of Argentina and around the Falkland Islands (Gianni 2004). As a result catches in the region increased from 45,700 t in 1950 to 1.66 million t in 1999. The peak catches has been achieved in 1997 with 1,792 million t, the catch percentage of DWFNs has increased from 0.02% in 1957 to 53% in 1989. The fact should be highlighted is that DWFNs – namely South Korea, Taiwan, Japan and China fleet as well as Germany, Italy, Portugal and Spain ones – experienced a growth ratio of 241% in the 1980s and 1990s, with a peak of 751,000 t in 1988 (Villasante *et al.* 2014).

1.3.7 Straddling fish stocks

The management of straddling stock fisheries is a critical issue in the global management of Argentinean fisheries, notably because of the distant-water fleet's activity in the adjacent zone of the Argentina Exclusive Economic Zone (EEZ) and the Falkland Islands. This phenomenon is explained by the intensification of fishing effort, either within the EEZ, between the 195-200 nm from shore or directly on the high seas, as well as by the recent increase of unreported catch from illegal or unregulated fishing.

Overall, the most important commercial resources harvested in the Patagonian LME over time are straddling stocks. It is estimated that between 2% and 12% of the total Patagonian squid biomass is found in the area beyond the 200 nm limit, whereas between 11% and 35% of the shortfin squid stock is concentrated in the area over the Patagonian shelf and slope beyond the 200 nm limit.

As regards their degree of exploitation, shortfin squid and common squid stocks are fully exploited, as is southern hake, while Argentine hake (mostly found and caught within the Argentinean EEZ) is reported to be overexploited or depleted. Southern blue whiting is fully overexploited as well, and the pink cusk-eel and the Patagonian toothfish are moderately to fully exploited (Maguire 2006).

2 METHODS

2.1 Catch-reconstruction approach

To estimate total fisheries removals, we followed the catch-reconstruction approach developed by Zeller and Pauly (2007) and previously used in various regions of the world' oceans (see www.seaaroundus.org). This approach requires occasional assumptions and interpolations, which are noted in the methods.

Despite uncertainties, this method generates results that are preferable to the alternative, where non-reported or missing data are interpreted as zero catch (Zeller and Pauly 2007). Including previously unreported catches is vital, as total fisheries removals are the most fundamental data in assessing the impact of fishing on exploited ecosystems.

The approach of Zeller *et al.* (2007) consists of six general steps:

(i) Collection of time series of available reported landings from regional or national sources, as well as international agencies, i.e., the Food and Agriculture Organization of the United Nations (FAO);
(ii) Identification of those fisheries sectors and components that currently produced or could have produced unreported removals using literature searches and secondary data sources, i.e., informal interviews with fisheries experts, newspapers, and personal observations during visits to harbours;
(iii) Searches for available alternative information regarding those sectors and components that produced unreported removals;
(iv) Collection of alternative estimates and development of anchor points in time for missing data;
(v) Interpolation between anchor points for time periods to estimate the different components of unreported removals;
(vi) Estimation of total fisheries removal time series as the sum of total reported landings and unreported removals.

For each year, we defined total fisheries removals (*TR*) as the sum of total fisheries landings (*TL*) and total discards (*TD*) for *S* caught species and *F* number of fishing fleets as follows:

$$TR = \sum_{s=1,\, f=1}^{S,N} (TL + TD) \tag{1}$$

TL for *S* caught species and *F* number of fishing fleets was composed by the following elements:

$$TL = \sum_{s=1,\, f=1}^{S,N} (OL + UL) = \sum_{s=1,\, f=1}^{S,N} (OL + BM + IC + AC + RC + SF) \tag{2}$$

where *OL* is official landings and *UL* is unreported landings. *UL* is composed of unreported catches by the domestic fleet that go to the black market (*BM*) and illegally caught species (*IC*) by foreign fleets in the relevant waters. It also includes artisanal catch (*AC*) not reported in OL, as well as recreational catch (*RC*) and subsistence fishing (*SF*), e.g., the personal consumption of seafood by fishers and their families.

TD for *S* caught species and *F* number of fishing fleets is estimated by:

$$TD = \sum_{s=1,\, f=1}^{S,N} (D + PM + GF) \tag{3}$$

where *D* is direct boat-based discards from fishing activities (Kelleher 2005), *PM* is underwater discards, of those specimens that die after escaping from fishing nets due to physical damages

(Suuronen 2005) and *GF* is ghost fishing mortality of those specimens that die due to lost or abandoned gear or the loss of fishing gear at sea (Macfadyen *et al.* 2009).

We considered all the elements of *TR* that are not included in *OL* as unreported landings. To calculate *TR*, we collected and compiled all material available, from primary literature and official sites, final projects report, grey literature, statistics from regional institutions, estimates from experts, observations in harbour areas and markets, and opinions of local fishers and fisheries experts collected through informal interviews. This study does not include catch from aquaculture activities or species of marine mammals, seabirds, marine turtles, worms, or various seaweed species.

2.2 Overview of methodology for Argentina

This study aims to reconstructs total fisheries removals for Argentina's marine fisheries catches from 1950-2010. First, reported catch data by taxa and year were obtained from Argentinean national data sources. Then, unreported landings and discards were within the commercial, subsistence, and recreational sectors of Argentina using grey literature and other sources as described in the preceding section. The summation of the reported national catch data and unreported catch resulted in total reconstructed catch for Argentina.

Thereafter, the total reconstructed catch was compared to the landings reported to the FAO by Argentina. For the eight major commercial species whose catch accounted for approximately between 80 – 90% of the total catch, i.e., Argentine anchovy, pink cusk-eel (*Genypterus blacodes*), Argentine shortfin squid, Patagonian squid (*Loligo gahi*), Patagonian grenadier, Argentine hake, southern blue whiting, and Argentine red shrimp, we compared the total reconstructed catch and FAO reported catch by species, and found in all cases that total reconstructed catch was higher than the catch reported to the FAO.

For all other species, which jointly contributed the remaining 10-20% of the catch, we noticed that there was a discrepancy in the number of species represented in each data series. Total reconstructed catch (which was based on national data sources) consisted of 53 species in addition to the eight major ones, while the catch reported to FAO had more (92). Also, the catch reported to and by the FAO (which corresponds to the commercial sector) was higher than total reconstructed catch for the commercial sector, due to a multitude of species groups not available in national data.

Hence, we assumed that for the commercial sector, FAO data for the non-major species were actually more comprehensive than reconstructed catch from the national data sources we consulted. Thus, we replaced the reconstructed reported and unreported landings for non-major species with the FAO data. Note, however, that this assumption does not apply to the subsistence sector, the recreational sector, or discards, as these are not included in the data reported by FAO, nor to the eight major commercial species.

2.3 Data sources

Although the first historical records of fishing in Argentina date back to 1898 (Sánchez *et al.* 2012), the systematization of information in its current form, disaggregated by species, dates from 1934, thus ensuring that national data from 1950 – 2010 were consistent for the entire time period. Additionally, these data were supplemented by official statistics on landings of the hake fleet, published by the Undersecretary of Fisheries and Aquaculture (www.minagri.gov.ar).

Data on the level of unreported commercial landings by species were taken from the Secretary of Agriculture, Livestock, Fisheries, and Food, *Secretaría de Agricultura, Ganadería, Pesca y Alimentos* (SAGPyA) combined with other sources, notably (Agnew *et al.* 2009), and (Villasante *et al.* 2014). A synthesis of these data sources enabled us to estimate a percentage of unreported catch by species, varying over time from 1950 – 2010. Estimates for the amount of unreported fisheries catch in the recreational and subsistence fisheries was taken from a compilation of local interviews and data sources (SAGPyA; Kelleher 2005; Agnew *et al.* 2009). Lastly, estimates for discards were taken from Bezzi *et al.* (1994); Cañete *et al.* (2000); Dato *et al.* (2003); Kelleher (2005); Dato *et al.* (2006); Villasante *et al.* (2014) and local interviews.

3 RESULTS

Total fisheries removals were estimated by summing all catch components investigated above: reported landings, unreported landings, and discards. Reconstructed catch began at 67,000 t in 1960 and increased in an exponential trend to reach over 2 million t in 1997, thereafter declining to 1.36 million t·year^{-1} in the 2000s (Figure 2a).

Total removals in the study area were mainly assigned to the industrial sector, while artisanal, recreational, subsistence fishing and discards removed smaller amounts of catch from the ecosystems (Figure 2a). By species, hake accounted for 48% of total reconstructed catch, followed by Argentine shortfin squid at 13%, Southern blue whiting at 5%, Patagonian grenadier at 4%, and the remaining 30% composed of 109 various marine fishes and invertebrates (Figure 2b). Clear declines of catch with time are observed for important commercial species such as hake, anchovy, and sardine, while the catch of other species increased in recent years (such as mackerel, blue witting, octopuses and other invertebrates).

Overall, reconstructed catch was 55% higher than FAO reported landings. Of this unreported component, unreported commercial catch accounted for 61.1%, discards accounted for 24.0%, recreational catch accounted for 14.7%, and catch in the subsistence sector was 0.2%.

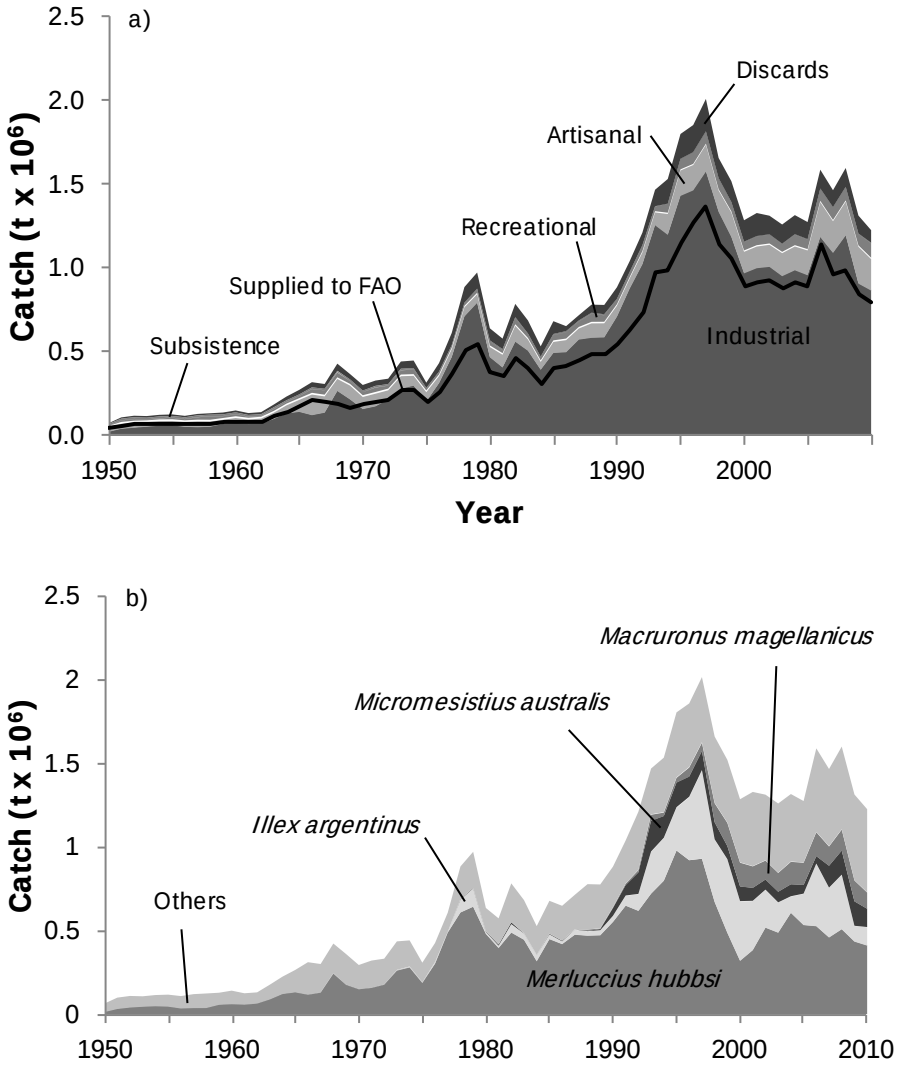

Figure 2. Total reconstructed catch within the EEZ of Argentina, 1950 – 2010, a) by sector plus discards, with data reported to FAO overlaid as line graph; and b) by species. 'Others' represents 109 additional taxonomic groups.

4 DISCUSSION

This study provides the first estimate of total fisheries removals from the EEZ of Argentina from 1950 to 2010. With total reconstructed catch 55% higher than FAO reported catch, there is a sizeable quantity of unreported landings and discards that are currently not incorporated when setting TAC. The result is over-exploitation of marine resources, as evidenced by the decline in catch the recent time period (Figure 2a) and the phenomenon of trophic cascade, or fishing down the marine food webs (Pauly *et al.* 1998). In Argentina, this is apparent in the form of a marked decline in the traditional fishery resources such as Argentine hake and whitemouth croaker, and an increase in lower trophic level taxa such as crustaceans, squids, and scallops (Jaureguizar and Milessi 2008).

The majority of unreported catch is in the form of unreported landings, followed by discards, the recreational sector, and lastly the subsistence sector. These estimates are conservative and should be treated as minima. Indeed, FAO Area 41 (South West Atlantic) has the highest level of illegal, unreported, and unregulated fishing (IUU), with annual economic losses ranging from $200-600 million USD annually (Agnew *et al.* 2009). Although there have been occasional illegal infringements by foreign fleets within the waters of Argentina (Pramod *et al.* 2008), the greater trend is foreign fleets fishing just outside the EEZ, and hence potentially over-exploiting straddling stocks. The volume of such illegal activities is not included in this report, yet should be noted.

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Appendix Table A1. FAO landings vs. reconstructed total catch (in tonnes), and catch by sector with discards shown separately, for Argentina, 1950 - 2010.

Year	FAO landings	Reconstructed total catch	Artisanal	Industrial	Recreational	Subsistence	Discards
1950	43,901	67,000	24,800	26,100	11,000	1,120	4,100
1951	62,101	102,000	30,500	44,100	19,600	562	7,170
1952	67,302	112,000	31,500	50,500	20,600	676	8,690
1953	68,001	110,000	27,500	56,700	15,800	488	9,380
1954	70,202	117,000	27,100	62,800	16,900	1,020	9,570
1955	71,002	120,000	26,100	64,600	19,400	594	9,040
1956	66,401	111,000	28,100	56,100	17,900	726	8,470
1957	71,601	123,000	34,600	53,600	25,300	975	8,230
1958	71,801	127,000	31,200	56,600	30,000	791	8,250
1959	76,801	131,000	25,100	73,000	21,700	684	10,700
1960	85,101	144,000	31,800	76,900	23,000	632	11,200
1961	77,502	128,000	27,100	72,700	16,200	928	11,000
1962	82,308	133,000	31,100	74,600	14,800	817	12,000
1963	110,372	179,000	38,000	103,000	21,400	857	16,200
1964	143,507	227,000	48,800	135,000	19,700	789	22,200
1965	172,102	267,000	71,700	145,000	22,500	678	26,800
1966	210,402	313,000	123,000	125,000	32,200	1,050	31,000
1967	194,062	302,000	97,500	140,000	35,600	478	28,300
1968	186,823	424,000	72,000	269,000	37,400	2,410	42,600
1969	169,102	361,000	83,100	219,000	26,700	715	31,900
1970	185,303	296,000	72,600	162,000	28,200	402	33,400
1971	200,710	323,000	75,900	178,000	35,900	1,370	31,500
1972	210,602	334,000	55,900	218,000	27,200	715	32,000
1973	269,691	437,000	74,600	283,000	34,500	1,300	43,000
1974	266,386	443,000	59,400	301,000	35,900	539	45,700
1975	199,068	310,000	55,900	207,000	16,100	120	30,700
1976	256,206	427,000	43,000	316,000	17,400	315	50,400
1977	369,432	607,000	47,700	471,000	15,600	300	72,500
1978	503,654	882,000	55,300	714,000	20,200	105	93,200
1979	549,276	970,000	51,600	795,000	25,900	472	96,500
1980	376,865	636,000	61,500	471,000	30,700	404	72,300
1981	351,857	574,000	76,400	410,000	24,600	515	62,700
1982	459,645	782,000	95,300	563,000	43,400	468	79,300
1983	401,771	682,000	67,500	509,000	27,300	267	78,000
1984	305,484	527,000	47,300	396,000	22,800	260	61,200
1985	396,832	678,000	66,000	496,000	38,900	332	76,400
1986	411,748	648,000	72,500	501,000	45,400	310	29,600
1987	450,797	714,000	66,600	576,000	39,400	421	31,400
1988	482,681	777,000	86,300	587,000	55,400	368	48,300
1989	481,383	775,000	84,600	589,000	45,900	505	55,500
1990	548,035	881,000	66,400	712,000	33,400	265	68,900
1991	629,906	1,040,000	61,000	879,000	32,900	359	63,800
1992	732,589	1,210,000	71,800	1,020,000	36,500	801	74,900
1993	970,326	1,470,000	76,900	1,260,000	31,300	757	98,600
1994	983,762	1,530,000	125,000	1,200,000	56,600	272	147,000
1995	1,155,001	1,800,000	152,000	1,430,000	65,800	404	148,000
1996	1,268,268	1,850,000	152,000	1,470,000	73,000	381	162,000
1997	1,365,915	2,010,000	161,000	1,580,000	76,800	388	194,000
1998	1,141,292	1,660,000	129,000	1,340,000	69,000	73	120,000
1999	1,051,944	1,520,000	146,000	1,190,000	57,600	443	125,000
2000	891,380	1,280,000	129,000	971,000	54,200	368	128,000
2001	915,545	1,330,000	129,000	1,000,000	56,700	182	138,000
2002	927,711	1,310,000	132,000	1,010,000	56,800	188	111,000
2003	883,604	1,260,000	137,000	954,000	50,200	279	115,000
2004	910,691	1,310,000	142,000	989,000	67,400	292	114,000
2005	895,651	1,270,000	148,000	960,000	61,400	258	102,000
2006	1,138,101	1,590,000	209,000	1,190,000	76,200	351	112,000
2007	965,455	1,460,000	190,000	1,090,000	78,600	323	101,000
2008	983,838	1,600,000	202,000	1,200,000	83,200	369	113,000
2009	845,716	1,310,000	221,000	910,000	72,300	466	107,000
2010	796,264	1,220,000	188,000	869,000	90,800	645	75,300

Appendix Table A2. Reconstructed total catch (in tonnes) by major taxa for Argentina, 1950 - 2010. 'Others' contain 109 additional taxonomic categories.

Year	*Merluccius hubbsi*	*Illex argentinus*	*Micromesistius australis*	*Macruronus magellanicus*	Others
1950	16,000	0	0	0	51,000
1951	34,300	0	0	0	68,000
1952	42,800	0	0	0	69,000
1953	47,500	0	0	0	62,000
1954	50,500	0	0	0	67,000
1955	48,100	0	0	0	71,000
1956	37,300	0	0	0	74,000
1957	39,700	0	0	0	83,000
1958	40,000	1,000	0	0	86,000
1959	59,000	0	0	0	72,000
1960	62,800	1,000	0	0	80,000
1961	59,900	1,000	0	0	67,000
1962	66,400	1,000	0	0	66,000
1963	91,000	1,000	0	0	88,000
1964	123,400	1,000	0	0	103,000
1965	133,300	1,000	0	0	133,000
1966	119,200	1,000	0	0	193,000
1967	131,800	2,000	0	0	168,000
1968	245,400	3,000	0	0	175,000
1969	178,000	1,000	0	0	182,000
1970	152,100	2,000	0	0	142,000
1971	160,100	2,000	0	0	161,000
1972	178,900	2,000	0	0	153,000
1973	263,400	4,000	0	0	169,000
1974	282,100	5,000	0	0	155,000
1975	189,600	4,000	0	0	116,000
1976	304,400	10,000	0	0	113,000
1977	490,500	3,000	0	0	114,000
1978	610,700	75,000	2,800	1,200	192,000
1979	645,300	107,000	3,000	295	214,000
1980	482,600	12,000	3,400	100	138,000
1981	397,990	14,000	6,480	1,300	154,000
1982	490,440	50,000	10,030	1,000	231,000
1983	447,400	36,600	1,010	800	197,000
1984	318,800	37,000	500	600	170,000
1985	451,240	27,500	3,300	1,200	195,000
1986	421,400	15,900	3,400	1,700	206,000
1987	477,710	29,600	300	900	205,000
1988	471,770	26,500	1,900	8,000	269,000
1989	474,230	29,500	7,145	3,500	261,000
1990	554,200	35,200	46,923	4,400	241,000
1991	651,490	59,000	63,080	8,600	255,000
1992	620,500	99,500	128,700	13,900	345,000
1993	723,500	249,300	183,700	36,500	272,000
1994	800,800	253,500	130,100	21,400	324,000
1995	982,000	254,700	147,500	28,800	386,000
1996	923,800	375,200	120,900	54,900	378,000
1997	932,810	524,900	114,200	49,800	387,000
1998	673,770	371,300	102,400	114,100	394,000
1999	489,000	437,900	78,700	138,700	373,000
2000	321,400	355,800	87,600	142,100	376,000
2001	385,200	293,600	77,600	128,500	441,000
2002	519,860	225,700	60,600	113,300	390,000
2003	489,900	179,700	63,700	112,300	411,000
2004	608,570	97,500	71,800	134,400	401,100
2005	535,436	186,300	52,400	132,400	365,000
2006	528,706	372,200	44,700	143,140	496,000
2007	461,173	296,100	130,900	115,260	459,000
2008	510,429	324,300	144,100	125,280	492,000
2009	436,797	93,300	146,000	124,800	510,000
2010	412,910	109,800	109,200	97,000	494,000