The cost of juvenile fishing: FADs management in the western and central Pacific Ocean tuna fishery

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NOTE: *This paper is only a draft. We are happy to receive comments: m.bailey@fisheries.ubc.ca*

Summary

Tuna fisheries in the western and central Pacific Ocean are important for both food and economic security globally. Yellowfin and bigeye tuna stocks are declining, in part due to the juvenile bycatch of these species by the purse seine fishery, often fishing on fish aggregating devices (FADs). There appears to be a conflict of interest between the longline fishery for these species, which targets adult fish, and the purse seine fishery, targeting skipjack, but catching juvenile yellowfin and bigeye. A third gear used in the region, handline, also fishes on FADs, but tends to be more selective in its catches, resulting in mostly adult fish. This paper develops an equilibrium model to determine if elimination of juvenile fishing might bring economic benefits to the region. Specifically, we model a two player cooperative game, evaluating the combined benefits of the purse seine and longline fisheries, and speculate on how this outcome could affect the domestic handline fishery in the Philippines. This is done for a multi-species fishery: skipjack, yellowfin and bigeye. Three management scenarios are run. Firstly, the status quo, which currently allows FAD fishing. Secondly, we model the potential profitability of a FAD regulation scheme, where the use of FADs is reduced. Thirdly, we totally eliminate the use of FAD fishing and juvenile bycatch, and estimate profitability. Our results suggest that, at equilibrium, the elimination of FAD fishing could result in increased benefits to the region of about US $180 million per year. In the long run, purse seine and longline fisheries both stand to benefit from such a management plan. Handliners currently fishing on FADs will be impacted by both positive and negative influences as the result of FAD elimination.

1 Introduction

The western and central Pacific Ocean (WCPO) is home to many species of commercially targeted fish, the most profitable of which are tuna. About 2.4 million tonnes of tuna were caught in the WCPO in 2007 (Williams and Reid 2007), accounting for about 54% of the world's tuna supply (Lawson 2008b). There are four main species found in the WCPO: albacore (*Thunnus alalunga*), skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*). The latter three species are often found in association with one another, especially around floating objects known as fish aggregating devices (FADs). This association leads to the bycatch of juvenile yellowfin and bigeye tuna in the purse seine fishery primarily targeting skipjack and adult yellowfin. The term bycatch has been defined several different ways (Hall 1996), but for the purposes of this paper, we consider bycatch to be any species caught, whether retained or not, that is not the main target of the fishery. The catching of juvenile fish of a target species can lead to both growth and recruitment overfishing, and can thus lead to a decline in the resource of interest (Gjertsen et al. 2010). In this context, bycatch of juvenile tuna in the fisheries of the WCPO has been discussed in recent stock assessment and technical reports (Langley et al. 2007; 2009; Williams and Reid 2007; Kumoru et al. 2009), and has been analyzed scientifically for at least one fleet, the Korean purse seine fleet (Moon et al. 2008). Purse seine bycatch is generally higher in the western part of the WCPO, such as in the waters around Philippines, Indonesia and Papua New Guinea, in an area known as the Coral Triangle[1]. As juvenile tuna grow, they tend to migrate east, resulting in smaller amounts of juvenile bycatch in the waters of the small Pacific Island states, and in the high seas. A recent study initiated in Papua New Guinea suggests that the mean size of bigeye tuna caught in the purse seine fishery has declined in recent years, with the majority of fish being between about 39 and 64 cm in length (Kumoru et al. 2009). The National Stock Assessment Program (NSAP) of the Philippines reports a size distribution of purse seine-caught yellowfin between 12 and 50 cm (NSAP, unpublished data.). Important to note is that bigeye and yellowfin mature at about 100 cm in length. If left in the ocean, yellowfin and bigeye can mature and spawn, supporting productivity of the stocks. Also, the adults could be targeted by longline and handline fishers, whose catch commands a much higher price than that paid for juvenile fish. There is thus a conflict of interest between purse seine fishers in the Coral Triangle and longline and handline fishers targeting adult yellowfin and bigeye. It is important to ask then, is there a cost to fishing juvenile tuna?

We address this question through the development of an equilibrium bioeconomic game-theoretic model simulating potential catches and values of the purse seine and longline fisheries in the WCPO resulting from three management scenarios: the status quo, a regulated FADs plan, and the total elimination of FADs fishing, and hence, no juvenile bycatch. In terms of catches, purse seine and longline represent the majority of reported biomass removals. The catch by large handline vessels in the Philippines averaged about 15,000 t per year between 2006 an 2008 (NSAP, unpublished data), which represents an almost negligible amount of the total tuna removals from the area[2]. Data for Indonesia are unavailable. As such, the model is driven by the profitability of the purse seine and longline fisheries, but we include possible affects on the handline fishery because of its importance to economic and food security in the Philippines and Indonesia.

We first introduce the reader to the relevant fisheries and management structures in the area, and follow this with the biological and economic model developed to run policy scenarios. In the results section, we present possible future catch and profit estimates for the fisheries, given the three management scenarios, and discuss possible implications of these in the concluding section.

1.1 Fishing gears and fisheries

Various gears are used to fish tuna in the WCPO. These include several artisanal gears, such as gillnet, hook and line and ring net, as well as commercial gears, including purse seine, longline and handline. In this paper, we are concerned with these three commercial fisheries. The purse seine fishery developed rapidly in the 1970s and 1980s. This was due to improved technology, as well as expanded foreign fleets from Korea, Japan and Taiwan. Furthermore, declining market demand for tuna caught in the eastern Pacific Ocean, where dolphin bycatch can be high, resulted in fleets moving to the western Pacific, where dolphin bycatch is not considered typical. Purse seine fleets target both skipjack and adult yellowfin, and they fish with or without FADs. The term FAD is a catch-all word that can mean simple floating objects, such as a log or a coconut, or it can mean a highly technical anchored device with sonar and satellite capabilities. FADs are used to exploit the fact that tuna and other pelagic fish naturally aggregate around floating objects in the open ocean. Smaller pelagic feed fish gather at the FAD (or are released at the FAD), which attracts skipjack schools, as well as juvenile yellowfin and bigeye. FADs reduce the fuel costs of fishing, which can be as high as 50% of operating costs[3]. In 2007, there were 1,400 active purse seine vessels in the WCPO tuna fishery. There is no regional estimate of the total number of FADs in operation. In the Philippines, it has been suggested that there are over 100 FADs in operation for *each* catcher vessel,[4] while Papua New Guinea has instituted a limit of 25 FADs per catcher vessel for any

[1] The Coral Triangle encompasses part or all of the waters in Philippines, Indonesia, Malaysia, Papua New Guinea, Solomon Islands and Timor Leste.

[2] The Philippines also has a small handline fleet which catches skipjack, as well as smaller-sized yellowfin and bigeye.

[3] Dexter Teng, TSP Industries, personal communication.

[4] Benjamin Tobias, Bureau of Fisheries and Aquatic Resources, Philippines, personal communication.

fleet operating in its waters.[5] The two principle canning destinations for purse seine-caught tuna are Bangkok, Thailand and Pago Pago, American Samoa (Reid et al. 2003). Philippines and Indonesia also have sizeable canning industries.

The longline fleet fishes in deep water, targeting both adult yellowfin and bigeye. There are currently 23 countries legally longlining in the WCPO, with a total of 4,869 active vessels engaged in the fishery in 2007 (Lawson 2008b). These vessels represent two categories of the fleet. The first, is the large distant water freezer vessels, generally greater than 250 gross registered tonnes (GRT), and taking voyages that can last months. The second category is the smaller, domestically-based vessels, which are most often less than 100 GRT. Longline catch is either destined for the sashimi market, where Japan essentially dominates (Reid et al. 2003), or is destined to become frozen steaks and loins. The longline catch has shifted from a majority yellowfin catch in the 1970s and early 1980s, to a majority bigeye catch in recent years (Williams and Reid 2007).

Handlining fleets vary in scale from very small vessels, able to fish only in municipal waters, to large operations that include a mother-boat carrying auxiliary vessels that heads out to fish on anchored FADs in deeper waters. Handliners in Indonesia and the Philippines often fish on FADs owned by purse seine companies. Handliners are allowed to fish on these FADs given that they respect the owners of the FAD, and their gear. Furthermore, allowing handliners to fish on FADs can give purse seine owners a good idea of the possible catch composition of the school aggregating around the device. Handline catch is not reported by the WCPFC, at least not as its own gear. It is presumably lumped into the "other" category. The large handliners of the Philippines catch virtually no skipjack. Eighty to ninety percent of the catch is yellowfin, and about 2-5 % is bigeye. In 2009, about 8,000 t of yellowfin and 300 t of bigeye was caught by the large handline vessels. Yellowfin caught by the large Philippine handliners range in size from about 90 to 140 cm, meaning that they are almost all mature individuals (NSAP, unpublished data). There is also a smaller handline fleet, which generally targets smaller tunas, as well as other pelagic fish, opportunistically.

In this paper, we focus on three species of tuna targeted in the WCPO, namely, skipjack, yellowfin and bigeye. For each of these species, we will briefly review the stock status, fishing gears used, and markets supplied.

1.1.1 Skipjack

The skipjack stock in the area is thought to be at a sustainable level (Langley and Hampton 2008). Skipjack are fished with several commercial gear types, including purse seine, handline, pole-and-line, and also with artisanal gears such as gillnet, hook and line, and ring net (Hampton 2002b). The majority of skipjack catch is by purse seiners. The biomass trends tend to be driven by recruitment, with more recent years (1985-2001) being characterized by high recruitment, thus allowing for high catches (Langley and Hampton 2008). However, Hampton (2002b) warns that, should a period of low recruitment occur, skipjack catch would have to decrease substantially. The 2008 assessment indicates that fishing mortality appears to be the highest in the western regions in the most recent years (Langley and Hampton 2008), having reduced recent biomass by about 40%. Skipjack are primarily sent to canneries (exported to Thailand, or processed directly in Philippines or Indonesia), where bycatch of other juvenile tuna species is usually purchased at the same price. In addition to the skipjack canned market, there is a domestic market in countries such as Indonesia and the Philippines for whole fish that are often smoked. In 2007, an estimated 1.46 million tonnes of skipjack were caught by purse seines (Lawson 2008b).

1.1.2 Yellowfin

The WCPO yellowfin tuna stock is now believed to be fully exploited (Langley et al. 2007). Yellowfin biomass declined in the 1990s, primarily due to lower average recruitment in those years, as well as high

[5] Sylvester Pokajam, Director, National Fisheries Authority, Papua New Guinea personal communication.

fishing mortality (Hampton 2002c). Hampton (2002c) states that there has been a significant depletion of some of the sub-populations in the WCPO due to fishing "by the domestic fisheries of the Philippines and Indonesia and the combined purse seine fishery". Yellowfin mature at about one year, however, Langley et al. (2007) report that juvenile yellowfin are encountered in commercial fisheries in the Philippines and Eastern Indonesia when they are a few months old. Generally, purse seiners catch a wide age range of yellowfin tuna, whereas longliners tend to take mostly adult fish (Langley et al. 2007). The longline yellowfin catch in 2007 was estimated at about 70,000 t, while purse seine catch was about 233,000 t (Lawson 2008b).

1.1.3 Bigeye

By 1970, bigeye biomass had decreased to about half of its initial biomass, and has declined an additional 20% in the last decade (Langley et al. 2009). A reduction in longline fishing mortality may be necessary to help move the stock out of its current state of being 'overfished' (Langley et al. 2009). Adult bigeye are targeted by longliners from both distant water fishing states (DWFS) as well as Pacific Island states (PIS). Of all tropical tunas, bigeye commands the highest price in the sashimi market (Langley et al. 2009). As illustrated in Figure 1, there has been a rapid increase in purse seine catches of juvenile bigeye since the early 1990s (Langley et al. 2009). Furthermore, it has been suggested that purse seine catches are significantly underestimated (Lawson 2008a) as bigeye is often classified as yellowfin in its juvenile years (Lawson 2007). Recently, reported catches have been adjusted to account for this misidentification (Williams and Reid 2007). However, data were not available for the domestic fleets of Indonesia and the Philippines (Lawson 2007), and therefore, whatever adjustments have been incorporated disregard the importance of the catches from these two countries. Bigeye purse seine catch is almost exclusively juveniles, and it is thought that this catch has increased in part because of the increased use of FADs (Hampton 2002a; Langley et al. 2009). In the Eastern Pacific Ocean, juvenile bigeye tuna is thought be one of the most non-sustainable bycatches (Archer 2005). The estimated 2007 longline catch of bigeye in the WCPO was about 78,000 t (Lawson 2008b). The 2007 purse seine catch, estimated as 39,000 t, is the highest annual catch since statistics began being compiled in 1960 (Lawson 2008b). In 2007 the landed value of bigeye tuna from the statistical area of the Secretariat for the Pacific Community (which does not include catch from Indonesia and Philippines) was approximately US$ 504 million (Williams and Reid 2007).

1.2 Management

The tuna fisheries in the WCPO are managed by the Western and Central Pacific Fisheries Commission (WCPFC), which is the regional fisheries management organization (RFMO) in the area (Figure 2). The WCPFC has 27 participating members, including large domestic countries (Indonesia, Philippines, Japan, Korea), PIS (such as Kiribati, Vanuatu) and DWFS, such as the United States, who, through bilateral or multilateral agreements, have access to fish in the exclusive economic zones (EEZ) of countries in the WCPO. Several of the domestic countries also have distant water fishing fleets, such as Japan and the Philippines, that fish in the waters of other member countries (i.e., Papua New Guinea). The Commission, established under the Convention on the Conservation and Management of the Highly Migratory Fish Stocks of the Western and Central Pacific Ocean in 2000, is currently faced with the challenge of managing declining tuna stocks in the area, namely, yellowfin and bigeye. The most recent stock assessments have suggested this decline is a result, in part, of the bycatch of juveniles in the purse seine fishery. Reduction in juvenile and adult fishing mortalities on both stocks would likely result in decreased economic benefits to both fisheries, at least in the short-term, especially those operating in the Coral Triangle countries, where it appears the bycatch is highest. It is estimated that over 150 million people live in the Coral Triangle, and that about 2.25 million fishers depend on marine resources for their livelihood (The Nature Conservancy 2004). It is therefore important to create sustainable fisheries management regimes in an effort to provide the population with continued benefits from tuna fisheries.

This issue of juvenile mortality in the WCPO has been explored before. In a paper maximizing

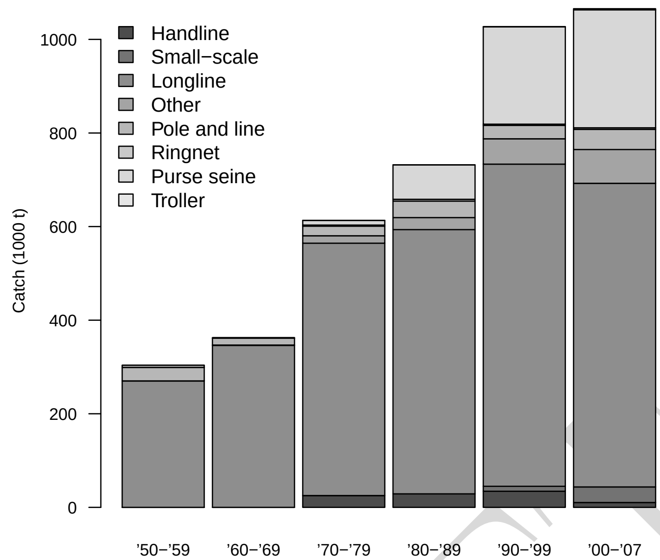

Figure 1: Total bigeye catch by decade and gear, compiled from Lawson (2008b).

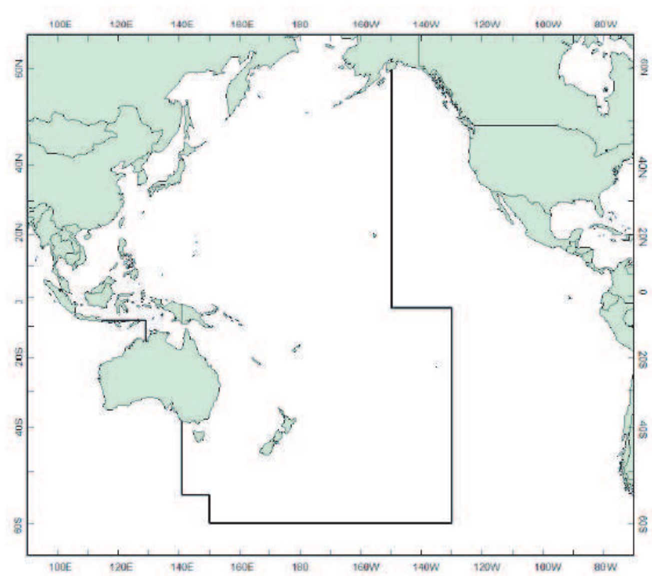

Figure 2: WCPFC convention area.

economic efficiency of tuna fisheries in the WCPO, Bertignac et al. (2000) concluded that shifting the fisheries from younger to older fish would improve efficiency. This work, however, notes its limitations in modeling bigeye bycatch in the purse seine fishery due to data deficiencies (Bertignac et al. 2000). Their study estimated that a reduction in effort to about 50% of the 1996 levels would maximize rent generated in the area of the Forum Fisheries Agency (a sub-section of the WCPO). Of course effort has not been reduced over the past decade, but has increased rather (Williams and Reid 2007). Of particular interest in the Bertignac et al. (2000) study is the conclusion that a substantial reduction in purse seine effort is required to maximize joint profit because of the high level of juvenile bycatch, which reduces recruitment of yellowfin and bigeye to their respective adult stocks.

1.3 Preliminaries on game theory

Game theory is a tool for explaining and analyzing problems of strategic interaction (Eatwell et al. 1989). Essentially, it uses mathematics to describe player strategies in sources of conflict (Luce and Raiffa 1957). The theory has been applied to political science, evolutionary biology, military strategies, economics (including natural resource economics), and computer science (Eatwell et al. 1989). Game theory is particularly applicable to the study of fisheries management, as many of the world's fisheries are common pool in nature (Sumaila 1999), thus having more than one interested user. Fisheries also exhibit dynamic externality (Levhari and Mirman 1980), that is, the underlying stock is affected by all players' decisions, and each player must take into account the other players' actions.

Generally speaking, most game-theoretic analyses have focused on addressing the difference in benefits derived from non-cooperative and cooperative management. It is almost always the case that, in fisheries management, the benefits from cooperation are higher than those from non-cooperation (Bailey et al. 2010). Cooperative games occur when players are able to discuss and agree upon a joint plan (they can communicate), and that the agreement is 'assumed to be enforceable', or binding (Nash 1953). It thus follows that non-cooperative games are those in which agreements are non-existent and/or non-binding, and where parties cannot communicate (Nash 1951). For a recent review of game theory applied to fisheries, see Bailey et al. (2010).

Games are structured around players, the constraints they face, the information sets they possess, and the possible outcomes players expect. Players are assumed to be individually rational, that is, they want to maximize their discounted profit through time, and will choose the strategy that does this. Furthermore, a player will only agree to cooperate if the payoff through cooperation is at least equal to the payoff they would expect from non-cooperation. In this paper, we formulate a three-player game, partitioned by gear type: purse seine, longline, and handline. Purse seine fisheries target skipjack and adult yellowfin, but have significant bycatch of juvenile yellowfin and bigeye. Longline and handline fisheries target adult yellowfin and bigeye. Dynamic externality therefore exists, as the juvenile mortality by purse seiners affects the biomass available to the longline and handline fisheries, and the longline and handline catch of adult fish affects what the purse seine fishers can catch. Players are asymmetric in several ways. The costs of fishing differ, as do the prices the players command for their products. Furthermore, the gears impart different fishing mortalities on the stocks, through differing selectivity.

2 Model

We have developed a multi-species, multi-gear bioeconomic game-theoretic model to address this issue of tradeoffs in fishing effort and economic benefits between purse seine fishers targeting skipjack and adult yellowfin primarily, and longline and handline fishers targeting adult yellowfin and bigeye. We are interested in knowing the optimal fishing effort each player (gear) will choose in order to maximize the overall, or joint, profit from the resource. All model equations can be found in the appendix.

2.1 Population dynamics

The population model used here was developed in Botsford and Wickham (1979) and Botsford (1981a;b), and is summarized in Walters and Martell (2004). A yield per recruit model, which considers growth and

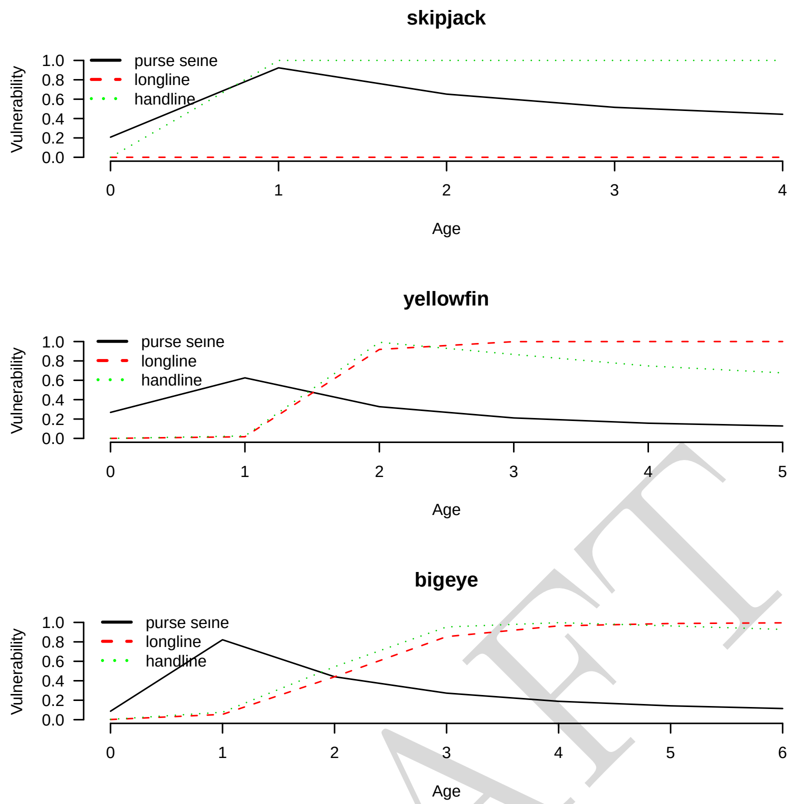

Figure 3: Vulnerability to gears at age for three tuna species.

mortality, is combined with a stock-recruitment model incorporating density dependent population effects.

Recruitment of the three fish stocks is assumed to be of the Beverton and Holt (Beverton and Holt 1957) form (Langley et al. 2007; 2009; Langley and Hampton 2008). Lengths and weights are assumed to follow von Bertalanffy growth equations. Survivorship to age, which is the probability of an individual surviving to age a, is assumed to be dependent on additive mortality, that is the summation of natural and fishing mortality. Estimates of natural mortality are strongly age-specific, with higher rates estimated for younger fish, often referred to as Lorenzen (1996) mortality. Vulnerability at age is assumed to be dome-shaped (Thompson 1994) for the purse seine fishery, and logistic for the longline and handline fisheries (Figure 3), and is based on the length at which 50% of the population is fully vulnerable to a given gear. Catchability is gear-specific. The reader is referred to Tables A1 and A2 for biological variables and equations used.

2.2 Simulations

Where possible, biological parameters were taken from the stock assessment documents of the relevant species. These values were used for the empirical simulations (for example, Langley and Hampton (2008); Langley et al. (2007; 2009)). Biological information for all three species is also reviewed in Molony (2008), and this paper was helpful in parameterizing the model. As stated in Reid et al. (2003), there is high variability in ex-vessel prices for tuna. Furthermore, the cost estimates we used are averages over several different fleets (for example, both domestic and foreign purse seine fleets). As such, although the direction of simulation outcomes would most likely not change as a result of price fluctuations and disaggregation of costs, the magnitude may differ. Simulation results are thus illustrative only. The model appears to be quite sensitive to input parameter estimates. Confidence in these estimates should be high. Therefore, discussions with experts in the area who may be able to help with data sources or provide better estimates is an important next step. Cost data for the purse seine and the longline fisheries were taken from Reid et al. (2003), however these cost estimates are probably quite dated. Fixed prices were given by J. Ingles, personal communication.

In running simulations, we assume three possible scenarios. The first scenario assumes that fishing on FADs is allowed - essentially the status quo. In the second scenario, fishing on FADs is reduced, mimicking a potential management plan that limits the number of FADs used. The third scenario assumes that fishing on FADs is not allowed. Scenarios two and three modify the vulnerability of yellowfin and bigeye juveniles to the purse seine gear. For these three scenarios, we are interested in the equilibrium catch and profit received by each gear type.

2.2.1 Data adjustments

To simulate a scenario where there is reduced, or no, fishing on FADs, we can change the length at which 50% of the population is vulnerable to the purse seine gear (lh). By changing these lengths to larger sizes, we force the system to not allow fishing on juvenile fish, which is what we would assume to see if fishing on FADs was not allowed. For scenario two (reduced FADs use), we assume $lh = 60$ cm for both yellowfin and bigeye. For scenario three (no FADs fishing), we assume $lh = 80$ cm for yellowfin, thus allowing some adult yellowfin catch, but we do not allow the bigeye population to be vulnerable to purse seining at all. Furthermore, to simulate the increased fuel costs when not using FADs, the cost of purse seining was increased by 10% and 20% for scenarios two and three, respectively. We also assumed that, because the landed yellowfin would now be all adult-sized, the average ex-vessel price was increased by 15% and 30% respectively, for scenarios two and three.[6]

3 Results

3.1 Status quo

The status quo simulations are run assuming that purse seining on FADs occurs, and there is thus juvenile bycatch of both yellowfin and bigeye in the purse seine fishery. Figure 4(a) shows a contour plot of the estimated joint profit potential at various combinations of purse seine and longline effort. A profit estimate for each fleet is calculated for every possible combination of fishing effort. The highest possible equilibrium profit potential for the system occurs at a combination of 46,000 purse seine fishing days, and about 30 million hooks set in the longline fishery. This equilibrium profit estimate is about US $1.17 billion. Figure 4b shows how, as purse seine effort increases, the profit potential of the longline fishery is substantially reduced. At equilibrium, the maximum profitability is attained at catches of 1.26 million t and 136,000 t, for the purse seine and longline fleet, respectively (Table 1).

3.2 Reduction in FADs fishing

Our second simulation assumes that the use of FADs is reduced through some sort of management regulation. For this simulation, maximum profitability is slightly higher than the status quo (by about US $77 million), estimated to be about US $1.24 billion. This maximum is reached with a purse seine effort of 44,000 vessel days, and a longline effort of 28 million hooks set. We actually see an overall net loss to longliners in this scenario (see Table 1). This result needs further investigation. Equilibrium catches for the purse seine and longline fleets are estimated at 1.27 million and 126,000 t, respectively (Table 1).

[6] Reid et al. (2003) explain that there is a size premium paid for larger fish; with fish weighing more than 7.5 kg receiving higher ex-vessel prices.

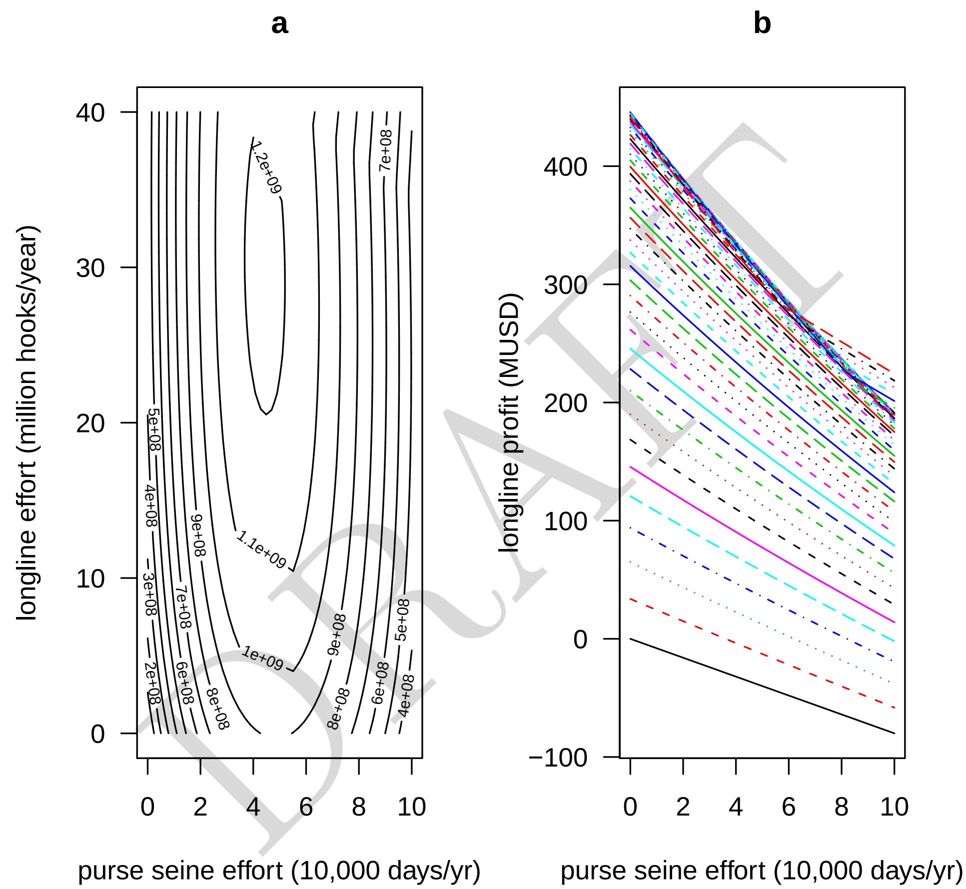

Figure 4: (a) Joint profitability potential at various combinations of purse seine and longline effort. (b) Longline profit potential as a function of purse seine fishing effort. From bottom to top, lines represent profit potential with increasing longline effort.

Table 1: Scenario results

		Status quo (FADs)			Reduced FADs			No FADs		
		PS	LL	Tot	PS	LL	Tot	PS	LL	Tot
Catch (1000 t)	SJ	1138	0	1138	1109	0	1109	1109	0 1109	
	YF	118	101	219	150	92	242	156	102	258
	BE	7	35	42	8	34	42	0	52 52	
	Tot	1263	136	1399	1267	126	1393	1265	154	1419
Revenue (M USD)	1701	0	1701	1663	0	1663	1663	0	1663	
	YF	168	252	420	259	231	490	304	253	557
	BE	10	106	116	12	102	114	0	156	156
	Tot	1879	358	2237	1934	333	2267	1967	409 2376	
Effort*		46	30		44	28		44	29.6	
Cost (M USD)		1012	59	1071	968	56	1024	968	59	1027
Net profit (M USD)		867	299	**1167**	966	277	**1243**	999	350	**1349**

PS = purse seine, LL = longline, Tot = total, SJ = skipjack, YF = yellowfin, BE = bigeye
*Purse seine effort: 10,000 fishing days/year, longline effort: million hooks set/year

3.3 No FADs fishing

The third scenario assumes that fishing on FADs no longer occurs, and thus, there is no juvenile bycatch of yellowfin or bigeye tuna. This scenario results in the highest equilibrium profit potential, an estimated US $1.35 billion. Interesting, this scenario results in increased profit to both the longline and purse seine fisheries. This is probably due to the fact that there is more yellowfin biomass available for the purse seine fishery when only adult fish are caught. Further to this, however, is our assumption of a price premium paid for adult fish. The equilibrium effort in this scenario is 44,000 purse seine vessel days, and about 30 million hooks set in the longline fishery. In all three scenarios, profit is maximized at about this same effort combination. With no FADs fishing, equilibrium purse seine catch is about 1.3 million t, while longline catch is about 154,000 t. Results from the three scenarios are summarized in Table 1. The difference between the status quo and the no FADs scenarios, is about US $180 million.

3.4 Handline

Modeling how a reduction in FADs may affect handliners in Indonesia and the Philippines is difficult. Firstly, data regarding catchabilities and selectivities are limited. We know that the large handline fleet catches almost exclusively adult fish (at least in the Philippines), so we would assume that a reduction in juvenile bycatch would have a positive impact on the handline profit, such as it does for the longline fleet. However, handline catchability and profitability seems to be influenced by the use of FADs. Catchability is increased because the adult fish are attracted to the FAD, so that a unit of effort on a FAD will yield a higher catch than a unit of effort on an unassociated school. Profitability is increased through the cost function, in that fuel costs are reduced by fishing on FADs. Therefore, the reduction or elimination of FADs in WCPO waters would result in opposite influences through the biology, acting to increase the stock size, and thus yield, and through the economics, by decreasing catchability and increasing costs. However, this could also be countered by the fact that the handline fishery would presumably be catching larger fish, which may end up commanding a higher ex-vessel price. In the Philippines, there are several different types of handliners, ranging in size from 1.5 to 27 gross tonnes. NSAP collects data on the average number of trips per year for each type of vessel. They estimate about 1,100 handline boats operating (in 2008), taking a combined 9,625 trips per year (NSAP, unpublished data). Trips can vary from a day or two for the smaller vessels, up to a month for the larger mother boat operations. Data from the Philippines suggests that the average cost per trip for handliners is about US $2,200 (NSAP, unpublished data).

A back of the envelop calculation with the data provided by NSAP suggests a profitability for the handline fishery of about US $23 million, summed over all vessel sizes. This is under the assumption that the total handline catch as reported for each vessel class, is composed of 95% adult yellowfin, and 5% adult bigeye tuna. Furthermore, we assume that handline-caught tuna commands a similar ex-vessel price to that taken by longline-caught tuna. It is usually the larger vessels that head out to fish on the

Table 2: Handline profitability

Size (GT)	YF catch (t)	BE catch (t)	Effort	Cost per trip (USD)	Net benefit (M USD)
1.5	627	33	3300	44	1.19
3	334	17.6	880	55	0.66
5	334	17.6	440	165	0.64
7	1755	92.4	1155	275	3.42
15	4389	231	1925	1100	7.24
21	3291	173	1155	2200	4.48
27	3291	173	770	2200	5.32

YF = yellowfin, BE = bigeye. Source: NSAP, unpublished data.

large purse seiner-owned FADs. Therefore, a FADs management plan would most likely have a larger impact on this fleet. However, if the loss in catch numbers is offset by the increase in weight of individual fish (due to the decrease in juvenile fishing), or if the increased cost of not fishing on FADs (through increased fuel use) is offset by an increase in profit due to the larger-weighted individuals, the short term impact to the handline fishery may not be too drastic. More work needs to be done here to identify what quantitative improvements in catchability and unit cost are gained by fishing on FADs. Through this understanding, we can start to identify possible impacts that FADs management will have on these fleets.

As stated above, currently, the handline fishery had a net profit of about US $23 million. If we compare this to the status quo simulation results of US $870 and US $300 earned by the purse seine and longline fisheries, respectively, we can easily see why smaller domestic fleets are often not invited to the negotiating table.

4 Conclusion

Tuna fisheries in the WCPO are highly profitable, but evidence suggests that at least two of the targeted species, namely, yellowfin and bigeye, may be fully exploited or overfished (Langley et al. 2007; 2009). The goal of the WCPFC is to try to manage tuna (and other) stocks in the WCPO in a sustainable way, so the Commission is currently facing some tough management decisions regarding the potential for tuna fisheries in the area to continue providing benefits to the region. The conflict between purse seine fisheries catching juvenile yellowfin and bigeye tuna, and longline fishers targeting adults of these species, is only one important challenge to address, but it has been raised numerous times in WCPFC technical reports (Langley et al. 2009; Williams and Reid 2007; Itano 2009; Kumoru et al. 2009).

The potential of the longline fishery to bring continued benefits may rest on an effective decrease in juvenile fishing by purse seiners. Contrary to our hypothesis, however, this may not entail costs (at equilibrium) to the purse seine fishery. Our results suggest that, at equilibrium, both the purse seine and longline sectors could gain overall benefits if FAD fishing was to be eliminated. Interestingly, measures regulating the use of FADs may, in fact, not bring significant benefits to the system. Rather, the entire removal of FAD fishing seems to yield the highest benefits. Gjertsen et al. (2010) discuses several types of economic incentives for reducing bycatch, including market-based, rights-based, and top-down incentives such as taxes and subsidies. With specific reference to the Eastern Pacific Ocean (EPO), the authors suggest that assigning property rights to set on floating objects, perhaps through a spatial management plan might help to control the use of FADs (Gjertsen et al. 2010). In fact, the WCPFC could probably adopt several management measures that the Inter-American Tropical Tuna Association (IATTC), responsible for management of tuna in the EPO, has considered or implemented. For example, size limits on catch retention might help to decrease the occurrence of juvenile fish, if, for example, a type of quota on bycatch is implemented. There are obvious challenges to implementing management measures in the WCPO tuna fisheries, but perhaps, through an adaptive management type of approach, those challenges can be addressed when encountered.

The handline fishery in the Philippines and Indonesia is an important part of their tuna fisheries sectors. The Philippines' effort to collect and report catch and effort data on this fishery may help to increase its presence in WCPFC management decisions. Similar data from Indonesia could only help this case. In the Philippines, the large handline fishery is currently worth about US $23 million. From the perspective of Indonesia and the Philippines, it is quite important to include the possible impacts that any type of FAD management plan may have on this sector. Regardless of the management measures or tools used, it does seem that both biological and economic benefits could be realized by reducing or eliminating the bycatch of juvenile yellowfin and bigeye in the western and central Pacific Ocean.

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5 Appendix

The biological and economic equations used in this paper are summarized here.

Table A1. Variable definitions

i	gear type
f	fish stock
L_a	length at age
L_{inf}	mean asymptotic length
w_a	weight at age
w_{mat}	weight at maturity
v_a	vulnerability at age
lh	length at 50% vulnerability
sd	standard deviation
M_a	mortality at age
z_a	total mortality (natural plus fishing)
Fec_a	fecundity at age
Lx_a	unfished survivorship at age
Lz_a	fished survivorship at age
R	recruits
a, b	recruitment parameters
vbk	von Bertalanffy metabolic coefficient
$recK$	Goodyear compensation ratio
ϕ_{VB}	per recruit vulnerable biomass
ϕ_B	per recruit biomass
ϕ_E	per recruit egg production (unfished)
ϕ_h	per recruit egg production (fished)
h_{eq}	per recruit yield
q	catchability coefficient
y	total yield
p	ex-vessel price
c	unit cost of effort
TR	total revenue
TC	total cost
F	fishing effort
π	profit

Table A2. Biological equations

Age-schedule information

$$L_a = L_{inf}(1 - e^{-(vbk)a}) \tag{1}$$

$$w_a^f = aL_a^b \tag{2}$$

$$v_a^{i,f} = \left[\frac{1}{1 + e^{-sd_1^{-1}(L_a^{i,f} - lh_{\omega 1}^{i,f})}}\right]\left[\frac{1}{1 + e^{sd_2^{-1}(lh_a^{i,f} - L_{\omega 2)}^{i,f}}}\right] \tag{3}$$

$$v_a^{i,f} = \left[\frac{1}{1 + e^{-sd_1^{-1}(L_a^{i,f} - lh_{\omega 1}^{i,f})}}\right] \tag{4}$$

$$M_a^f = M_{adult}^f \left(\frac{L_{inf}^f}{L_a^f}\right) \tag{5}$$

$$z_a = M_a + F^{i,f} q^{i,f} v_a \tag{6}$$

$$Fec_a = w_a - w_{mat}, \quad Fec_a \geq 0 \tag{7}$$

Survivorship

$$Lx_a^f = Lx_{a-1} * e^{-M_a}, \quad \text{given} \quad Lx_0 = 1 \quad \forall f, \quad 0 < a < A \tag{8}$$

$$Lx_A = Lx_A/(1 - e^{-M_a}), \quad a = A \tag{9}$$

$$Lz_a^f = Lz_{a-1} * e^{-z_a^i}, \quad \text{given} \quad Lz_0 = 1 \quad \forall f, \quad 0 < a < A \tag{10}$$

$$Lz_A = Lz_A/(1 - e^{-z_a^i}), \quad a = A \tag{11}$$

Equilibrium calculations

$$R^f = \frac{a^f \Phi_h^f - 1}{b^f \Phi_h^f}, \quad R^f \geq 0 \tag{12}$$

$$\Phi_E^f = \sum_a^A Lx_a^f Fec_a^f \tag{13}$$

$$\Phi_h^f = \sum_a^A Lz_a^f Fec_a^f \tag{14}$$

$$\Phi_B^f = R_{eq}^f Lx_a^f \sum_a^A w_a^f \tag{15}$$

$$\Phi_{VB}^{i,f} = \sum_a^A q^{i,f} v_a^{i,f} \frac{Lz_a w_a^f}{z_a^f(1 - e^{-z_a^f})} \tag{16}$$

$$h_{eq}^{i,f} = R^f \Phi_{VB}^{i,f} F^{f,i} \tag{17}$$

Table A3. Economic equations

Cost and revenue

$$TR^i = \sum_f y^{i,f} p^{i,f} \tag{18}$$

$$TC^{i,f} = c^{i,f} F^{i,f} \tag{19}$$

Profit and objective

$$\pi^i = \sum_f TR^{i,f} - TC^{i,f} \tag{20}$$

$$\max \Pi = \sum_i \sum_f TR^{i,f} - TC^{i,f} \tag{21}$$

$$\tag{22}$$