Biological and ecological traits of non-targeted species caught by the tuna purse seine fishery in the western Indian Ocean

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Abstract

The tuna purse seine fishery of the western Indian Ocean is estimated to have relatively low bycatch rates, i.e. about 3.4 % of the total catch in recent years. Yet, with the implementation of the yellowfin tuna quota (IOTC Res. 17/01) in January 2017 and discard ban policy (IOTC Res. 17/04) since January 2018, removal of non-targeted species is expected to increase due to the change in strategy now mostly oriented to fishing on Fish Aggregating Devices and potential increased mortality of bycatch. Purse seine observer programs provide information for monitoring the magnitude and composition of incidental catches. Nevertheless, little quantitative information exists on the biology and ecology of non-targeted species, particularly in the western Indian Ocean. Thus it is difficult to assess their removal effect on the role and function of the pelagic ecosystem. Within this context, three objectives have been defined for this paper. First the main biological and ecological traits for purse seine bycatch species were reviewed from the literature. Secondly, a new biological sampling launched in Seychelles in 2017 was presented. Finally, length-weight relationships for 15 non-target species were updated for the western Indian Ocean using morphometric data collected on board and at port.

Keywords

Epipelagic species, Tropical, Fish aggregative devices, Length-weight relationships

1. Introduction

Although purse seine has been shown to be selective, resulting in lower levels of bycatch than most fishing gears (Kelleher 2005), more than 70 species can be incidentally caught in tropical tuna purse seine fisheries (Amandè et al. 2010, 2008; Lezama-Ochoa et al. 2015). These include vulnerable and sensitive species that display low fecundity and slow growth rate, including charismatic species such as sharks and turtles (Torres-Irineo et al. 2014). In the western Indian Ocean between 2003 and 2007, the annual average bycatch of the European purse seine tuna fishery was estimated at about 9,600 t, corresponding to a mean annual value of 35.5 t per 1000 t of tuna landed and 3.4 % of the total catch (Amandè et al. 2008).

The term bycatch is commonly used to describe all the non-targeted species plus small or damaged target tuna species that are not marketed through canneries. Diversity and catch estimation of these non-targeted communities from the pelagic ecosystem in the western Indian Ocean have been estimated in the last decades (Taquet et al. 2007; Romanov 2002; Santana 1998). For the EU tuna purse seine fishery, Amandè et al (2008) found that tuna represented 54 % of the total discard, followed by bony fishes (33.7 %), sharks (10.1 %), billfishes (1.5 %) and rays (0.7 %). Differences of bycatch diversity between fishing modes, i.e. drifting fish aggregating devices (FADs) and free school sets, have also been studied, showing that fishing on FADs is the main source of bycatch (Fonteneau et al. 2000; Torres-Irineo et al. 2014; Amandè et al. 2008). In particular in the western Indian Ocean, Lezama et al. (2015) have recently shown that FAD communities were more diverse with higher number of species (74 species) than free school communities (56 species).

Until now, most of the non-targeted species were discarded at sea, dead or alive. Only a small amount was kept, either because they had been put in wells accidentally during the fishing operation, or for consumption on board. Wahoo (*Acanthocybium solandri*), dolphinfish (*Coryphaena hippurus*), barracuda (*Sphyraena barracuda*) and carangids were the most valorised categories generally for cooking on board (Amandè et al. 2008). Since January 2018, a discard ban has been adopted by the Indian Ocean Tuna Commission (IOTC) requiring all purse seine vessels to retain on board and then land, to the extent practicable, the non-targeted species, except fish considered unfit for human consumption (Resolution 17/04).

Compared to targeted species catch, incidental bycatch is difficult to estimate on the basis of logbook information as it is poorly reported by fishing master. Thus, since 2001 within the EU mandatory sampling programme for the collection of data in the fisheries sector, a common framework has been developed to better estimate fisheries bycatch. In that sense, observer programs were implemented to collect, monitor and analyze bycatch onboard the EU tuna purse seine fishery (EC Res. 199/2008). Among the data collected by onboard observers, length measurements and fish enumeration are key to estimate catch of discarded tuna and non-targeted species. Fish number estimates are indeed converted to weight of the catch with species-specific length-weight relationships. Most relationships come from the literature and are considered to be stable in time and space. Nevertheless, data and methods used to estimate the parameters are often missing, resulting in obsolete and/or unsuitable relationships.

Finally, because observer programs do not cover 100 % of the fishing effort, the weight estimates are extrapolated to the total catch following the method of Amandè et al. (2010).

Although bycatch monitoring in terms of biomass and composition estimates is relatively well supported by observer programs in the western Indian Ocean, there is a dearth of information concerning the basic biology of those species and their role within the ecosystem. Yet, it is known that the degree to which fisheries affect the structure and function of ecosystems relies on the biomass and the species composition but also on life history and ecological role of the different species captured. Indeed, the capture of non targeted species could negatively impact biodiversity either by removing key species or species in unsustainable quantities or by affecting the balance of the species composition in the community of the ecosystem (Hall 1996). While some management practices have been developed for free-swimming school fishing by IOTC, there is still no FAD management plan and no strategy in place to address the impact of this fishery on the bycatch communities. Among the 74 non-targeted species associated to FAD (Lezama-Ochoa et al. 2015), only two (*Euthynnus affinis* and *Auxis thazard*) are covered by the management mandate of IOTC. Recently, an increasing use of FADs has been recorded for the EU tuna purse seine fishery. For the French fleet for example, sets on FADs represented 66% of the total number of sets in 2016 when it was about 50% ten years ago (Floch et al. 2017). In particular, with the implementation of a quota on yellowfin tuna (*Thunnus albacares*) by IOTC in 2017 (IOTC Res. 17/01), fishing effort of the purse seine fleet has shifted significantly to a quasi exclusive use of FADs, with 75% of the total sets made on FADs for the French purse seiners in 2017 (Floch et al., pers. comm.). As FADs are associated with a higher number and weight of bycatch (Lezama-Ochoa et al. 2015; Fonteneau et al. 2000), removal of non-targeted species and its potential impacts on the structure and function of the ecosystem are expected to be much more important in the forthcoming years. In this context, some certifications like the Marine Stewardship Council (MSC) are currently in progress for tuna purse seine with the main objective of better characterize non-targeted species and better estimate and address the impacts of this fishery on the bycatch communities.

Some recent studies have tried to describe and measure the effects of tropical tuna fisheries on the ecosystem (Gerrodette et al. 2012) and to rank the species most at risk among the ones being caught incidentally (Murua et al. 2009; Arrizabalaga et al. 2011; Cortés et al. 2010; Frédou et al. 2016). In the Indian Ocean, an Ecological Risk Assessment (ERA) for tropical tuna purse seiner and longliner revealed two main risk groups. The first one consists of pelagic and coastal sharks and is characterized by relatively low productivities while the second group includes teleosts characterized by higher productivities but high susceptibility to purse seine gear (Murua et al. 2009). Those studies are particularly useful to identify the most sensitive species but can be limited when assessment at a species level is required. Indeed for some bycatch species, especially bony fishes that do not belong to the Scombridae or billfish families, the lack of reported life history information available at species level imposes to work at a species group level. Besides, a recent study (Hordyk and Carruthers 2018) showed that such qualitative risk-based approaches are often subjective and not reproducible as their assumptions can be inappropriate and their expected performance poor for a wide range of conditions.

With the overall goal of better characterizing the biology and ecology of the bycatch species of the tuna purse seine fishery in the western Indian Ocean, the paper aims to (i) compile and review the biology and ecology available for those species, (ii) present the biological sampling launched in 2017 in Seychelles on these non-targeted species and (iii) update the length-weight relationships for some pelagic bycatch species combining morphometric data in the western Indian Ocean collected on board and at landing.

2. Data collection

Since July 2017, 18 different bycatch species have been collected on board for biological sampling, all coming from FAD fishing sets (Table 1). Lezama et al. (2015) listed a total of 74 species associated to FAD sets and revealed that only ten of them represented more than 93% of the species composition in terms of abundance. The most abundant ones were rough triggerfish (*Canthidermis maculata*), rainbow runner (*Elagatis bipinnulata*) and mackerel scad (*Decapterus macarellus*).

The review tried to focus on the Indian Ocean; yet due to the dearth of data available, information from the Atlantic and the Pacific oceans were also recorded. Besides, when information was not available in published documents, web based library FishBase (Froese and Pauly, 2003, http://www.fishbase.org) was used. Finally, as estimates of von Bertalanffy growth parameters, L_{inf} (asymptotic length), K (growth rate parameter) and t_o (initial condition parameter) can vary substantially among studies, those obtained with the largest size range of fish sampled were selected.

For biological data collection, fish were routinely collected on purse seiners during the landing in Seychelles or directly during the fishing operation by observers. Some lengths and weights of dolphinfish and wahoo were also collected during sport fishing tournaments of trolling lines in Seychelles. Thanks to the collaboration of fishermen and the access to logbooks and well plans, information on fishing date and fishing location was recorded. Because sets are often mixed in purse seiner brine-freezing wells, it was impossible in some cases to know the exact date and position of the fishing operation; mean date and mean coordinates were then calculated. The biological sampling protocol developed for commercial tuna species by Bodin et al. (2018) has been adapted to bycatch species. For every fish, morphometric data were first collected: the reference length (i.e. total length or fork length) and the first thorax girth were measured to the nearest cm; the total weight and the gutted weight were recorded to the nearest 0.01 kg. Sex and macro-maturity stage were also retrieved by visual exam. Because of the large diversity of species sampled, only three maturity stages were used for this study: immature, developing and spawning. Gonads, liver, stomach and the rest of viscera were weighted to the nearest 0.01 g. Finally, information on the stomach content was recorded using five main prey groups: fish (F), crustaceans (CR), cephalopods (CE), algae (A) and other (O).

Finally, length and weight data collected on board by observers or at landing were combined. When the sample size per species was sufficient ($n > 50$), the allometric length-weight relationship ($W = a * L^b$) was estimated with linear models fitted to log-transformed data (Hayes et al. 1995). The function lm was used in R and the estimator a was corrected following the method of Neyman and Scott (1960).

3. Review of the biology and ecology of the main bycatch species

3.1. Habitat, vertical distribution and aggregative behavior

Most of the studied bycatch species are offshore pelagic ones. Yet some of them can also been found near the coast, or even in the demersal zone or associated to reef (Table 1). This diversity of "natural habitats" among the species associated to floating objects is often used to support the assumption that FADs might act like an "ecological trap" (Marsac, Fonteneau, and Ménard 2000). The ecological trap concept assumes that the attraction and association of tuna and bycatch species with FADs may alter some of their biological characteristics (e.g. growth) and could affect their movements and migrations (Wang et al. 2014), potentially moving them away from coastal areas. Among the 18 species, 14 are recognized to be extranatant, i.e. they remain within 0.5-2 m of the floating object (Fréon and Dagorn 2000). Rough triggerfish is particularly known to be associated to drifting objects, forming massive schools of thousands of individuals (Matsuura 2013; Taquet et al. 2007).

Table 1: *Ecological classification of the studied bycatch species.*

Scientific name	Common name	ASFIS code	Family	Ecological classification	References
Aluterus monoceros	Unicorn leatherjacket filefish	ALM	*Monacanthidae*	Demersal & coastal & offshore pelagic	Taquet et al. 2007
Ablennes hians	Flat needlefish	BAF	*Belonidae*	Offshore pelagic	Nations 2016
Platax teira	Longfin batfish	BAO	*Ephippidae*	Reef	Taquet et al. 2007
Canthidermis maculata	Rough triggerfish	CNT	*Balistidae*	Offshore pelagic	Taquet et al. 2007
Caranx sexfasciatus	Bigeye trevally	CXS	*Carangidae*	Coastal & offshore pelagic	Taquet et al. 2007
Coryphaen hippurus	Common dolphinfish	DOL	*Coryphaenidae*	Offshore pelagic	Taquet et al. 2007
Carcharhinus falciformis	Silky shark	FAL	*Carcharhinidae*	Offshore pelagic	Taquet et al. 2007
Auxis thazard	Frigate tuna	FRI	*Scombridae*	Coastal & offshore pelagic	Nations 2016
Sphyraena barracuda	Great barracuda	GBA	*Sphyraenidae*	Coastal and offshore pelagic	Taquet et al. 2007
Euthynnus affinis	Kawakawa	KAW	*Scombridae*	Coastal pelagic	Taquet et al. 2007
Kyphosus cinerascens	Blue sea chub	KYC	*Kyphosidae*	Reef	Choat 2002
Kyphosus vaigiensis	Brassy chub	KYV	*Kyphosidae*	Reef & demersal & coastal & offshore pelagic	Taquet et al. 2007; Choat 2002
Lobotes surinamensis	Tripletail	LOB	*Lobotidae*	Offshore pelagic	Taquet et al. 2007
Decapterus macarellus	Mackerel scad	MSD	*Carangidae*	Coastal & offshore pelagic	Taquet et al. 2007
Elagatis bipinnulata	Rainbow runner	RRU	*Carangidae*	Coastal & offshore pelagic	Taquet et al. 2007

Urapsis secunda	Cottonmouth jack	USE	*Carangidae*	Demersal & offshore pelagic	Fishbase
Acanthocybium solandri	Wahoo	WAH	*Scombridae*	Coastal & offshore pelagic	Taquet et al. 2007
Seriola rivoliana	Longfin yellowtail	YTL	*Carangidae*	Coastal & offshore pelagic	Taquet et al. 2007

3.2. Age and growth

Different methods such as analyses of length frequencies or use of hard structures like sagittal otoliths, vertebrae and dorsal spines are usually used to estimate age and growth (Panfili et al. 2002). Table 2 shows the maximum length, weight and age available in the literature as well as the estimated von Bertalanffy growth parameters. Some species are known to be fast growing, like dolphinfish or wahoo while others are characterized by slow growth rates, e.g. flat needlefish (*Ablennes hians*). More generally, caution must be used when considering estimates of growth as they can vary substantially due to sampling design, size selectivity of fishing gear, and (Pauly and Morgan 1987).

Table 2: *Age and growth parameters available for the studied bycatch species. TL = total length; FL = fork length; SL = standard length; n/a = not available*

Species ASFIS code	**Max. length (cm)**	**Max. weight (kg)**	**Longevity (year)**	**Von Bertalanffy growth parameters** Fork length range (cm)	L_{inf} (cm)	K ($year^{-1}$)	t_0	**References**
ALM	76.2 TL[3]	2.7[3]	n/a	n/a	63.5[3]	0.220[3]	n/a	Fishbase
BAF	114 FL	4.8[3]	n/a	42 - 114 FL	123.3	0.6052	0.1178	Mohamad Kasim 1996; NATIONS 2016
BAO	70 TL[3]	n/a	n/a	n/a	n/a	n/a	n/a	Fishbase
CNT	50 TL[3]	n/a	n/a	n/a	n/a	n/a	n/a	Fishbase
CXS	120 TL[3]	18[3]	n/a	n/a	n/a	n/a	n/a	Fishbase
DOL	200 FL[3]	39[3]	4[3]	29 – 197 FL	194	0.91	n/a	Cole 2010; Chang and Maunder 2012
FAL	316 TL[1]	45.5	20	55 - 262 TL	299.4	0.066	n/a	Hoyos-Padilla et al. 2012; N. G. Hall et al. 2012
FRI	62 FL	2.1[2]	4[3]	? – 55 FL	63.5	0.72	n/a	Cole 2010; Juan-Jorda et al. 2016
GBA	200 FL	45	18	18 – 135 FL[2]	123.6[2]	0.26[2]	-0.71[2]	De Sylva et al. 1963; Kadison et al. 2010
KAW	100 FL	13.1	n/a	? – 74 FL	76.8	0.52	n/a	Juan-Jorda et al. 2016
KYC	34 SL	1.7	n/a	n/a	n/a	n/a	n/a	Choat 2002
KYV	36 SL	1.9	n/a	n/a	n/a	n/a	n/a	Choat 2002
LOB		8.4	4[2]	n/a	n/a	n/a	n/a	Strelcheck et al. 2004
MSD	~ 37 FL[1]	n/a	8[1]	~ 19 - 37 FL[1]	42.8[1]	0.310[1]	-0.821[1]	Shiraishi 2010
RRU	98 FL	n/a	6[3]	n/a	n/a	n/a	n/a	Fishbase
USE	50 TL[3]	2[3]	n/a	n/a	n/a	n/a	n/a	Fishbase
WAH	239 FL	83.5[1]	9	? – 165 FL[2]	155[2]	0.32[2]	-1.172[2]	Juan-Jorda et al. 2016
YTL	160 SL[3]	59[3]	n/a	n/a	n/a	n/a	n/a	IGFA 2014

[1] Data from the Pacific Ocean
[2] Data from the Atlantic Ocean
[3] Data with no particular location

3.3. Reproductive biology

Among the studied species, only two show an external sexual dimorphism: mature males dolphinfish display a prominent bony crest in front of the head; males of silky shark (*Carcharhinus falciformis*), like all male elasmobranchs, have claspers which are elongated pelvin fin edges. For the rest of the bycatch species, sex determination has to be done by visual examination of the gonads. The main reproductive traits are only available for ten of the 18 studied bycatch species (Table 3). For several species, and especially for dolphinfish, sea temperature seems to be one of the most important factors for reproduction as spawning season can be extended year round in tropical areas or limited to summer in sub-tropical or more temperate latitudes.

Table 3: *Reproductive traits available for the studied bycatch species. L_{50} = length at which 50% of individuals are sexually mature; L_{95} = length at which 95% of individuals are sexually mature; TL = total length; FL = fork length; SL = standard length; n/a = not available*

Species ASFIS code	L_{50} (cm)	L_{95} (cm)	Reproductive season	References
ALM	n/a	n/a	n/a	-
BAF	n/a	n/a	n/a	-
BAO	n/a	n/a	n/a	-
CNT	n/a	n/a	n/a	-
CXS	n/a	n/a	n/a	-
DOL	45 FL[3]	64 FL[3]	all year in tropical regions – April to July in temperate areas[3]	Cole 2010
FAL	180 TL[1]	223 TL	n/a	Hoyos-Padilla et al. 2012; N. G. Hall et al. 2012
FRI	30 FL[3]	n/a	all year[3]	Cole 2010
GBA	n/a	n/a	May - September	De Sylva 1963
KAW	37	n/a	all year	Juan-Jorda et al. 2016
KYC	n/a	n/a	n/a	-
KYV	n/a	n/a	n/a	-
LOB	48 TL[2]	n/a	June – August[2]	Brown-Peterson and Franks 2001
MSD	28.5 FL[2]	33 FL[2]	April – July[2]	Shiraishi 2010
RRU	60.6 FL[2]	n/a	January – June[2]	Pinheiro 2011; Assan et al. 2017
USE	n/a	n/a	n/a	-
WAH	90 FL[2]	n/a	May – October[3]	Juan-Jorda et al. 2016; Cole 2010
YTL	n/a	67 SL[2]	n/a	Roo et al. 2015

[1] Data from the Pacific Ocean
[2] Data from the Atlantic Ocean
[3] Data with no particular location

3.4. Feeding ecology

Feeding habits of bycatch species have been studied quite well compared to other traits, with studies relying mainly on stomach content analysis. Overall, most of the species feed on a large variety of prey and are thus considered to be opportunistic feeders. Some species are known to be more specialist, like bigeye trevally (*Caranx sexfasciatus*), silky shark or kawakawa (*Euthynnus affinis*) with a limited amount of prey dominating their diet. With the exception of the two *Kyphosidae*, unicorn leatherjacket filefish (*Aluterus monoceros*) and rough triggerfish, all the studied species display close trophic levels between 4.0 and 5.0, suggesting that the studied bycatch species would feed on similar trophic levels. Some species like flying fish, but also juveniles of epipelagic species (mackerel scad, dolphinfish and tuna species) are indeed found in stomachs of several non-targeted species. Yet, the study of the trophic function of FADs for tunas revealed that drifting objects are rather a refuge for pelagic communities (Ménard et al. 2000). More investigation on trophic niches and potential overlap (i.e. competition) between fish communities is thus needed to better characterize the FAD ecosystem within a trophic point of view.

Table 4: *Trophic ecology available of the studied bycatch species. n/a = not available*

Species ASFIS code	Main prey groups	Trophic level	References
ALM	benthic organisms[3]	3.8[3]	Fishbase
BAF	mainly on fishes[3]	4.5[3]	NATIONS 2016; Fishbase
BAO	algae, crustaceans, molluscs and other vertebrates	4.0[3]	Marimuthu et al. 2005; Fishbase
CNT	zooplankton[3]	3.5[3]	Fishbase
CXS	fish and cephalopods	4.5[3]	Bachok et al. 2004; Fishbase
DOL	wide variety of fishes and invertebrates	4.4[3]	Oxenford 1999; Fishbase
FAL	fish, elasmobranchs, molluscs, crustaceans and turtles[1]	4.5[1]	Estupiñán-Montaño et al. 2018
FRI	fish and cephalopods	4.4[3]	Bachok et al. 2004; Fishbase
GBA	fish and invertebrates	4.5[3]	Fishbase
KAW	fish	4.5[3]	Bachok et al. 2004; Fishbase
KYC	algae	2.9[3]	Choat 2002; Fishbase
KYV	algae	2.0[3]	Choat 2002; Fishbase
LOB	fish and crustaceans	4.0[3]	Strelcheck et al. 2004; Fishbase
MSD	plankton	4.0[3]	Taquet et al. 2007; Fishbase
RRU	small fish (juv. of tuna, *D. macarellus* etc), small cephalopods, crustaceans[2]	4.3[3]	Xuefang et al. 2013; Fishbase
USE	n/a	4.0[3]	Fishbase
WAH	fish, cephalopods and rarely crustacean	4.3[3]	Baque-Menoscal et al. 2012; Fishbase
YTL	fish, cephalopods and crustaceans[2]	4.5[3]	Manooch III and Haimovici 1983; Fishbase

[1] Data from the Pacific Ocean
[2] Data from the Atlantic Ocean
[3] Data with no particular location

3.5. Food security

Although it has become evident that instead of being discarded, non-targeted species could constitute an additional and valuable food resource for populations, little is known about their nutritional value and their exposure to contaminants. Within a preliminary study of trace elements in oceanic pelagic communities in the western-central Indian Ocean, five of our studied bycatch species (rough triggerfish, dolphinfish, silky shark, rainbow runner and wahoo) have been investigated in terms of mineral composition (Bodin et al. 2016). The study revealed that those five species had levels of lead and cadmium, two toxic elements, below the maximum legal sanitary limits. Concerning mercury, only wahoo showed some concerns with 60% of the individuals above the maximum sanitary limit of 1 ppm. Relatively high concentrations of mercury in this large and highly mobile pelagic species were also found in the central Atlantic Ocean (Ahrens and Ebinghaus 2010), showing the need to better assess the potential sanitary risk of this species for human consumption. Overall, more investigation on the relationships between levels of essential and toxic elements and size, trophic position and diet sources of tuna purse seiners bycatch would be needed for these incidentally catches.

Ciguatera toxicity has also been retrieved in some of the studied bycatch species. Ciguatera fish poisoning (CFP) is a seafood-borne illness endemic to tropical and subtropical coral reef regions of the world and is caused by consumption of fishes that have accumulated lipid-soluble, polyether toxins known as ciguatoxins (CTXs) (Stewart et al. 2010). In particular, recent cases of ciguatera food poisoning associated to consumption of longfin yellowtail (*Seriola rivoliana*) have been registered in the Canarian islands (Boada et al. 2010; Nunez et al. 2012). In the Caribbean area, it has been found in liver of great barracuda (Matta 1999). Even if only rare cases of ciguatera fish poisoning has been registered in the vicinity the EEZ of Seychelles (Lavenu et al. 2018), it is essential to investigate the potential exposure of all bycatch species to these ciguatoxins before developing products for human or animal consumption.

3.6. Level of vulnerability

Almost all the bycatch species reviewed here are listed as “least concern” in the IUCN red list. Among them, the population status of bigeye trevally is considered to be decreasing while it is estimated stable for eight other species: rough triggerfish, dolphinfish, frigate tuna (*Auxis tazard*), tripletail (*Lobotes surinamensis*), rainbow runner, cottonmouth jack (*Urapsis secunda*), wahoo and longfin yellowtail. Only the silky shark is listed “vulnerable”, with a population trend considered to be decreasing.

Intrinsic vulnerability of the studied species has also been reviewed (Fig. 1). The idea behind this feature is that life history of a fish species affects its vulnerability to fishing (Cheung et al. 2005; Cheung et al. 2007); for example, species with larger body size, higher longevity, higher age at maturity and lower growth rate are expected to have higher vulnerability to fishing (Jennings et al. 1999). This inherent capacity to respond to fishing is calculated combining maximum length, age at first maturity, longevity, von Bertalanffy growth parameter K, natural mortality rate, fecundity, strength of spatial behavior and geographical range. It varies between 1 to 100, with 100 being the most vulnerable. Among the reviewed species, four are associated to a low intrinsic vulnerability (frigate tuna, tripletail, mackerel scad and cottonmouth jack), 11 to a relatively moderate one (unicorn leatherjacket filefish*,* flat needlefish, longfin batfish (*Platax teira*), rough triggerfish, dolphinfish, kawakawa, the two *Kyhosidae*, rainbow runner and wahoo) and three to a high one (silky shark, great barracuda and longfin yellowtail). This index is recognized to be a useful tool for management as it allows rapidly identifying potentially vulnerable species groups (Dulvy et al. 2004). Yet considering that some biological and ecological traits are poorly known for some of our studied species, caution should be taken to assess a comparison at a species level.

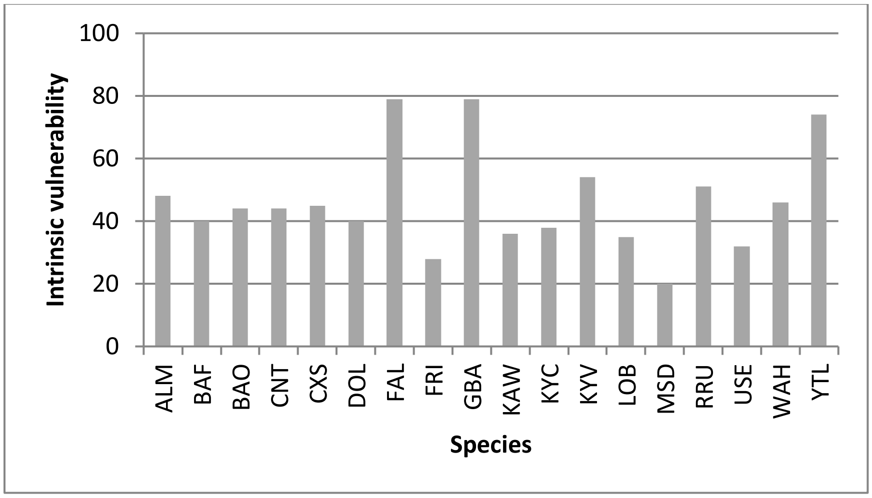


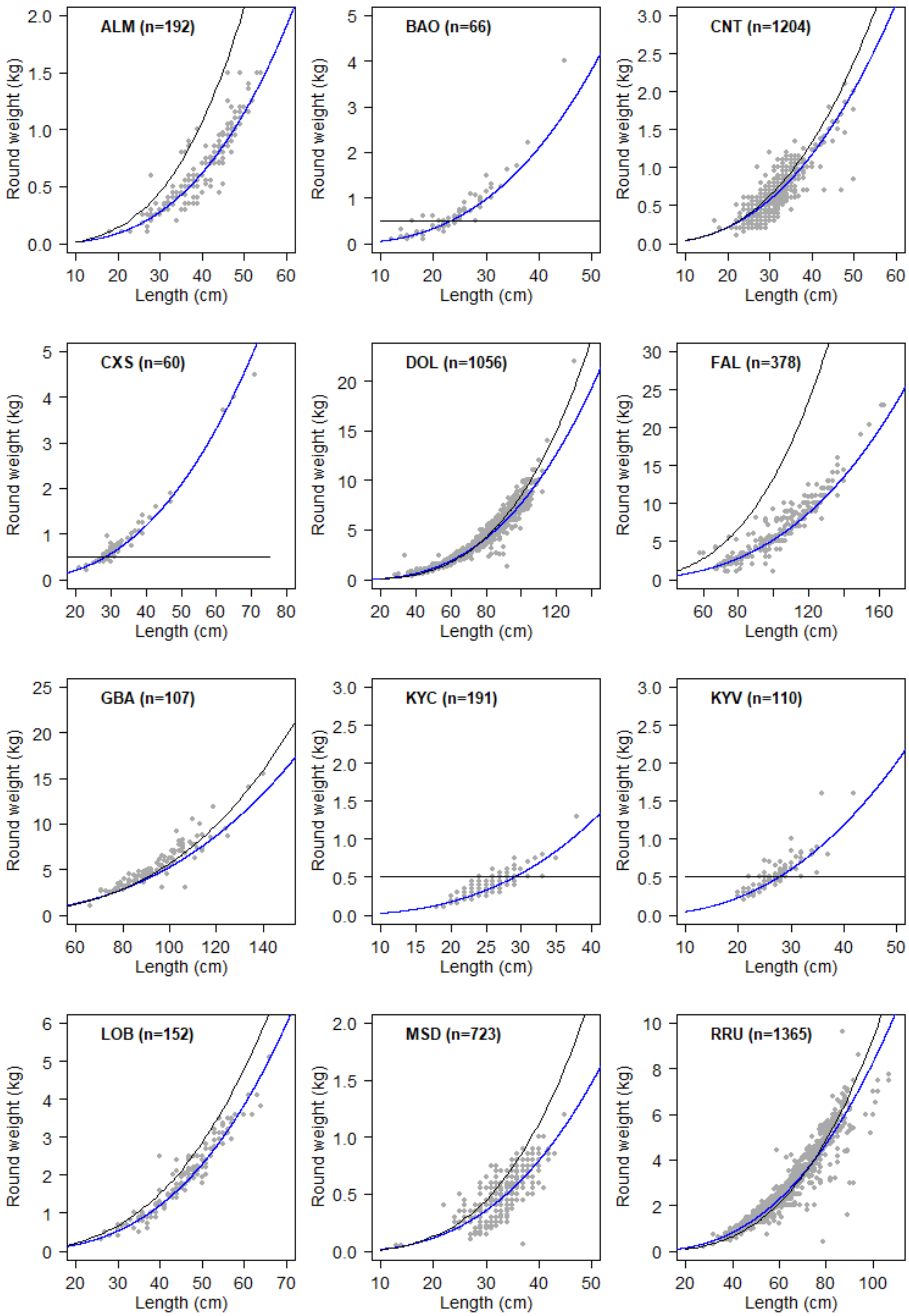
Figure 1: *Intrinsic vulnerabilty by species (Cheung et al. 2005; Cheung et al. 2007). Species acronyms given in Table 1*

4. Length-weight relationships

We collected a total of >6000 length-weight data and fitted models to 15 of the 18 studied species. Our size sample covers well the size range observed in the purse seine (Table 5, Fig. 2).

Table 5: *Length-weight relationships for some bycatch species of purse seine in the western Indian Ocean (both sex). TL = total length; FL = fork length*

Species ASFIS code	Number of observations		a	b	R^2	Length range (cm)	Size type	Weight range (kg)
	Observer	Port sampling						
ALM	173	19	2.228e-05	2.775	0.8469	18 - 54	TL	0.1– 1.5
BAO	49	17	1.135e-04	2.664	0.8499	12 – 45	TL	0.1 – 4.0
CNT	1166	66	1.415e-04	2.447	0.5869	17 – 50	TL	0.1 – 2.1
CXS	59	1	1.033e-04	2.534	0.9321	21 – 71	FL	0.2 – 4.5
DOL	995	61	2.669e-05	2.730	0.9608	28 – 130	FL	0.3 – 22.0
FAL	362	16	1.271e-05	2.808	0.8244	58 – 163	TL	1.0 – 23.0
GBA	104	3	1.516e-05	2.770	0.8427	66 – 140	FL	1.0 – 15.5
KYC	188	4	3.898e-05	2.809	0.7336	18 – 38	FL	0.1 – 1.3
KYV	77	33	2.029e-04	2.352	0.7835	20 – 42	FL	0.2 – 1.6
LOB	144	10	3.233e-05	2.855	0.9261	26 – 66	TL	0.3 – 5.1
MSD	696	27	2.862e-05	2.773	0.5812	13 – 45	FL	0.05 – 1.20
RRU	1289	76	7.438e-05	2.523	0.9275	28 – 107	FL	0.2 – 9.6
USE	219	39	1.459e-05	3.128	0.7256	21 – 37	FL	0.07 – 1.25
WAH	272	42	4.173e-06	3.062	0.9043	57 – 148	FL	1.1 – 21.0
YTL	57	4	1.391e-04	2.396	0.7954	20 – 44	FL	0.2 – 1.5


ALM (n=192)
BAO (n=66)
CNT (n=1204)
CXS (n=60)
DOL (n=1056)
FAL (n=378)
GBA (n=107)
KYC (n=191)
KYV (n=110)
LOB (n=152)
MSD (n=723)
RRU (n=1365)
Round weight (kg)
Length (cm)

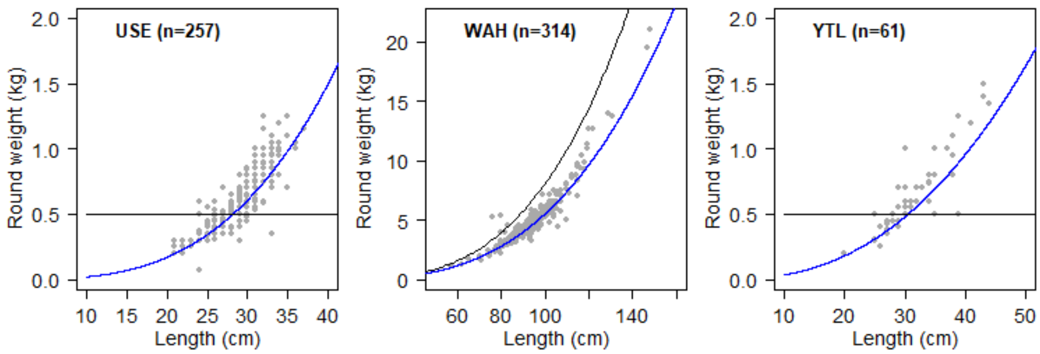


Figure 2: *Relationship between length and total weight of some non-targeted species caught with purse seine in the western Indian Ocean. The grey dots represent the observations, the blue line the fitted length-weight relationship and the black line the length-weight relationship used in Observe*

As it is shown in figure 2, some new fitted length-weight relationships, like the one for dolphinfish or rainbow runner, give similar results to the ones currently used in Observe. On the opposite, our new results highlight the fact that some relationships used in Observe, especially the one for silky shark, may be unsuitable as they overestimate the weight. Finally, for 6 of the 15 studied species (longfin batfish, bigeye trevally, the two *Kyphosidae*, cottonmouth jack and longfin yellowtail), fitting new length-weight relationships appears to be particularly useful as the ones currently used in Observe are considered to be constant. In general, it is important to update length-weight relationships as it allows to better estimate the bycatch rates, which is required in the context of certification such as the MSC, but also for comparison purpose between fishing gears and oceans. Thus a continuous process of data acquisition is needed to complement size range, estimate relationships for species with currently limited data sets but also to get best estimates for tuna RFMOs.

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