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Estimation of catches and condition of edible bycatch species taken in the equatorial purse seine fishery

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Abstract

This Information Paper presents further analyses of 'edible bycatch' within the equatorial purse seine fishery, following the presentation of preliminary estimates of catch levels and analysis of species fates described in EB-WP-18 at Scientific Committee 8 (2012). The work responds to the request made at SC7 in the Ecosystem and Bycatch Theme:

> "SC7 noted the importance of food security issues and that these be considered in the strategic research plan of the SC. It was suggested that the starting points be:
> a) A preliminary assessment of the volumes of food fish discarded in regional tuna fisheries, especially in tropical fisheries near developing states (conducted by an agency such as SPC), and;
> b) A proposal for the WCPFC to look further at the impact of tuna fishing on key food stocks, noting that Resolution 2005-03 identified mahi mahi, rainbow runner and wahoo as important for sustainable livelihoods."

The report of SC8 recommended: "SC8 requested that the Commission Scientific Services Provider continue to produce and update the type of analysis presented in Estimation of catches and fate of edible bycatch species taken in the equatorial purse seine fishery (SC8-EB-WP-18) for presentation to the SC, with analyses to include the WCPO longline fishery and to address some of the issues raised in the Next Steps section of the paper."

Since SC8, further work has been performed in particular to:

- refine the modelling approach;
- gain understanding of the finer spatial pattern of bycatch relative to the location of unloading ports.

A scientific paper has been developed on the basis of these analyses. This paper has been submitted to a relevant journal and is currently under review. The methods and results sections of the paper are appended here.

In the coming year, the time-series of purse seine bycatch estimates derived here will be combined with estimates of bycatch from the longline fishery (estimated by raising observer catch data) to 'tune' the existing pelagic ecosystem Ecopath model for the western and central Pacific Ocean (Allain et al. 2007). The Ecopath model will be used to examine the potential impact of WCPO fisheries on key bycatch species.

Can the tuna purse seine fishery in the tropical Western and Central Pacific contribute to the food security of Pacific Island populations?

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Materials and Methods

Data

Three sources of data were examined: fishery observer information; purse seine regional vessel logsheet information; and census-based population estimates. The analysis concentrated on observations from fishing operations in the EEZs of seven of the PNA members: Federated States of Micronesia, Kiribati, Republic of the Marshall Islands, Nauru, Papua New Guinea, Solomon Islands and Tuvalu (Figure 1). Insufficient data were available from Palau waters to develop estimates.

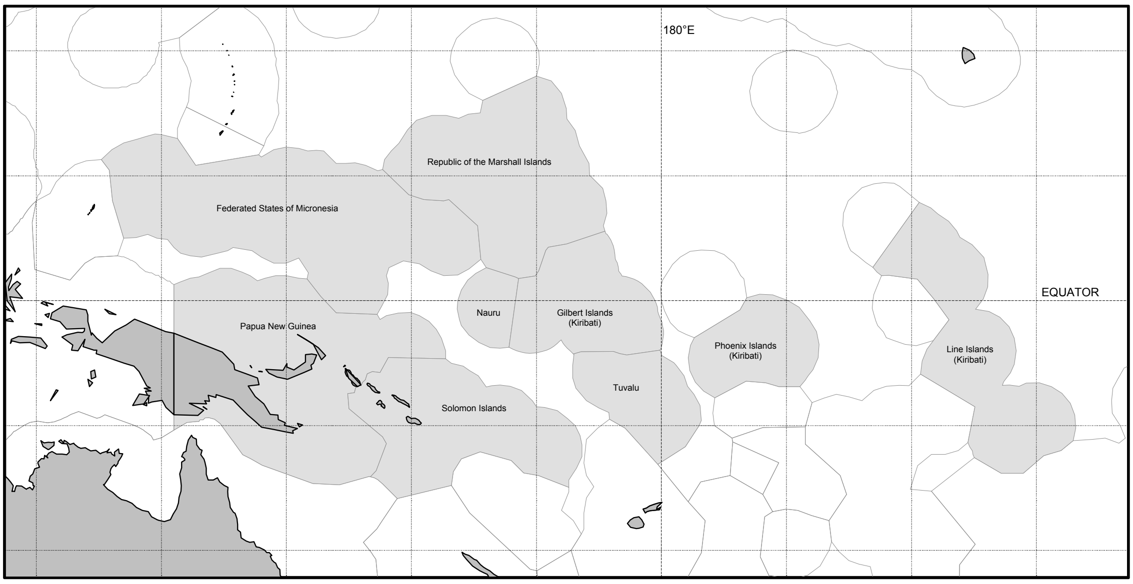


Figure 1. National Exclusive Economic Zones from which observer and logsheet data were analysed.

Records from Fishery Observer Programmes held by the Secretariat of the Pacific Community (SPC) provide the most comprehensive data set available on the level of non-target species caught by purse seiners. Observer coverage of purse seine activity has increased over time, particularly following the requirement for 100% observer coverage through WCPFC Conservation and Management Measures from 2010. Nevertheless, observer data represent a sub-set of regional total purse seine activity (coverage increasing from 5-10% of trips prior to 2009 to 80-90% coverage in recent years). Set-by-set observer data on individual species' occurrence and catch levels were collated across the WCPO from 20°N to 20°S, by EEZ. These data were used to estimate non-target species catch rates, for the period 2000 to 2010 inclusive.

Data were analysed for specific species and species groups, guided by recent discussions on potential catch retention requirements (WCPFC 2012). In addition to the combined catch of the three main tunas (skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna, grouped into a total tuna category), eight key non-tuna edible finfish species were examined (Table 1), representing the most common 'edible' species observed in purse seine catches in the WCPO. Billfish species - black marlin, blue marlin, striped marlin and sailfish - were also combined into a total billfish category.

Purse seine regional vessel logsheets provide information on fishing effort. Total annual effort (number of sets) by set type ('FAD' or 'free school') was calculated from logsheet information. As logsheet returns cover a high proportion of fishing, but not all (over 85% of activity; Williams 2012), effort was raised to represent the total purse seine fishing activity in each of the EEZs. While catch weight of non-target species is also available from logsheets, these data are expected to be less complete than that obtained through observers.

Purse seine regional vessel logsheets also provide information on the port in which tuna catches from each vessel's trip were landed. The port of landing was identified on logsheets for 91% of records. This information provided a reasonable indication of the destination of potential non-target catch landings.

Human population census estimates for each country were available through SPC's Statistics for Development population census programmes (http://www.spc.int/sdp/). These provide the most up to date estimates of total population, from which potential current demand for protein can be estimated.

Catch rates

The geographical location of fishing events is expected to be an important factor determining catches given known influences of environmental and oceanographic features on catch rates and pattern of fishing activity. Estimates were therefore calculated by EEZ.

In a high proportion of sets (see Table 1), no catch of a species under consideration was noted by observers ('zero catch' sets). To take this into account, a delta-lognormal Generalized Linear Model (GLM) approach was taken, where presence/absence in a set was treated separately, and non-zero catch rates were modelled using a lognormal distribution (Lo et al. 1992). All models were fitted to the data using the R-software (R Core Team 2012).

For presence/absence, set by set data for each species were re-coded into binary format. The proportion of sets where a species was present in the catch (positive sets) was modelled using the logit function as the link between the linear factor component and a binomial error distribution:

$$\text{Species\_present}_{i,j,k} \sim \text{Year}_i * \text{Set\_type}_j * \text{location}_k \qquad (1)$$

where i = 2000-2010, j = FAD or free school set and k = the geographic location (EEZ).

The catch rate (kg per set) in sets where a species was caught (positive sets) was modelled assuming that the error followed a lognormal distribution:

$$\text{Ln(Species\_cpue)}_{i,j,k} \sim \text{Year}_i * \text{Set\_type}_j * \text{location}_k \qquad (2)$$

where i = 2000-2010, j = FAD or free school set and k = the geographic location (EEZ).

A natural log transformation was sufficient to achieve normality of catch rate data in the majority of species' models. For the model of total tuna catch rate, the Box-Cox procedure was applied to improve normality of the log-transformed data (Box and Cox 1964); a constant of 2.15 was first added to the untransformed values. For dolphinfish and rainbow runner CPUE models, a $\log_{10}$ transformation was most appropriate.

For each species and both model components, the most complex initial model examined contained the three way interaction between year, set type and location. The 'best' - generally more simple - model for each was selected on the basis of the Akaike information criterion (AIC) value and model parsimony, and through examination of residual patterns and linearity of the quantile-quantile plot (positive CPUE value models only).

Based upon the models for each species, an average catch rate by year, set type and location was estimated from the product of the two model predictions, with appropriate bias correction applied to the lognormal estimates.

Total catch levels

Raised annual effort (number of sets) by set type were estimated from logsheet information for the period 2000-2010 in the relevant EEZs (Figure 1). Predicted species' average catch rates by year, set type and location from the GLMs were multiplied by the corresponding number of sets (effort) to estimate annual species catches. 95% confidence intervals around the mean catch were estimated using Cox's method (Fletcher 2008).

Contribution to food security

To examine the utility of local (EEZ) non-target species catch as a source of protein for local consumption, recent (2008-2010) mean total non-target catch estimate for each EEZ were divided by the most recent SPC population census information for each country.

Using logsheet information on each vessel's destination port, and effort from the seven EEZs, we estimated the non-target catches by unloading port for the recent period (2008 - 2010). Destination ports were grouped into four categories: 'distant water fishing nation'; 'Pacific Island country or territory with onshore processing facilities' or 'Pacific Island country or territory without onshore processing facilities', based upon the information provided within Hamilton et al. (2011); and 'unknown', where no destination port information was entered. It is important to note that just because fish have a destination port with a processing facility, it does not mean that target tuna catches are processed there. It is common for transshipment, i.e. the unloading of fish from a fishing vessel to carrier vessel, to occur in ports with processing facilities. That fish may not, therefore, reach the shore.

Results

Catch rates

Observer data were available for 69,563 sets undertaken during 2000-2010. For a number of species (striped marlin and sailfish in particular), there were limited catch events across the data set (Table 1), and hence estimates were less precise. The general structure of the species-specific GLM models developed from the data, and related statistics, are presented in Table 2.

A higher proportion of FAD sets succeeded in catching fish compared to free-school sets, for all species. Over the period 2008-2010, 81% of FAD sets resulted in a tuna catch, compared to 40% of sets on free school tuna (Table 1). The most common non-target species were rainbow runner (noted in 37% of FAD sets) and dolphinfish (in 15% of FAD sets), while the incidence of other species was noted in less than 10% of FAD sets. For free-school sets, the frequency of occurrence was less than 10% of sets for each species.

To illustrate the relative pattern of catch levels by set type, mean catch rates for each species were calculated by set type across EEZs and years over the period 2008-2010 inclusive (Table 1). All species had a higher catch rate in FAD sets. For total tuna, the average catch in FAD sets (around 40 mt/set) was almost twice that from free-school sets (21 mt/set). Combined non-tuna species average catch rates (in kg/set) were over fifteen times greater in FAD sets than free-school sets; on average 265 kg of the species examined here were caught in each FAD set, compared to 17 kg in an free-school set. Rainbow runner and dolphinfish were the most common non-target species by weight in FAD sets with average catch rates of 169 kg/set and 66 kg/set in recent years, respectively. In free-school sets blue marlin was the most common species by weight, with a catch rate of 7 kg/set, followed by black marlin and rainbow runner (3 kg/set).

Table 1. Finfish species examined, and the proportion of 'positive catch' sets and mean catch rates (kg/set, for non-target species) by species and set type across the period 2008-2010 and areas of the tropical WCPO shown in Figure 1. Total represents combined estimates for non-tuna species (excluding the combined billfish species group).

Common name	Scientific name	Proportion of observed sets with positive catch		Catch rate (kg/set)	
		FAD sets	Free school sets	FAD sets	Free school sets
Total tuna		0.81	0.40	40.1[a]	21.1[a]
Total billfish		0.11	0.07	20.5	13.0
Black marlin	*Istiompax indica*	0.03	0.02	5.8	3.3
Blue marlin	*Makaira nigricans*	0.06	0.04	11.6	6.9
Striped marlin	*Kajikia audax*	0.01	0.01	2.0	1.2
Sailfish	*Istiophorus platypterus*	0.01	0.00	0.4	0.3
Barracudas	*Sphyraena spp.*	0.07	0.01	2.1	0.2
Dolphinfish	*Coryphaena hippurus*	0.15	0.05	66.0	2.0
Rainbow runner	*Elagatis bipinnulata*	0.37	0.09	169.3	3.2
Wahoo	*Acanthocybium solandri*	0.09	0.02	7.5	0.3
Total non-tuna				**264.7**	**17.3**

[a] total tuna catch rate in mt/set

Table 2. Delta-lognormal GLM structures and ANOVA statistics, as used to estimate species-specific catch rates (mt/set).

Species	Model	*P* value where variable significant (ANOVA)						Resid. Dev	Df
		Year	School	EEZ	Year*School	Year*EEZ	School*EEZ		
Total tuna	Bin.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	75936	69469
	Ln+2.15	<0.001	0.254	<0.001	<0.001	<0.001	<0.001	47939	42625
Billfish	Bin.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	42160	69469
	Ln	<0.001	0.739	<0.001	<0.001	-	<0.001	5339	6519
Black marlin	Bin.	<0.001	<0.001	<0.001	-	-	<0.001	18216	69539
	Ln	0.259	0.276	0.116	-	<0.001	0.035	1472	2005
Blue marlin	Bin.	<0.001	<0.001	<0.001	-	<0.001	<0.001	26691	69479
	Ln	0.012	0.201	<0.001	-	-	0.020	2410	3417
Striped marlin	Bin.	<0.001	<0.001	<0.001	-	-	<0.001	8189	69539
	Ln	<0.001	-	-	-	-	-	538.4	749
Sailfish	Bin.	<0.001	<0.001	<0.001	-	-	-	6146.5	69545
	Ln	-	-	<0.001	-	-	-	443	530
Barracudas	Bin.	<0.001	<0.001	<0.001	-	<0.001	<0.001	24213	69479
	Ln	0.014	<0.001	<0.001	0.001	<0.001	<0.001	3788	3853
Dolphinfish	Bin.	<0.001	<0.001	<0.001	-	<0.001	<0.001	37502	69479
	Log_{10}	<0.001	<0.001	<0.001	<0.001	<0.001	-	2958	8054
Rainbow runner	Bin.	<0.001	<0.001	<0.001	-	<0.001	<0.001	44674	69479
	Log_{10}	<0.001	<0.001	<0.001	<0.001	<0.001	-	8554	18241
Wahoo	Bin.	<0.001	<0.001	<0.001	-	<0.001	<0.001	26250	69479
	Ln	<0.001	-	<0.001	-	<0.001	-	5554	4536

Effort data

Raised total annual effort by set type showed a general increasing trend in the total number of purse seine sets made in the EEZs examined since 2000. Number of sets increased from 21,473 sets in 2000 to 49,528 sets in 2010 (Figure 2). The proportion of FAD and free-school sets per year was comparable, with 40-60% of sets being one type or the other. An exception was 2010, where the fishery showed a significantly greater proportion of sets on free schools (75%), commensurate with a different fishing pattern around a 3 month FAD-fishing closure in that year, while in 2004 there was a greater proportion (65%) of FAD sets.

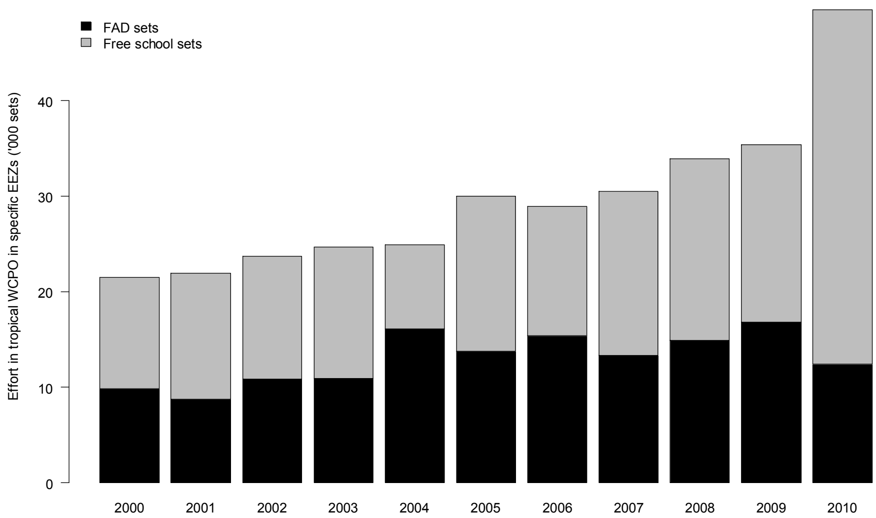


Figure 2. Level of effort (sets) by year and set type in the EEZs examined.

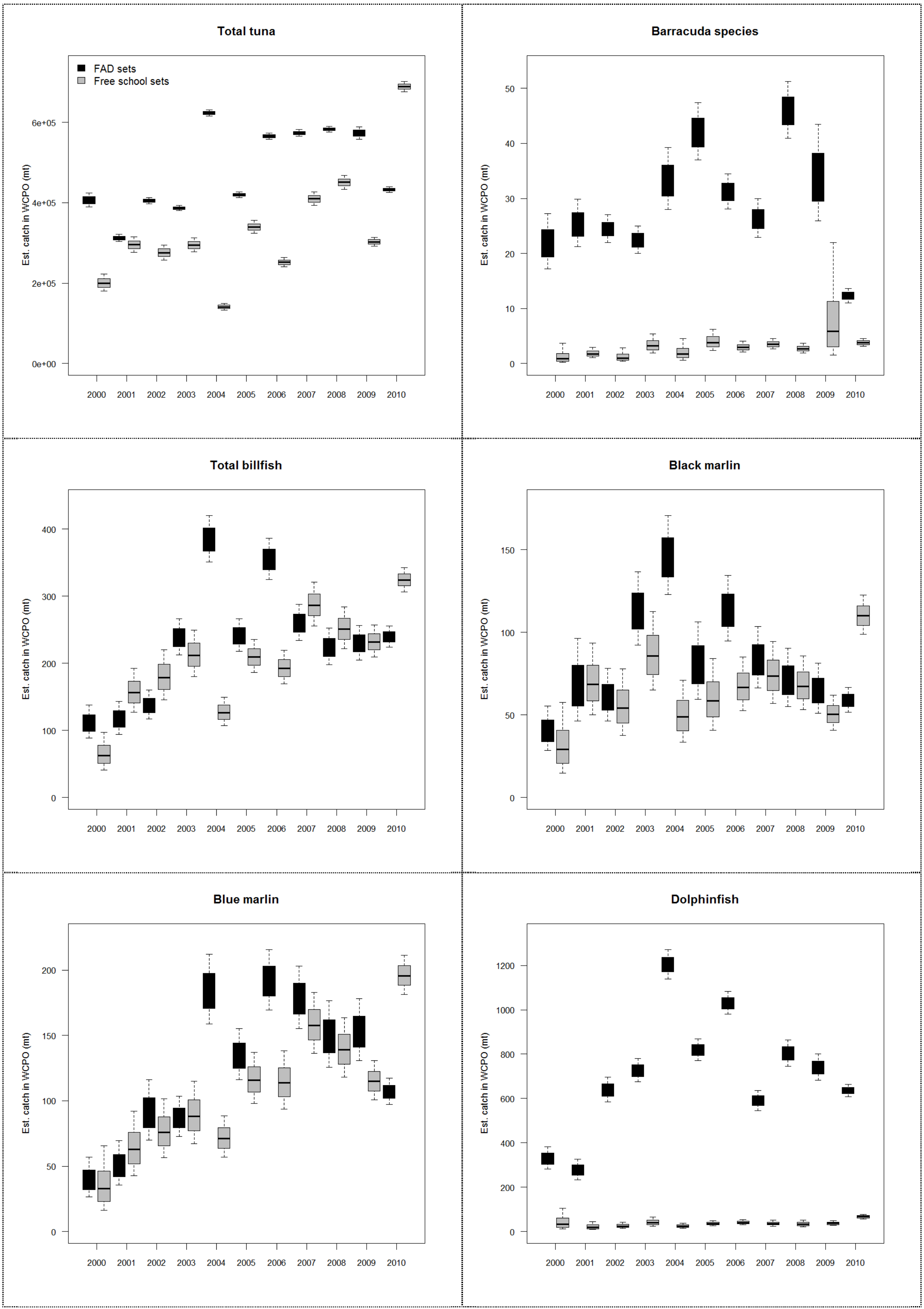
Total catch levels

Estimated annual catches for each species and species group (all set types combined) are presented in Table 3. The time series of annual catch levels (including estimated uncertainty) by species and set type is presented in Figure 3. To place total non-target species catch estimates in context, combined catches represent less than 0.75% of total tuna catch estimates. Free school catches were estimated to contain a non-target catch component of <0.2% of the total catch, while in FAD sets this catch was <1% of the total.

Greatest total mean estimated catch of combined non-tuna species examined was in 2004 at 5,675 mt, coinciding with peaks in the estimated catch of rainbow runner (around 67% of the total non-target catch; Table 3) and dolphinfish. Taking into account the variability in CPUE estimates, the 95% confidence intervals indicated that the total catch of non-tuna species was between 5,438 and 5,931 mt in that year.

Table 3. Estimated mean total catches (mt) for each species or species group by year across the EEZs examined. Total represents the estimated weight of non-tuna species (excluding the combined billfish species group).

	Total tuna	Billfish	Black marlin	Blue marlin	Striped marlin	Sailfish	Barracudas	Dolphinfish	Rainbow runner	Wahoo	**TOTAL (non tuna)**
2000	606,414	173	69	72	20	5	23	362	1168	88	**1,806**
2001	607,464	272	135	113	10	11	27	296	1544	82	**2,218**
2002	680,737	315	114	166	18	10	25	662	1896	55	**2,946**
2003	680,986	450	198	175	55	16	26	766	1736	49	**3,020**
2004	764,495	510	194	255	39	19	35	1227	3789	117	**5,675**
2005	759,721	450	138	250	30	19	46	854	2960	63	**4,358**
2006	817,642	547	180	305	49	17	34	1070	3646	50	**5,351**
2007	983,623	546	156	335	44	11	30	625	2747	51	**3,999**
2008	1,033,875	474	138	288	34	16	48	836	2564	83	**4,007**
2009	876,106	461	115	267	49	8	39	775	2023	79	**3,355**
2010	1,121,480	563	169	302	65	16	16	702	2226	44	**3,540**
Average	**812,049**	**433**	**146**	**230**	**37**	**13**	**32**	**743**	**2391**	**69**	**3,661**


Total tuna
FAD sets
Free school sets
Est. catch in WCPO (mt)
0e+00
2e+05
4e+05
6e+05
Barracuda species
Total billfish
Black marlin
Blue marlin
Dolphinfish
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

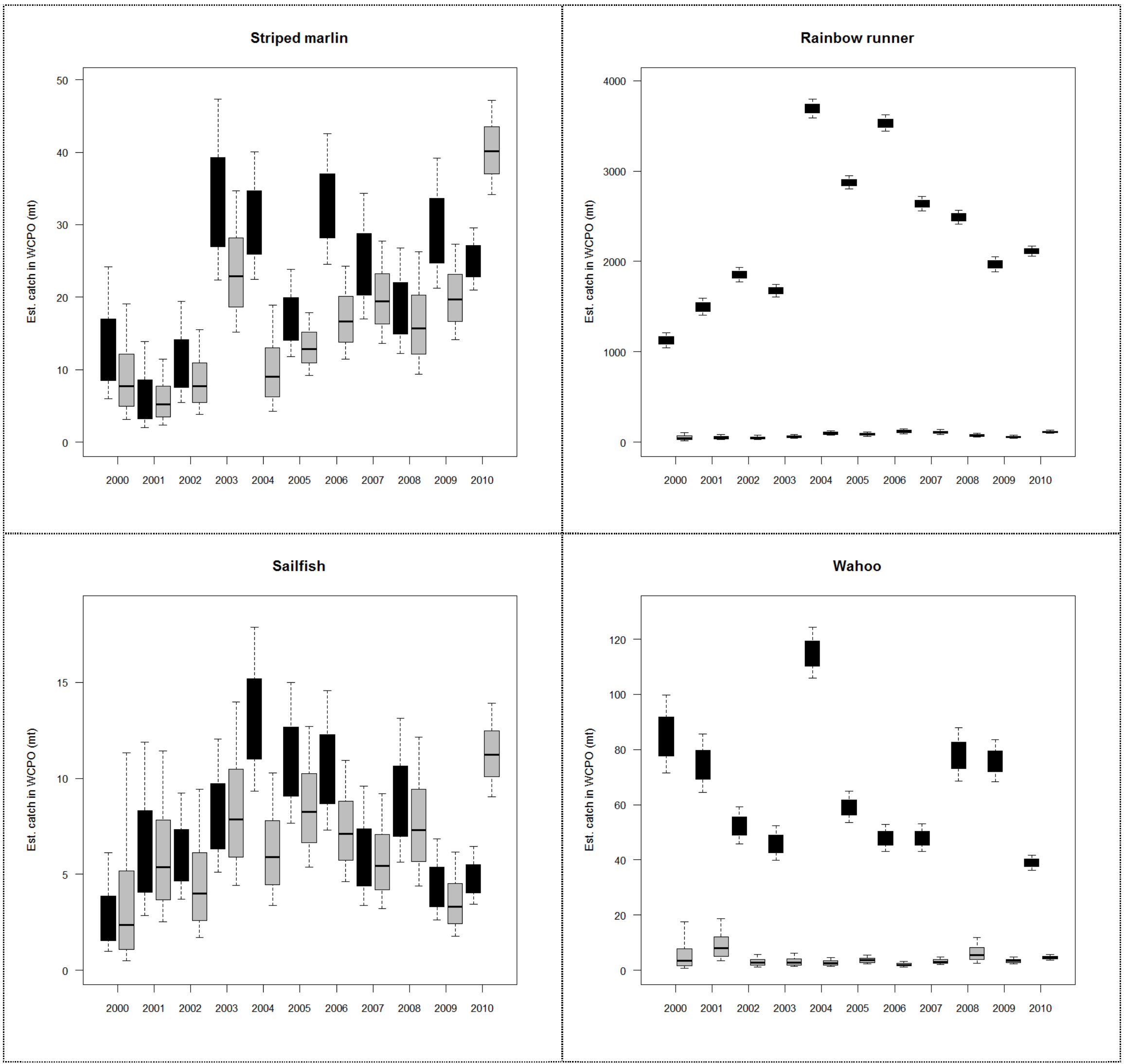


Figure 3. Total catch of each species and species group (mt) by year and set type for the period 2000-2010. Whiskers represent the 95% confidence interval range of the mean catch estimate of each species (extreme values therefore not presented). Note the different scales on the y-axis of each graph.

Following the pattern seen in catch rates, total annual tuna catches were generally higher from FAD sets compared to that from free school sets. This pattern was, however, reversed in 2010 (Figure 3).

Estimated non-billfish catches were higher in FAD sets compared to free-school sets. Highest non-target catch levels were estimated for rainbow runner, with catches peaking in the FAD set component at around 3,690 mt in 2004, and remaining above 2,500mt until 2009. For dolphinfish, the next most common non-target species, the highest catch level was also estimated to be in FAD sets in 2004 at around 1,200 mt, and catch estimates from FAD sets remained over 550 mt between 2002 and 2010. Catch levels in free-school sets for both species were an order of magnitude lower (below 120 mt and 70mt respectively). For other non-billfish species, estimated mean catches combined across set types were below 50 and 120 mt per year, respectively.

The pattern in total billfish catches over time varied between set types, but was generally higher in FAD sets (a combination of higher catch frequency and catch rates) before 2007, and subsequently higher in free-school sets. FAD set catches peaked in 2004, declined to around 250 mt and then remained stable through to 2010, while free-school set catches increased to a peak in 2007 at 290 mt, peaking again in 2010. Combined, mean catch estimates were greatest in 2010 at 563 mt (Table 3). Total billfish catch patterns were primarily driven by blue marlin catches, and to a lesser extent those of black marlin. Annual catches of other billfish species (striped marlin, sailfish) were estimated to be below 70 mt and 20 mt respectively.

Contribution to food security

Estimates of the potential contribution to per capita population protein supply arising from the local (EEZ) non-target species catch are presented in Table 4. Based on 2008-2010 average catches, a potential benefit of from 270 g (PNG) to 25 kg (Tuvalu) per person per annum could be gained from landing non-target species catch caught in each country's EEZ into local ports.

Table 4. Estimated per capita non-target catch weight by country, estimated additional fish needed for food to meet protein demands by 2035 (from Bell et al., 2011) and average non-target species catch over the period 2008-2010.

Country	Per capita non-target species catch weight (kg/person)	Additional fish needed for food by 2035 (mt)	Average non-target catch (mt per annum, 2008-2010)
Federated States of Micronesia	4.262	7,300	437
Kiribati	9.239	9,000	855
Republic of the Marshall Islands	0.774	2,200	39
Nauru	21.034	790	194
Papua New Guinea	0.268	140,700	1,393
Solomon Islands	0.917	33,900	473
Tuvalu	25.289	1,400	242

Examining the destination of recent (2008-2010) tuna catches from the seven EEZs as a proxy for the destination of retained non-target catches, between 0% (Nauru) and 61% (Solomon Islands) of potential estimated total non-target catch within an EEZ also had a destination port noted within that EEZ (Table 5). However, only four of those countries have a port with tuna processing facilities (ports to which between 20 and 60% of the total non-target catch was taken).

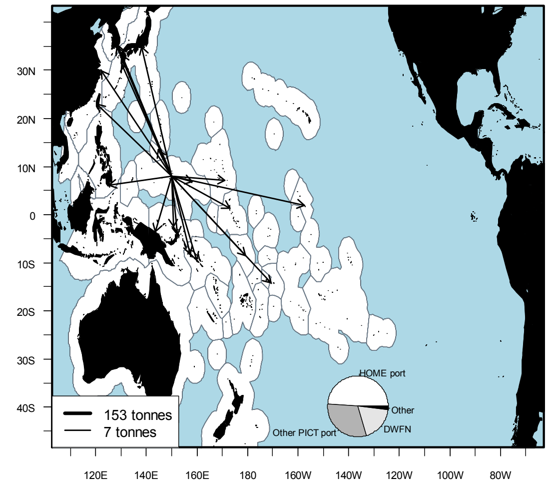
The destination of between 67% and 96% of non-target catches within an EEZ were PICT ports within the WCPO region, which included ports in American Samoa and Fiji (10% and <1% of the estimated potential non-target catch respectively; Figure 4).

Landing of fish from EEZs directly into foreign (distant water fishing nation) ports (primarily in Japan, Philippines, Korea, China and Taiwan) was significant for estimated non-target catches taken in the EEZs of Federated States of Micronesia (19% of catches) and Papua New Guinea (11%), but was less than or equal to 5% for other EEZs.

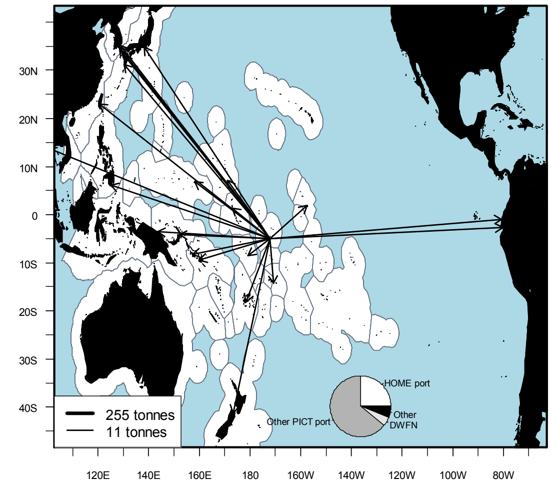
Table 5. Proportion of 2008-2010 estimated potential non-target catch within specific PICT EEZs whose destination port was noted as the home port (port within that EEZ) or other PICT ports with or without processing facilities, distant water fishing nation (DWFN) ports, or whose delivery port was unknown.

	Home port			Other PICT port		**Total PICT**	DWFN	UNK
	With processing	Without processing	***TOTAL***	With processing	Without processing			
Federated States of Micronesia	0.00	0.48	***0.49***	0.26	0.04	**0.79**	0.19	0.02
Kiribati	0.00	0.25	***0.25***	0.53	0.11	**0.89**	0.05	0.06
Republic of the Marshall Islands	0.59	0.00	***0.59***	0.05	0.30	**0.94**	0.04	0.02
Nauru	0.00	0.00	***0.00***	0.45	0.50	**0.95**	0.04	0.01
Papua New Guinea	0.36	0.00	***0.36***	0.05	0.26	**0.67**	0.11	0.22
Solomon Islands	0.21	0.40	***0.61***	0.23	0.11	**0.96**	0.02	0.02
Tuvalu	0.00	0.02	***0.02***	0.68	0.25	**0.95**	0.01	0.04

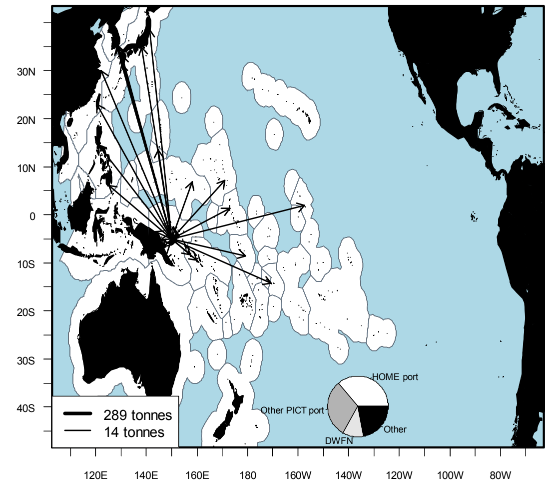
Federated States of Micronesia



Kiribati (centred on Phoenix Islands)



Papua New Guinea



Solomon Islands

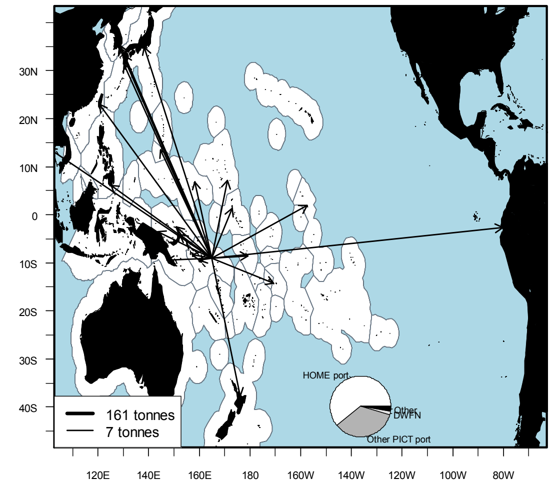


Figure 4. Landing port and quantity of tuna (legend presents the level of tonnage (total 2008-2010) presented by the line thickness). Pie chart presents proportion of total tuna catch delivered to port country groups.

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