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Original Article

Evaluation of a fishing captain's ability to predict species composition, sizes, and quantities of tunas associated with drifting fish-aggregating devices in the eastern Pacific Ocean

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Experiments were conducted to evaluate a fishing captain's ability to predict species composition, sizes, and quantities of tunas associated with drifting fish-aggregating devices (FADs), before encirclement with a purse-seine net. Operating in the equatorial eastern Pacific Ocean, during 11 May–23 July 2011, Captain Ricardo Diaz detected small quantities of bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) tunas within large FAD-associated aggregations dominated by skipjack tuna (*Katsuwonus pelamis*). The captain's predictions were significantly related to the actual total catch and catch by species, but not to size categories by species. His predictions of species composition were most accurate when estimates of bigeye and yellowfin tuna were combined. If purse-seine captains are able to make accurate predictions of the proportion of bigeye and yellowfin tunas present in mixed-species aggregations associated with FADs, managers may wish to consider incentives to fishers to reduce the fishing mortality on those species.

Keywords: bigeye tuna, bycatch, catch prediction, purse-seine, skipjack tuna, yellowfin tuna.

Introduction

Targeting aggregations of tuna while associated with drifting fish-aggregating devices (FADs) has become the dominant purse-seine fishing method worldwide. In equatorial waters of the eastern Pacific Ocean (EPO) purse-seine captains utilize FADs to aggregate mixed species schools, typically dominated in proportion by skipjack tuna (*Katsuwonus pelamis*); however, these aggregations can, at times, have high proportions of small bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) tunas. Sets on FADs have success rates of more than 90% compared with ~50% for sets on free-schools (Fonteneau *et al.*, 2000; Sakagawa, 2000). Although purse-seine captains commonly use sonar coupled with other observations to estimate the total amount of tunas associated with a FAD before setting their net, they currently have little incentive to evaluate species and size composition of the aggregation and catches often include small, undesirable sizes of yellowfin and bigeye tunas (<65 cm) (Anon., 2012). Noting that some size and species segregation may exist naturally in FAD-associated aggregations (Muir *et al.*, 2012), Harley and Suter (2007) hypothesized that captains could reduce their take of small bigeye tuna if they avoid setting on aggregations dominated in proportion by bigeye tuna. This may be possible based on the results of a recent survey of purse-seine captains conducted by the International Seafood Sustainability Foundation (ISSF). Three-quarters of the captains surveyed claimed that, before setting on a FAD, they do evaluate the species present; and 40% of them claimed that they can correctly distinguish bigeye tuna from skipjack and yellowfin tunas (ISSF, 2012). How they do this is currently undocumented, but perhaps the captains judge morphological, behavioural, and acoustical differences between bigeye, yellowfin, and skipjack tunas, such as those identified by Schaefer and Fuller (2007). This study evaluates the ability of one purse-seine captain to predict, before setting a net, the species, sizes, and quantities of FAD-associated tunas he will capture.

Material and methods

Experiments were conducted aboard the Ecuadorian-flag purse-seine vessel *Yolanda L.* during 11 May–23 July 2011, between

2°–5°N and 100°–105°W (Figure 1; Table 1), and at the Starkist® GALAPESCA S. A. fish processing facility, Manta, Ecuador. Before dawn, before each of eight purse-seine sets on FADs, Captain Ricardo Diaz estimated the quantity present of each tuna species, by size (<2.5, 2.5–15, or >15 kg), which he believed he would catch. At this time, the captain also provided an error estimate (t) for each species category. The captain made his predictions using information from: (i) a crewman in a 5.5-m light-boat using a 50-kHz echosounder (Furuno FCV-620); (ii) the purse-seine vessel's 68 kHz scanning sonar (Furuno CSH-5l) and 200 kHz echosounder (Furuno FCV-292); and (iii) four crewmen visually observing from the vessel's crow's-nest, ~33 m above the water.

Before each set, 04:00–04:30 local time, the light-boat and crewman were deployed, subsequently tying to the FAD, and shining four 500 W halogen lights into the water. During the next 30–60 min, the crewman reported on the aggregation density and maximum depth as observed on the light-boat's echosounder. Meanwhile, the captain estimated the horizontal dimensions of the aggregation vs. depth (Figure 2a) and the position of the aggregation relative to the FAD and the light-boat, by altering the declination angle of the scanning sonar beam (see Brehmer *et al*., 2006). The captain also gathered information on aggregation size and species composition from the vessel's echosounder (Figure 2b), as well as catch reports from other vessels operating in the area. Additionally, crewmen in the crow's nest provided their estimations of the horizontal dimensions and behaviour of the aggregation. Based on information accumulated from these sources, the captain derived his estimate of species composition, sizes, and quantities which he believed he would capture. The purse-seine net was then set to capture the entire aggregation. During the set, the captain noted if fish were observed escaping from the net.

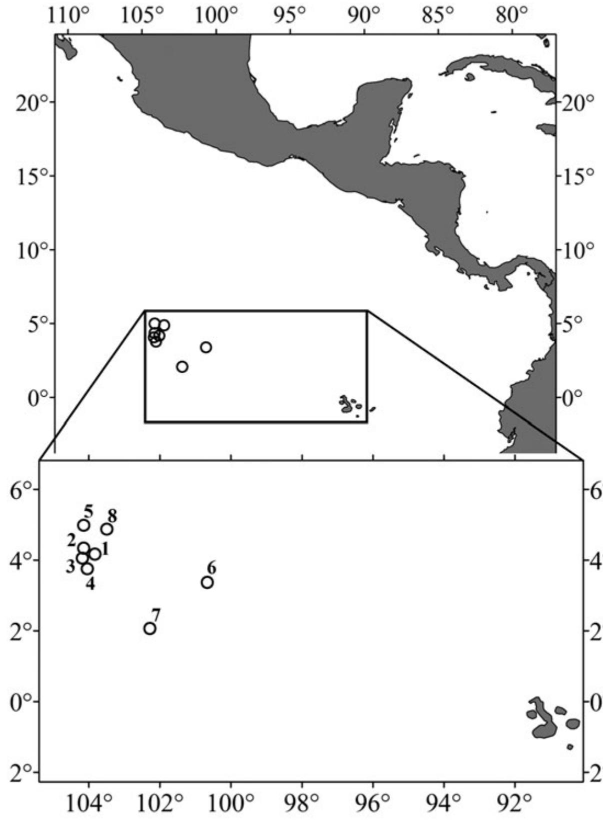

Figure 1. Purse-seine set positions (Table 1) where eight catch prediction experiments were conducted.

For 30 min to several hours following a set, depending on the amount captured, the catch was loaded aboard the vessel. Catches from each set were separated by well or, in the cases of partially filled wells, by 7.6-cm mesh net.

Upon returning to port, the vessel was unloaded by hand, over the course of 7 days while carefully maintaining separation of the individual sets. A truck transported the fish to the processing facility located ~12 km from the pier. Species and size sorting was conducted by Starkist® employees at the processing facility. Fish were placed on a large stainless steel sorting table ~10 m by 10 m where sorting was conducted by three to four individuals. Each fish was manually placed into specific bins for each species and size category. Species and size bins were established based on observations of GALAPESCA S.A. personnel who estimated the overall species and size composition of the set at the time of vessel unloading. To validate the accuracy of species and size sorting by GALAPESCA S.A. personnel, staff of the Inter-American Tropical Tuna Commission (IATTC) sampled 10 fish from each sorted bin (species and size category) from three individual sets (Figure 3). Once sorted, all bins from each set were weighed and weights were recorded. Total weight by species and size class for each set was provided by the processing facility at the completion of the unloading and sorting process (Table 1). For comparison with the captain's predictions, these data were aggregated into the same three weight classes predicted by the captain and the percent differences between the predicted and actual catch were calculated (Table 2).

To evaluate the captain's prediction of catch weight for each species and all species combined, weighted linear regressions were utilized (Tables 3 and 4). Weights were derived from the reciprocal of the captain's estimated error. These error estimates were also used

Table 1. Summary for eight purse-seine sets for which tuna catch prediction experiments were conducted.

		Position		Catch (t)			
Date	**Set**	**Latitude**	**Longitude**	**Skipjack**	**Bigeye**	**Yellowfin**	**Total**
27 May 2011	1	4°10N	103°50W	50.9	6.3	14.2	71.5
31 May 2011	2	4°20N	104°09W	55.1	5.9	13.4	74.5
1 June 2011	3	4°03N	104°11W	16.4	1.0	4.6	21.9
4 June 2011	4	3°45N	104°03W	115.1	13.8	18.0	146.9
9 June 2011	5	4°59N	104°09W	14.5	11.7	12.8	39.0
23 June 2011	6	3°22N	100°40W	166.9	6.6	8.9	182.4
30 June 2011	7	2°04N	102°17W	110.9	2.0	29.9	142.8
10 July 2011	8	4°52N	103°30W	56.3	2.3	13.7	72.3

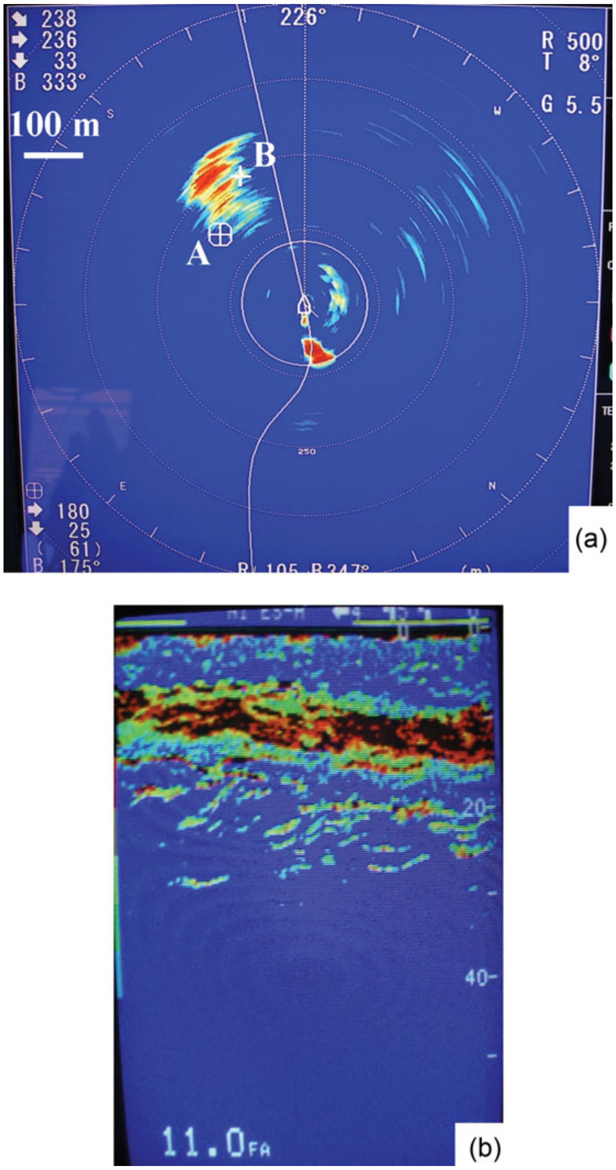

Figure 2. Image of the Furuno CSH-5l full circle scanning SONAR aboard the *Yolanda L.* (**a**) showing a large mixed-species aggregation, associated with a drifting FAD, before making a purse-seine set. Using the two cursors (labelled A and B), the captain can derive the horizontal dimensions, in metres, of the aggregation. Image of the Furuno FCV-292 (200 kHz) echosounder aboard the *Yolanda L.* (**b**), where the echo-intensity and the depth distribution of fish within the aggregation provide the captain with an estimate of species composition.

to derive a coefficient of variation (*CV*) (Table 5) for each species. The *CV* is an estimate of the captain's perceived accuracy and is derived from the captain's error estimate divided by his total estimated catch.

Results

In each of the eight sets, the captain was able to detect the presence of bigeye and/or yellowfin tuna, even when present in very limited quantities and proportions (Tables 1 and 2). For example, bigeye were detected before sets 1, 7, and 8, where there were between 1 and 2.3 t of bigeye captured, comprising 5% or less of the total catch. A Shapiro–Wilk test for normality indicates that the captain's predicted amounts for the three species follow a normal distribution. Correlation analysis (Pearson) indicates no significant relationship between the total size of the aggregation and the proportion of bigeye ($r^2 = 0.102$, $p = 0.441$) or yellowfin ($r^2 = 0.028$, $p = 0.703$) predicted by the captain.

Sampling by IATTC scientists at the processing facility confirmed that species and size sorting by Starkist® employees were accurate. Considering the weight distributions for bigeye, yellowfin, and skipjack tunas vs. size category (Figure 3a–e), only a small percentage (3.1%) of the scientist's measurements differed from the sorted weight categories. There were no observed cases of species misidentification.

Weighted linear regressions were applied to the predicted and measured catch for individual species and for all species combined (Figure 4a–d). These linear regressions indicate that there is a significant relationship between what the captain predicted to be present and what was caught (Table 3). The slope indicates whether the captain over- or underestimated the amount of tunas present. A slope >1, as in the case for bigeye (1.991) and yellowfin (1.447) indicates that he consistently overestimated the amounts present (Table 3). Slopes were not significantly different from 1 for all species combined ($p = 0.47$), bigeye ($p = 0.63$), and yellowfin ($p = 0.74$), but the slope was significantly different from 1 for skipjack ($p = 0.003$).

Linear regressions were used to test the relationship between the predicted and measured catch, by species, within each of five size categories for which data exist (Table 4). These linear regressions indicate that there is no significant relationship between the captain's prediction and what was caught (Table 4). Slopes ranging from 0.210 to 0.687 further indicate the great difficulty the captain had predicting the size composition of the catch, by species.

The captain perceived that his predicted catches of individual species and total catch were imprecise (Table 5). There is no correlation between the captain's predicted catch precision and aggregation size for bigeye ($r^2 = 0.040$, $p = 0.636$), yellowfin ($r^2 = 0.003$, $p = 0.896$), skipjack ($r^2 = 0.126$, $p = 0.389$), or all species combined ($r^2 = 0.001$, $p = 0.929$).

Discussion

Results from this study indicate that the captain was consistently able to predict the presence of small quantities of bigeye and yellowfin tunas when evaluating FAD-associated aggregations (22–182 t), most often dominated by skipjack tuna (37%–91%; average = 71.7%). The captain was also able to predict, with deviations ranging from 0.3 to 178.4% (Table 2), the quantities of bigeye, yellowfin, and skipjack tunas present. The deviation of predicted vs. actual catch of bigeye tuna was >100%, on average. The deviation of predicted vs. actual proportion of bigeye tuna ranged from 32 to 180% and was 96%, on average. The captain's predictions were more precise for the combined catch quantities of bigeye and yellowfin tunas (range = 7.0–129.1%; average = 57.2%; Table 2); the combined proportions of bigeye and yellowfin tunas in the catch (range = 4–66%; average = 30%; Table 5); and the total weight of the combined aggregation (Figure 4; Table 2). Dagorn *et al.* (2012) reported that French purse-seine captains' operating in the Indian Ocean had similar prediction performance when evaluating the total size of the aggregation. For predicted catches <10 t, 73% were <10 t, and for predicted catches >10 t, 75% were >10 t, but did not evaluate their ability to predict size composition, by species (Dagorn *et al.*, 2012).

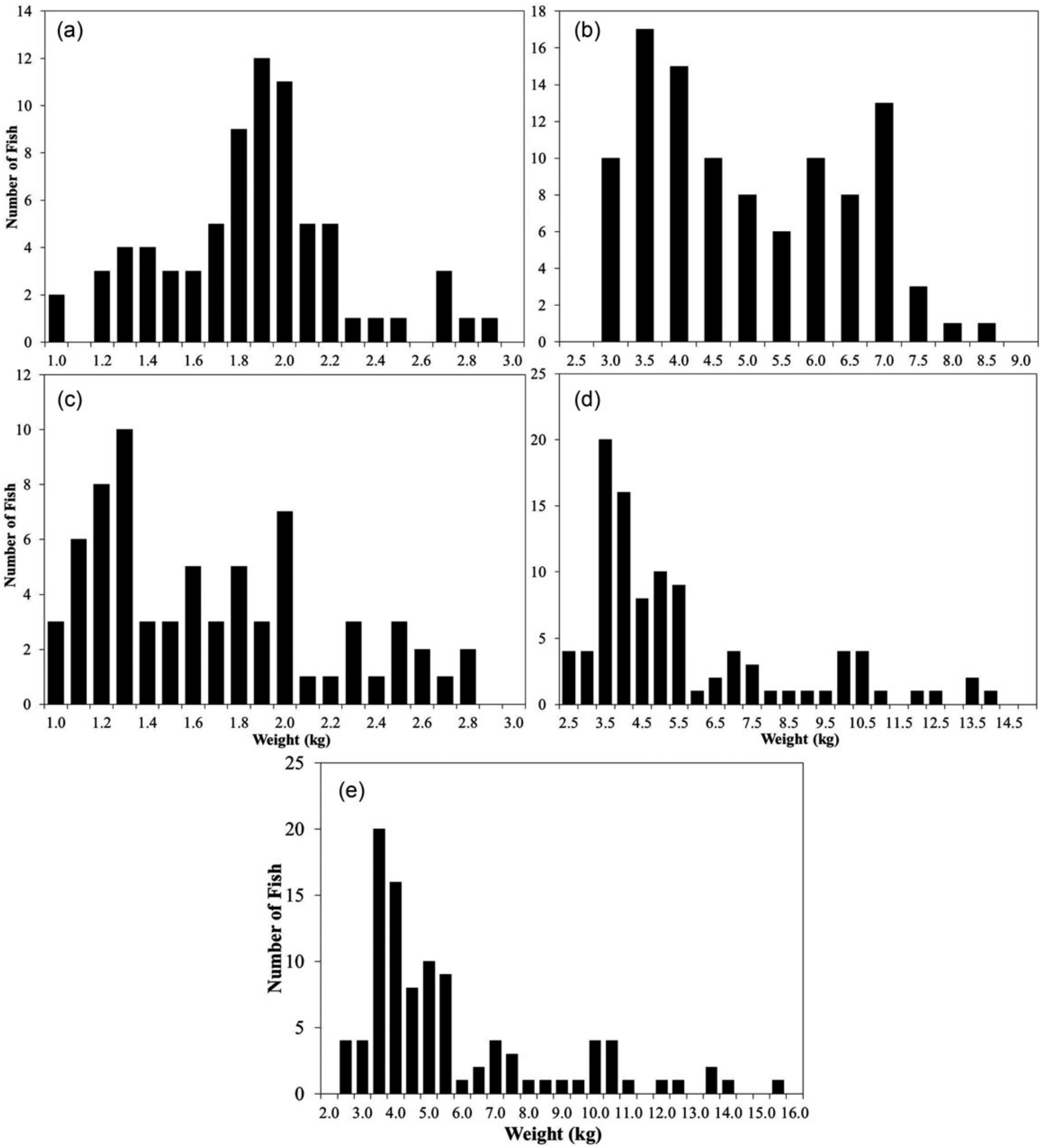

Figure 3. Weight frequency distributions for (**a**) skipjack <2.5 kg, (**b**) skipjack 2.5 – 15 kg, (**c**) yellowfin <2.5 kg, (**d**) yellowfin 2.5 – 15 kg, and (**e**) bigeye 2.5 – 15 kg, measured during sorting at the Starkist® GALAPESCA S.A. processing facility in Manta, Ecuador.

Captains may observe differences in fish depth distributions to aide in the identification of tuna species present within aggregations. Results from acoustic and archival tag experiments indicate that FAD-associated skipjack and yellowfin tunas tend to be shallower than bigeye tuna (Matsumoto *et al.*, 2006; Schaefer and Fuller, 2013). In the western and central Pacific Ocean (WCPO), the depth distributions of tagged bigeye (37.7–85.5 cm) and yellowfin (35.8–93.1 cm) tunas overlapped, while larger tunas were deeper (Matsumoto *et al.*, 2006). Also in the EPO, skipjack tuna are often shallower than bigeye tuna, and larger bigeye tuna are slightly deeper than smaller bigeye tuna (Schaefer and Fuller, 2005, 2013; Schaefer *et al.*, 2009).

Captains may also interpret acoustic backscatter when predicting catches. Greater than 90% of acoustic backscatter from fish with swimbladders is from that organ (Foote, 1980), and fish without swimbladders have much lower acoustic target strength (*TS*) values. Therefore, captains may cue on differences in acoustic backscatter resulting from differences in swimbladder presence and

Table 2. Predicted and actual weight (t) by species, and bigeye and yellowfin combined, along with the percent difference (% Dif) for the eight catch prediction experiments.

	Skipjack			Bigeye			Yellowfin			Bigeye and yellowfin		
Set	Predicted	Captured	% Dif	Predicted	Captured	% Dif	Predicted	Captured	% Dif	Predicted	Captured	% Dif
1	35.0	50.9	37.0	18.0	6.3	96.3	22.0	14.2	43.1	40.0	20.5	64.5
2	45.0	55.1	20.2	7.0	5.9	17.1	11.0	13.4	19.7	18.0	19.3	7.0
3	13.0	16.4	23.1	5.0	1.0	133.3	2.0	4.6	78.8	7.0	5.6	22.2
4	93.0	115.1	21.2	33.0	13.8	82.1	34.0	18.0	61.5	67.0	31.8	71.3
5	8.0	14.5	57.8	30.0	11.7	87.8	20.0	12.8	43.9	50.0	24.5	68.5
6	90.0	166.9	59.9	35.0	6.6	136.5	37.0	8.9	122.4	72.0	15.5	129.1
7	65.0	110.9	52.2	35.0	2.0	178.4	30.0	29.9	0.3	65.0	31.9	68.3
8	25.0	56.3	77.0	9.0	2.3	118.6	12.0	13.7	13.2	21.0	16.0	27.0
$\bar{x}$ % difference			43.5			106.3			47.9			57.2

Table 3. Statistics from weighted linear regressions between the captains predicted catch (t) and the actual catch (t), by tuna species and all species combined, in the eight catch prediction experiments.

	Slope	Intercept	r^2	*F*	*p*-value
Skipjack	0.554	4.950	0.92	71.32	0.0002
Bigeye	1.991	3.564	0.51	6.32	0.0455
Yellowfin	1.447	−3.017	0.62	9.96	0.0197
Combined species	0.93	1.098	0.94	87.98	0.00008

Table 4. Statistics from linear regressions between the captains predicted catch (t) and the actual catch (t), by species/weight class, in the eight catch prediction experiments.

	Slope	Intercept	r^2	*F*	*p*-value
Skipjack <2.5 kg	0.210	3.55	0.294	2.50	0.165
Skipjack 2.5–15 kg	0.687	16.52	0.343	3.13	0.127
Bigeye 2.5–15 kg	0.475	12.18	0.044	0.28	0.616
Yellowfin <2.5 kg	0.498	2.05	0.145	1.01	0.353
Yellowfin 2.5–15 kg	0.597	10.47	0.074	0.48	0.515

volume to differentiate three tuna species. Skipjack tuna do not have swimbladders (Schaefer and Fuller, 2007). Swimbladder volumes are similar for small (<60 cm) bigeye and yellowfin tunas, and the differences increase with fish size (Schaefer, 1999; Bertrand and Josse, 2000). For tuna lengths ranging from 50 to 140 cm, the 38 kHz *TS* of bigeye tuna was ~5 dB higher than that for yellowfin tuna (Bertrand *et al.*, 1999; Manik, 2010). Therefore, skipjack tuna may be distinguishable from bigeye and yellowfin tunas, and large bigeye tuna may be distinguishable from large yellowfin tuna, but small bigeye tuna may be acoustically indistinguishable from small yellowfin tuna (Bertrand and Josse, 2000; Schaefer and Fuller, 2007). Therefore, bigeye and yellowfin tunas may be more easily detected when they are larger than ~60 cm and comprise larger proportions of the large fish in an aggregation. It may not be necessary to accurately predict their proportions because there is currently concern that both bigeye and yellowfin tunas are being overfished (Aires da-Silva and Maunder, 2012a, b).

In this study, the accuracy of the captain's predictions improved by nearly an order of magnitude when the proportions of bigeye and yellowfin were combined. This is likely because their depth and *TS* distributions overlap, but perhaps also because the catches in this study contained less bigeye tuna and more yellowfin tuna than the average EPO FAD set during 2000–2011 (27.1% bigeye, 15.2% yellowfin, and 57.3% skipjack; Anon, 2012). In the present study, only one set (5) contained ~30% bigeye while seven sets contained <10% bigeye. Historically too, catches in the study area (north of 3°N and 100°–105°W) have included higher proportions of yellowfin tuna and lower proportions of bigeye tuna.

In four tropical areas where purse-seine fisheries operate, FAD sets with larger catches of tunas included proportionally less bycatch, specifically silky sharks (Dagorn *et al.*, 2012). Conversely, most FAD sets where catches were small (<10 t) and also comprised a small portion of the total tuna catch, included proportionally more bycatch. Another study (Harley and Suter, 2007) indicated that more than 50% of the bigeye catch was captured in sets where bigeye tuna were present in proportions >60%, accounting for <15% of the total FAD sets. Collectively, these studies suggest that the fishing mortality of bigeye tuna in the EPO could be reduced, along with undesirable bycatch, by fishing on larger (>10 t) FAD-associated aggregations with low proportions of bigeye tuna.

Here, we report the first evaluation of a purse-seine captain's ability to predict the species composition, sizes, and quantities of tunas associated with a FAD, before making a set. Although these results are for just eight sets in a limited area for one captain, they demonstrate the value of evaluating fishers' potentials to avoid bycatch. Relative to the laborious methods used in this study, future investigations could employ shipboard observers and "spill sample" methods (see Lawson, 2008, for details) to study the predictions by many captains using different acoustic and net equipment, throughout a wider geographic region.

Summarizing, bigeye and other tunas have an affinity to floating objects. In the EPO and elsewhere, there has been an increase in purse-seine fishing on FAD-associated tuna aggregations and consequently bigeye tunas are being fully exploited or overfished. Management efforts to reduce fishing mortality of bigeye have also reduced skipjack catches (Aires da-Silva and Maunder, 2012a). If fishers can avoid setting on large aggregations with high proportions of bigeye tuna, then fishing mortality of bigeye tuna and the durations of consequential fishing closures may be reduced.

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Table 5. The captain's predicted catch by species and total catch, in metric tonnes, and the coefficient of variation (*CV*). The *CV* was derived from the error estimates (in metric tonnes) provided by the captain before setting divided by the total predicted amount (in metric tonnes).

	Predicted catch							
	Skipjack		**Bigeye**		**Yellowfin**		**Total**	
Set	**Prediction**	***CV***	**Prediction**	***CV***	**Prediction**	***CV***	**Prediction**	***CV***
1	35	0.057	18	0.111	22	0.091	75	0.080
2	45	0.111	7	0.286	11	0.182	63	0.143
3	13	0.154	5	0.200	2	0.500	20	0.200
4	93	0.215	33	0.303	34	0.353	160	0.263
5	8	0.750	30	0.400	20	0.350	58	0.500
6	90	0.078	35	0.343	37	0.405	162	0.210
7	65	0.385	35	0.486	30	0.500	130	0.438
8	25	0.280	9	0.667	12	0.667	46	0.457

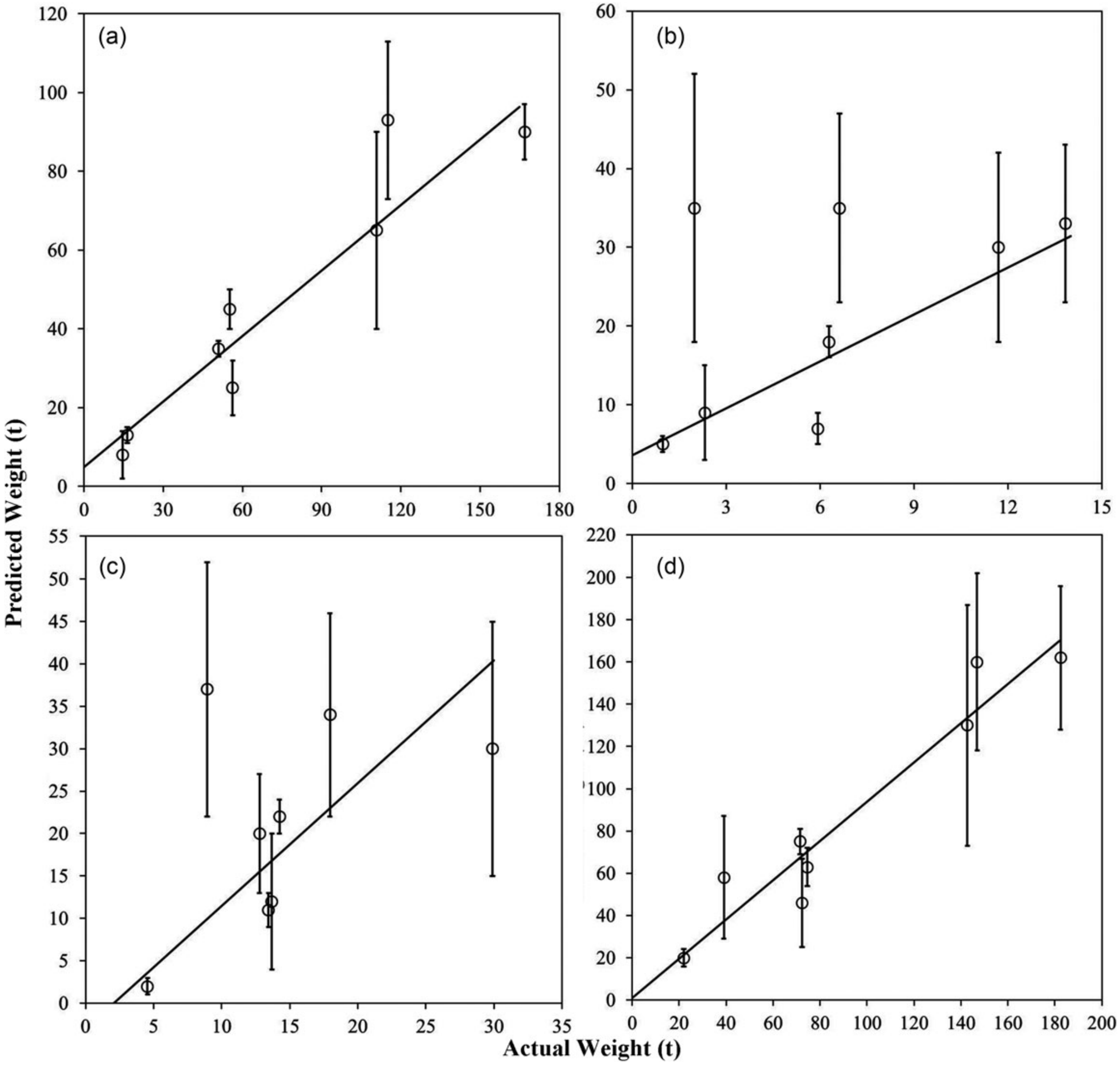

Figure 4. Relationships between the captain's predicted catch in weight and the actual catch in weight for (**a**) skipjack, (**b**) bigeye, (**c**) yellowfin, and (**d**) all species combined. Error bars generated from the estimates provided by the captain.

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