ISC/20/ALBWG-01/05

Relationship between the effort of longline and surface fleets in the North Pacific and Albacore Fishing Mortality

Desiree Tommasi[1,2], Steven L. H. Teo[2]

[1]University of California Santa Cruz, Institute of Ocean Sciences
[2]NOAA Fisheries, Southwest Fisheries Science Center
8901 La Jolla shores Drive
La Jolla, CA, 92037, USA

Email: desiree.tommasi@noaa.gov

This working paper was submitted to the ISC Albacore Working Group Stock Assessment Workshop, 6-15 April 2020 held by webinar.

Abstract
In the first round of the North Pacific Albacore (NPALB) Management Strategy Evaluation (MSE), effort was not modeled explicitly as the number of hooks, fishing days, or vessels. It was modeled as fishing intensity. One of the recommendations from managers and stakeholders following presentation of the first round of MSE results during the 4th NPALB MSE Workshop was that the relationship between how effort is modelled in the MSE operating models and effort in the real world should be examined by the ALBWG and included in the future round of MSE to help managers and stakeholders, if possible. To that end, members of the ALBWG compiled effort data from their respective country on number of vessels, number of hooks (for longline vessels) or number of fishing days (for surface fleets). Here we show temporal trends in the effort data and assess if fishing mortality as estimated by the base case operating model is correlated with changes in effort. Japanese effort, both for the longline and surface fleet, has decline from 1993 to present. Effort of the U.S. and Canadian surface fleet has remained relatively stable. Chinese Taipei's longline effort has been relatively stable since the mid-2000s. U.S. longline effort, Korean longline effort, Vanuatu longline effort, and China's longline effort (numbers of hooks, quarter 1) have increased from 1993 to present. However, albacore fishing mortality showed an increasing trend only for the Japanese surface fleet in the northern area April-June and for the Japanese longline fleet operating in Area 2. Longline effort was often found not to be representative of albacore fishing mortality, possibly because many longline vessels are not targeting albacore. Implications of these results for the second round of NPALB MSE are also discussed and a workplan for the second round of NPALB MSE is presented.

Introduction

North Pacific albacore (NPALB) is a highly migratory species whose habitat spans the entire North Pacific. Adult fish inhabit subtropical and tropical waters in the Central to Western Pacific, with spawning peaking in March and April in the Western Pacific (Chen et al. 2010) and in the summer in the central Pacific (Otsu and Uchida 1959). Little is known about movement of juvenile fish during their first year of life but it is postulated that juveniles make their way northward from the spawning grounds to the Kuroshio Current and that a fraction of them follows the transition zone to make a trans-Pacific migration to the productive waters of the west coast of North America to feed in summer and fall (Ichinokawa et al. 2008, Childers et al. 2011). These juveniles (largely 2-5 years old) move back to the central Pacific every late fall and winter following suitable thermal habitat, and back to the coast again when temperature warm in summer (Childers et al. 2011, Snyder 2016). Once mature, they move to southern more tropical waters in the Central and Western North Pacific to spawn (Ichinokawa et al. 2008).

Such movement patterns affect availability of albacore to different fisheries operating in the different regions of the North Pacific. Two main gear types are employed to catch albacore in North Pacific: surface (troll and pole-and-line) and longline. From 1993-2015 surface fleets have caught approximately 53% of the total NPALB catch and have targeted smaller, juvenile albacore (ISC 2017). The surface fleet consists of the USA and Canada troll and pole-and-line, and the Japanese pole-and-line. The USA and Canadian fleets operate in summer and fall, with most of the catches occurring July-September when juvenile albacore move towards the coast and become available to the fleet (Childers et al. 2011). Japanese pole-and-line operations are concentrated north of 30^{o}N, mostly in the eastern Pacific, and, in addition to albacore, also target skipjack (Kiyofuji 2013). They include an offshore fleet with relatively smaller boats which fishes albacore April to July, and a distant water fleet that travels further, stays out months at a time, and operates April to November (Kiyofuji 2013).

Longline vessels generally operate further south than the surface fleet and catch larger fish (ISC 2017). Most of the longline albacore catch is from Japan, USA, Chinese-Taipei, and more recently China and Vanuatu (ISC 2017). Japanese longline operations changed their spatial footprint in the 1990s, moving to more southern latitudes (10-35^{o}N) in 1993 (Ijima and Satoh 2014). In addition to these offshore and distant water fleets targeting bigeye and catching larger, adult fish, there exists a Japanese longline coastal fleet that targets juvenile albacore near southern coastal Japan (Ijima and Satoh 2014). By contrast, no longline vessel from the USA targets albacore directly. The USA shallow-set longline operates in the northern central/eastern Pacific and targets swordfish, but also catches juvenile and subadult albacore (Teo 2017). Operations of the USA shallow set longlines were suspended 2001-2004 due to turtle interactions and then severely limited following 2004 (Teo 2017). The USA deep-set longline vessels target bigeye, and at times also catch adult albacore (Teo 2017). The deep-set fleet moves around seasonally starting in January to March in southern waters (0-30^{o}N) west of 150^{o}W, then gradually moving north of 30^{o}N and eastward of 150^{o}W in summer (Woodworth-Jefcoats et al. 2018). In October-December operations move back south closer to the Hawaiian Islands (Woodworth-Jefcoats et al. 2018). In 1995-2015, there was an expansion of the fishery in the northeast region in July-September (Woodworth-Jefcoats et al. 2018). This shifted the seasonality of the fleet from October to March to July-December (Woodworth-Jefcoats et al. 2018). With effort moving away from the southern areas, the contribution of albacore to the total catch dropped dramatically (Woodworth-Jefcoats et al. 2018). Chinese-Taipei longline operations initially targeted albacore and were focused in subtropical waters (Chen and Cheng 2016). Operations then expanded to tropical waters starting in 2000 and catches of albacore decreased as yellowfin and bigeye became target species (Chen and Cheng 2016).

The widespread nature of this stock and the large number of nations involved in its fisheries requires international cooperation via regional fishery management bodies, the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter American Tropical Tuna commission (IATTC), for effective management. To refine the interim harvest strategy currently in place for NPALB and adopt a target reference point (TRP), the WCPFC and IATTC endorsed development of an MSE (WCPFC 2017). The harvest control rules (HCRs) evaluated in the first round of the MSE impose reductions in fishing mortality once specific biomass thresholds (i.e. reference points) are crossed and aim to maintain fishing mortality at a pre-defined target level.

Controls on fishing mortality are achieved through the setting of a total allowable effort cap (TAE) or a total allowable catch (TAC) every three years, following the assessment cycle for NPALB. In the first round of MSE, TAE appeared to perform better as it was able to respond faster to changes in biomass between assessment periods (ISC 2019).

However, simulation of effort control in the MSE framework was greatly simplified. Effort was modeled as a fishing mortality for the overall NPALB fleet, rather than the number of vessels or number of fishing days specific to each country and gear-type as it would likely be enforced in the real world. Realism of the effectiveness of the simulated effort control relies on a linear relationship between real-world effort and fishing mortality (i.e. that a specified decline in fishing mortality can be scaled to a decline in effort in terms, for instance, of fishing days). Given, as discussed above, that many vessels catching NPALB are not targeting albacore directly, and that catchability may be affected by environmentally driven changes in fish movement, this assumption needs to be examined. Here we compare observed levels of effort in fishing days (surface fleets), number of hooks (longline), or number of vessels (both) to assess if there is a relationship between effort as measured in the real world and effort in the simulated world in the form of fishing mortality.

Methods

Fleet-specific Fishing Mortalities

In each HCR fishing mortality is characterized as a fishing intensity. Fishing intensity is defined as 1-SPR, where SPR is the spawning potential ratio, or the spawning stock biomass (SSB) per recruit relative to the unfished population. For instance, F40 represents a fishing intensity that leads to a SSB per recruit that fluctuates around 40% of the unfished (i.e., removing about 60% of the SSB). This overall fishing intensity on the stock is a function of the fishing mortalities imposed by each of the fleets in the MSE operating model, developed with the Stock Synthesis version 3 (SS3) software (Methot and Wetzel 2013). Here, the fishing mortality for each fleet was the seasonal, fully selected F multiplier extracted from the Report file of the base case MSE operating model. See ISC (2019) for a detailed description of the operating model structure. SS3 estimates fully selected fleet-specific fishing mortalities each year and season given the selectivity of each fleet, natural mortality, and numbers at age so that the observed catches are matched. As an example, we show in Fig. 1 how total catches for season 3 for the Eastern Pacific Ocean (EPO) surface fleet computed outside of the SS3 model as

$$C_y = \text{sum across ages } (F_{fsy} * / Z_{ya} * S_{fsya} * N_{sya} * (1\text{-exp}(-0.25*Z_{ya}))$$

where y is year, f is fleet, s is season, a is age, F is the fully selected fishing mortality, S is the age selectivity, N is the numbers at age, and Z is the mortality, corresponds to the retained catch estimated within the SS3 operating model. While not explicitly being a function of effort and catchability, the fully selected fishing mortality implicitly reflects changes in those quantities. To account for changes in availability to the EPO fleet resulting from variability in juvenile migration patterns, age selectivity of the EPO fleet for ages 1 to 4 was time-varying in the MSE operating model. EPO age selectivities varied each year based on estimated random deviations. For this fleet, therefore, between-year changes in effort would not only be reflected in the fully selected fishing mortalities but also in the age selectivity. Therefore, effort for this fleet was correlated to the product of the fully selected EPO fishing mortality and age selectivity. We refer to this product as the fishing mortality for the EPO fleet. Fishing mortalities for the other fleets are only a function of the fully selected fishing mortality.

Effort

Effort data for the fleets represented in the MSE operating model were obtained from members of the ALBWG, with the exception of the no-longer operating high seas drift net and Japanese longline catches reported in weights for which no effort data is available. The fleets used in this analysis are described in Table 1. For each fleet, effort was always reported in number of vessels. We refer to number of vessels as fleet capacity in this document. In addition, effort in number of hooks was reported for longline fleets and in number of fishing days for surface fleets. For the Japanese longline fleets, effort in number of hooks was calculated from data aggregated at a 5ºx5º spatial resolution, while number of vessels was calculated from operational logbooks. Data for Chinese-Taipei were derived from the 5ºx5º data from the Task II file provided by the Overseas Fisheries Development Council (OFDC), while the number of vessels were estimated from returning logbooks given by OFDC. For China and Vanuatu effort in number of hooks was obtained from the raised aggregate data, and the number of vessels from unraised operational data. Vanuatu only had data for all seasons stating in 2002, so data prior to 2002 was not used in the analysis. Effort data from the USA and Canadian surface fleet were combined as they are considered a single fleet in the operating model. Surface fleet effort data from the USA was only available since 1995 and data for 1993 and 1994 for the Canadian surface fleet was preliminary as data only started to be regularly collected in 1995. Therefore, only data from 1995 onwards was used for the EPO (USA+Canada) surface fleet. For the Japanese pole-and-line fleet, data on skipjack catches was also made available. For the Chinese-Taipei fleet, information on the number of vessels registered as albacore or bigeye targeting was available from 2007 onwards.

Statistical Analysis

To explore how fishing mortality scales with changes in effort, we developed a linear model of fleet-specific fishing mortality as the response variable against fleet-specific effort. Models were constructed in R for each fleet and each effort type (fleet capacity and number of hooks or fishing days). To maximize the number of data points we built a single model for the fleets that belonged to the same country, used the same gear, and operated in the same area, such as F16 and F17 (Table 1). The model for the EPO fleet, which exclusively targets albacore, and for the northern Chinese-Taipei longline fleet (F21), which has 99% of vessels registered as albacore targeting, had a 0 intercept so that if effort were 0 fishing mortality would also be 0. The Japanese pole-and-line fleet switches between targeting skipjack and targeting albacore, so a second linear model was built for the Japanese surface fleets (F16-F18) with an interaction term between skipjack catch and effort. While all but 2 vessels operating in the F21 Chinese-Taipei northern longline fleet were registered as albacore targeting, most vessels operating in the F22 Chinese-Taipei southern longline fleet were bigeye targeting. A second model was built for the F22 fleet where effort was weighted by the numbers of albacore targeting vessels relative to the number of bigeye targeting vessels.

Table 1 – Description of the fleets represented in the analysis. Quarters represent seasons with Q1 being January-March, Q2 April-June, Q3 July-September, and Q4 October-December. For a map of the fishing areas for the longline fleet see Fig. 3.2 of ISC 2017. Briefly, area 1 is near southern coastal Japan, areas 3 and 5 are north of ~25°N, areas 2 and 4 are south of 25°N. Areas 3 and 2 are in the Western Pacific, whereas areas 4 and 5 are in the Eastern Pacific.

ID	Country	Gear	Season	Fishing Area
F5	Japan	Longline	Q1	1 and 3
F6	Japan	Longline	Q2	1 and 3
F7	Japan	Longline	Q3	1 and 3
F8	Japan	Longline	Q4	1 and 3
F11	Japan	Longline	Q1	2
F12	Japan	Longline	Q2, 3 and 4	2
F14	Japan	Longline	All	4
F15	Japan	Longline	All	5
F16	Japan	Pole-and-line	Q1 and 2	≥ 30°N
F17	Japan	Pole-and-line	Q3 and 4	≥ 30°N
F18	Japan	Pole-and-line	All	< 30°N
F19	USA	Longline	All	3 and 5
F20	USA	Longline	All	2 and 4
F21	Chinese-Taipei	Longline	All	3 and 5
F22	Chinese-Taipei	Longline	All	2 and 4
F23	Korea	Longline	All	All
F24	China	Longline	All	3 and 5
F25	China	Longline	All	2 and 4
F26	Vanuatu	Longline	All	All
F27	USA and Canada	Pole-and-line and troll	All	Eastern Pacific Ocean (EPO)

Table 2 – Results of linear regressions of fishing mortality against effort or fleet capacity for each fleet or group of fleets of the same country and gear operating in the same region. Note that regression coefficients are only shown for models with an adjusted R^2 greater than 0.5. No R^2 is shown for models with a p-value < 0.05 for the F-test of overall significance. For the F16/F17 fleet, results of the model with a skipjack interaction effect are shown, and for the F22 fleet, results of the regression where effort was weighted by the number of albacore targeting vessels relative to the

bigeye targeting vessels are shown. *** denote a statistically significant effect of effort or fleet capacity at a p-value of <0.001.

	Fishing Effort			Fleet Capacity		
Fleet	Regression Coefficient ±SE	DF	R^2	Regression Coefficient ±SE	DF	R^2
F27	$5.8x10^{-5}$ ±$0.2x10^{-5}$ ***	83	0.94	1.0 $x10^{-3}$ ±$0.4x10^{-4}$ ***	83	0.87
F16-F17	$8.5x10^{-4}$ ±$0.7x10^{-4}$ ***	85	0.74		85	0.48
F18		89	0.24		89	0.24
F5-F8	$6.6x10^{-9}$ ±$0.4x10^{-9}$ ***	90	0.73	$5.8x10^{-4}$ ±$0.6x10^{-4}$ ***	90	0.53
F11-F12		86			86	
F14		90	0.37		90	0.37
F15	$3.3x10^{-9}$ ±$0.2x10^{-9}$ ***	90	0.83		86	0.48
F19		90			90	
F20		90			90	
F21	$5.2x10^{-6}$ ±$0.5x10^{-6}$***	83	0.61	$1.7x10^{-3}$ ±$0.2x10^{-2}$ ***	83	0.53
F22		34	0.35		34	0.35
F23		90	0.27		90	
F24		15	0.48		15	
F25		62	0.25		62	
F26		54	0.48		54	0.24

Results and Discussion

The fishing activities of the EPO surface fleet were concentrated in July-September, with both effort and fleet capacity being highest in season 3 (Fig. 2). Effort in July-September increased from the mid-1990s to the early 2000s and then remained relatively stable until 2015, when it started decreasing (Fig. 2). By contrast, fleet capacity in July-September has decreased over time (Fig. 2). Patterns in EPO fishing mortality mirrored trends in effort, with mortality being lowest in the mid-1990s and highest in July-September (Fig. 3). Indeed, effort explained much of the variability in fishing mortality between seasons and years (Table 2). Fleet capacity was also a good predictor of fishing mortality, albeit the correlation was not as strong as with effort (Table 2).

Japanese pole-and-line fleet capacity has decreased over time both north and south of 30°N (Fig. 4). More vessels operate in the southern region from January to June, while vessels in the northern region operate from April to December (Fig. 4). As fleet capacity, effort in the southern region peaks from January to June. However, while fleet capacity has decreased over time, effort in the southern region has remained relatively constant after a decrease in the late 1990s (Fig. 4). In the northern region, effort is highest in July-September (Fig. 4). Like fleet capacity, there is almost no effort in the northern region January-March and effort has decreased over time, particularly from July-December (Fig. 4). While Japanese pole-and-line fleet capacity across seasons is comparable for the northern and southern region, fishing mortality is very low in the southern area (Fig. 5). This suggests that vessels in this region may be largely targeting skipjack. However, including an interaction effect in the model of fishing mortality for the southern Japanese pole-and-line fleet, F18, did not result in a model with a high goodness of fit (Table 2). Juvenile albacore may not be available to the surface gear in this region, resulting in low fishing mortality despite substantial effort. Indeed, cluster analysis of size data from both the surface and longline fleet shows that albacore in the southern region tend to be larger (Ochi et al. 2016). While effort in the northern region was consistently highest in July-September, fishing mortality was highest April-June since the mid-2000s (Fig. 5). Part of the discrepancy between effort and fishing mortality was explained by effort being targeted at skipjack, with the AIC and R^2 showing improved goodness of fit for the model with a skipjack-effort interaction term (AIC = 186 and $R^2 = 0.74$) than the effort only model (AIC = 233 and $R^2 = 0.30$). By contrast, fleet capacity did not explain a large fraction of the variability in fishing mortality in either region even when the effect of skipjack catches was considered (Table 2).

Both the fleet capacity, effort, and fishing mortality of the Japanese longline fleet are highest in Area 1 and 3 and lowest in Area 5 (Fig. 6 and 7). In recent years, effort and fleet capacity have been extremely low in the Eastern Pacific (Areas 4 and 5, Fig. 6). Japanese longline fleet capacity has decreased over time across all areas, with the sharpest decrease in Area 4 (Fig. 6). Despite the decrease in fleet capacity, effort has remained relatively constant in Area 1 and 3 and Area 2. Effort in Area 2 and 4 were poor predictors of albacore fishing mortality (Table 2). For instance, while effort was generally comparable across seasons in Area 4, fishing mortality was highest January-March, and extremely low April-September despite considerable effort levels, particularly early in the time series (Fig. 6 and 7). Japanese longline vessels in the southern regions (Areas 2 and 4) of the North Pacific generally target bigeye (Harley et al. 2015), and thus changes in effort may not be associated with variability in albacore fishing mortality. By contrast, changes in effort in the north-western region (Areas 1 and 3) explained a large fraction of variability in albacore fishing mortality (Table 2). Most of the vessels operating in this area belong to the coastal longline fleet that targets albacore (Ijima and Satoh 2014), and thus fishing effort from this region may be more representative of changes in fishing mortality. There was a strong relationship between effort and fishing mortality also for Area 5, but inspection of the scatterplot of fishing mortality against effort showed that one outlier with high effort and mortality levels was influential to the regression output (Fig. 8). It was also evident that in some cases fishing mortality remained 0 or was very low despite moderate levels of effort (Fig. 8).

USA longline fleet capacity and effort have increased since 1995 (Fig. 9). There was an expansion of the fleet operating in the northern region (Areas 3 and 5) in July-September since the early 2000s. Despite increases in effort in the northern region, fishing mortality by the USA longline fleet remains low (Fig. 10). This suggests that adult albacore that could be potentially caught by the bigeye targeting deep-set longline fleet may be distributed further south, and that the juvenile albacore present in the northern region may have too shallow of a distribution to be available to this fleet. In the southern region, effort in July-September has remained relatively constant since the early 2000s but has increased in other seasons (Fig. 9). Fishing mortality was highest April-June in the late 1990s and early 2000s and declined in the late 2010s despite continued increases in effort and fleet capacity (Fig. 10). USA longline fishing mortality does not appear related to changes in effort or fleet capacity (Table 2) and may instead depend on variability in albacore migration, distribution, and its overlap with the spatial footprint of the bigeye targeting longline fleet.

Chinese-Taipei fleet capacity and longline effort expanded in the southern region in the early 2000s and are now at moderate levels after a peak in the mid-2000s (Fig. 11). Less vessels operate in the northern region (Fig. 11). Nevertheless, effort levels in October-March reached comparable levels to those in the southern areas in January-June in the late 1990s and then again in the mid-2000s. Data on species targeted, available since 2007, shows that most Chinese-Taipei longline vessels (all but 2) operating in this area are albacore targeting. Indeed, the drop in effort after 2005 was reflected in a drop in fishing mortality over the same period (Fig. 12). Variability in effort can explain moderate levels of fishing mortality in the northern region, but fishing mortality does not appear driven by changes in fishing effort in the southern region (Table 2). Expansion in the southern region was associated with a switch from targeting albacore to yellowfin and bigeye (Chen and Cheng 2016), and thus effort in this region may not be reflective of changes in albacore fishing mortality.

Patterns in Korean longline effort and fleet capacity are characterized by high interannual variability and no consistent trends over time (Fig. 13). Fishing mortality has been relatively low except for a peak in January-March 2008 (Fig. 14) and is not strongly associated to variability in effort or fleet capacity (Table 2).

Chinese longline fishing effort is concentrated in the southern region (Areas 2 and 4, Fig. 15). Despite declines in fleet capacity, fishing effort January-June has increased over time (Fig. 15). Fishing effort July-December has remained relatively constant resulting in higher effort in the first half of the year from ~2010 onward (Fig. 15). Like effort, fishing mortality is highest in the southern region, however, while effort is highest January-June, fishing mortality peaks October-March (Fig. 15 and 16). Fishing mortality increased sharply from 2010 to 2012-2013 but declined in 2015 (Fig. 16). Changes in effort are not strongly associated with changes in fishing mortality, suggesting that Chinese longline vessels operating in the southern region may not be targeting albacore.

Vanuatu fleet capacity has increased overtime and is highest October-June (Fig. 17). By contrast, effort is highest December-March and is characterized by large interannual fluctuations and no consistent trend (Fig. 17). Fishing mortality also peaks December-March and shows a moderate relationship with fishing effort (Fig. 18).

Conclusions

Effort was a strong driver of changes in fishing mortality for the EPO surface fleet, which targets juvenile albacore. The Japanese surface fleet operating north of 30°N also linearly scaled with effort, but only after accounting for skipjack catches as the fleet targets both species (Kiyofuji 2013). Very little albacore is caught by the pole-and-line fleet operating in the southern area (Kinoshita et al. 2017), and fishing mortality from the Japanese pole-an-line fleet is very low despite moderate levels of effort. These results suggest that input control in the form of TAE may be effective to limit fishing mortality from the albacore surface fleets. The analysis also provides a method to relate changes in fishing intensity as simulated by the MSE to changes in effort in fishing days and supports the simplified use of fishing mortality as a measure of effort for these fleets in the MSE simulation.

By contrast, fishing mortality resulting from most longline fleets does not scale with effort. The Japanese longline fleet operating in the northern areas 1 and 3 and the Chinese-Taipei longline operating in northern areas 3 and 5, which generally target albacore (Ijima and Satoh 2014, Chen and Cheng 2016), were the exception. By contrast, effort of all other longline fleets is concentrated in the southern regions and bigeye or yellowfin are the main target species (Harley et al. 2015, Chen and Cheng 2016). We find that effort of these longline fleets is not strongly related to albacore fishing mortality. Albacore catches may be more dependent on variations in overlap of albacore and bigeye habitat. The MSE assumed that TAE control could be effectively implemented across all fisheries given a 5-20% implementation error. However, these results show that, in the real world, TAE control may be quite ineffective at controlling the fishing mortality of most longline fleets and that TAE control as simulated in the MSE would be quite unrealistic for longline vessels.

Implications for the MSE simulation

As recommended by the ISC ALBWG, managers, and stakeholders during the 4th albacore working group meeting (ISC 2019), the following changes were implemented to the MSE code:

1. Because of limitations in the fishing capacity of the fleets, the TAC/TAE was capped to a level not exceeding those generated by using maximum fishing mortalities over the period of 1997-2015.
2. An additional option was added to the MSE management module to simulate no harvest control if spawning stock biomass was greater than the threshold reference point. Catches were generated by sampling the historical fishing mortalities.
3. Implementation error was set to be bidirectional (i.e., fleets can fish at, less or more than the TAE or TAC).
4. Stricter risk levels (80 or 90%) were used in evaluation of the risk of breaching candidate limit reference points. The management module was modified to compute this risk by running the NPALB future projection software.

With regards to points 1 and 2, this analysis shows how the historical fishing mortalities used in the MSE code can be translated into effort in terms of number of fishing days for the albacore surface fleets and number of hooks for the Japanese and Chinese-Taipei northern longline fleets. More generally, this analysis relating how effort is modelled in the MSE and effort measures in the real world can help managers and stakeholders interpret MSE results and the realism of TAE control measures as simulated in the MSE.

This work also demonstrates that MSE runs where all fleets are under TAE control would show overly optimistic results as the MSE assumes that fishing mortality can be effectively managed by changes in effort. This assumption does not appear realistic for most of the longline fleets. Considering these results, TAE runs for the second round of MSE will be the last to be completed (see Table 3 for a timeline of milestones for the second round of albacore MSE results).

Table 3. Work plan for the second round of the North Pacific Albacore MSE.

Date	**Task**
April 2020	TAC runs completed
May 2020	Finalize results and visualizations for TAC results
July 2020	Complete mixed TAE (surface fleets)/TAC (longline) runs
August 2020	Finalize results and visualizations for mixed TAE/TAC results
October 2020	Complete TAE runs
November 2020	Finalize results and visualizations for mixed TAE/TAC results
December 2020	Complete draft report of round 2 MSE Report
Early 2021	Present MSE round 2 results at the 5th MSE workshop
Summer 2021	Present MSE round 2 results to fisheries management bodies (e.g. ISC, IATTC)

References

Chen, C.Y. and Cheng, F.C. (2016). The development of Taiwanese longline fishery in the North Pacific Ocean and estimation of albacore CPUE exploited by albacore-targeting fishery, 1995-2015. ISC/16/ALWG-02

Chen, K.-S., Crone, P.R., and Hsu, C.-C. (2010). Reproductive biology of albacore *Thunnus alalunga*. J. Fish Biol. 77(1): 119–136.

Childers, J., Snyder, S., and Kohin, S. (2011). Migration and behavior of juvenile North Pacific albacore (*Thunnus alalunga*). Fish. Oceanogr. 20(3): 157–173.

Harley, S., Williams, P.G., Nicol, S., and Hampton, J. (2015). The Western and Central Pacific Tuna Fishery: 2013 Overview and Status of Stocks (Tuna Fisheries Assessment Report N° 14).

Noumea, New Caledonia: Secretariat of the Pacific Community, Oceanic Fisheries Programme.

Ichinokawa, M., Coan, A.L., and Takeuchi, Y. (2008). Transoceanic migration rates of young North Pacific albacore, *Thunnus alalunga*, from conventional tagging data. Can. J. Fish. Aquat. Sci. 65(8): 1681–1691. doi:10.1139/F08-095.

Ijima, H. and Satoh, K. (2014) Abundance indices of albacore tuna for the Stock Synthesis III by Japanese longline fishery in the north west Pacific Ocean. ISC/14/ALBWG-01

ISC (2017). Stock assessment of albacore tuna in the North Pacific Ocean in 2017. Available at http://isc.fra.go.jp/pdf/ISC17/ISC17_Annex12-Stock_Assessment_of_Albacore_Tuna_in_the_North_Pacific_Ocean_in_2017.pdf

ISC (2019). Report for the first North Pacific Albacore Management Strategy Evaluation. ISC/19/ANNEX/12.

Kinoshita, J., Ochi, D., and Kiyofuji, H. (2017). Revised of standardized CPUE for North Pacific albacore caught by the Japanese pole and line data from 1972 to 2015. ISC/17/ALBWG/05.

Kiyofuji, H. (2013) Reconsideration of CPUE for albacore caught by the Japanese pole and line fishery in the northwestern North Pacific Ocean. ISC/13/ALBWG-1/11

Methot, R.D., and Wetzel, C.R. (2013). Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142: 86–99. Elsevier B.V. doi:10.1016/j.fishres.2012.10.012.

Ochi, D., Ojima, H., Kinoshita, J., Kiyofujii, H. (2016). New fisheries definition from Japanese longline North Pacific albacore size data. ISC/16/ALBWG-02/03

Otsu, T., and Uchida, R.N. (1959). Sexual maturity and spawning of albacore in the Pacific Ocean. Fish. Bull. 59(148): 287–305.

Snyder, S. (2016). Navigating a seascape: physiological and environmental motivations behind juvenile North Pacific albacore movement patterns. (Doctoral dissertation). University of California San Diego, San Diego, California, USA.

Teo, S.LH. (2017) Relative abundance indices of adult albacore tuna for the US pelagic longline fishery in the north Pacific Ocean. ISC/17/ALBWG/11

WCPFC (2017). Interim Harvest Strategy for North Pacific Albacore tuna. WCPFC14 Summary Report Attachment I

Woodworth-Jefcoats, Polovina, J.J., Drazen, J.C. (2018). Synergy among oceanographic variability, fishery expansion, and longline catch composition in the central North Pacific Ocean. Fishery Bulletin 116: 228-239.

Figures

Figure 1. Total catches for season 3 for the Eastern Pacific Ocean (EPO) surface fleet extracted from the operating model over the conditioning period (1993-2014) and computed outside of the SS3 operating model using fleet-specific fishing mortalities, fleet and age specific selectivities, numbers at age, and age-specific natural mortality.

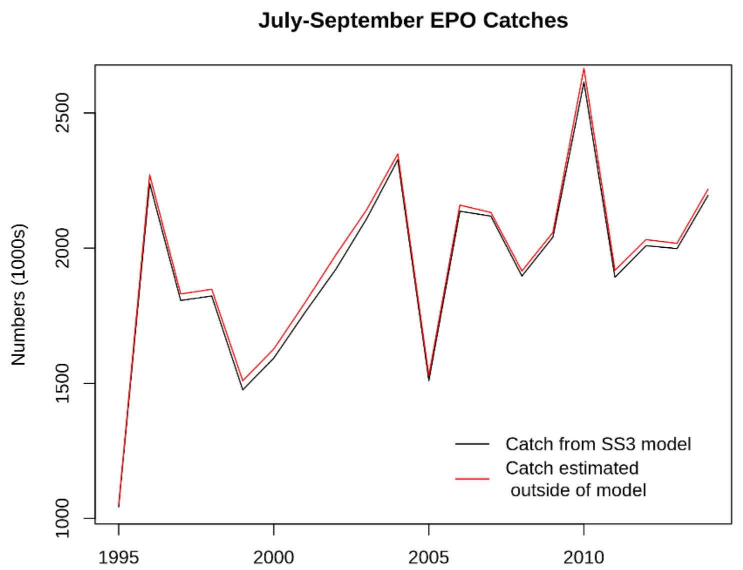

Figure 2. Trends in the effort (fishing days) and fleet capacity (number of vessels) for the Eastern Pacific (EPO) surface fleet.

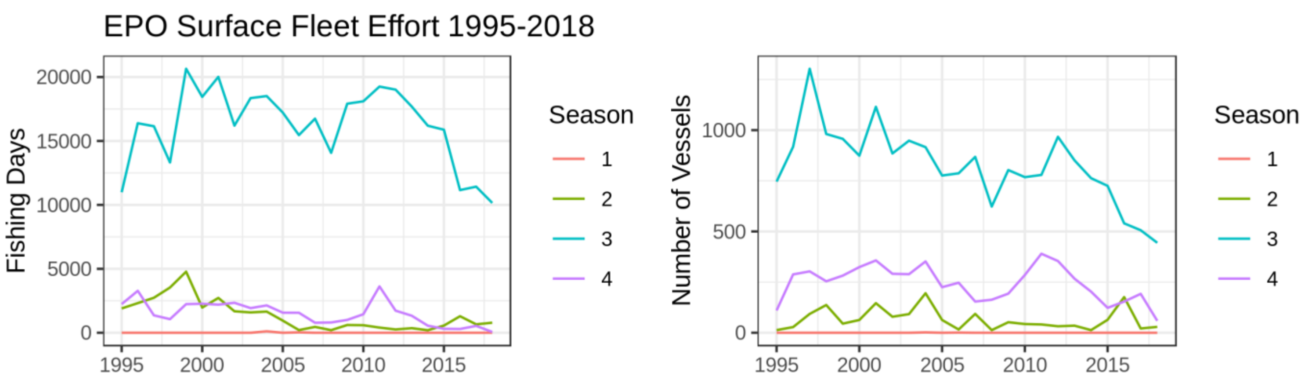

Figure 3. Trends in fishing mortality for the Eastern Pacific (EPO) surface fleet.

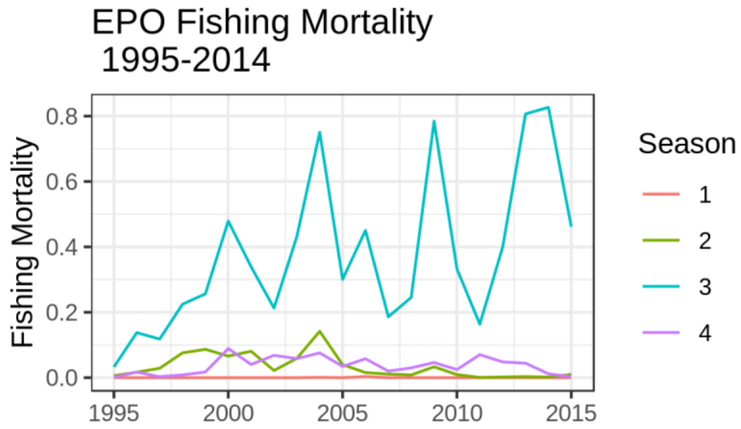

Figure 4. Trends in the effort (fishing days) and fleet capacity (number of vessels) for the Japanese pole-and-line fleet.

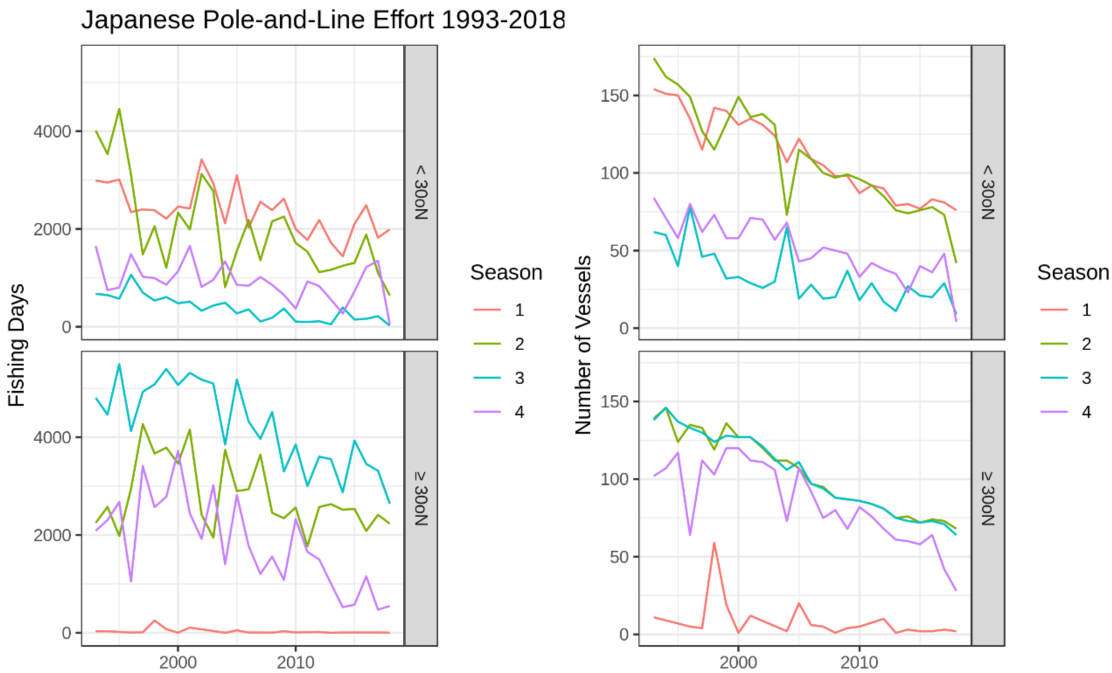

Figure 5. Trends in fishing mortality for the Japanese pole-and-line fleet.

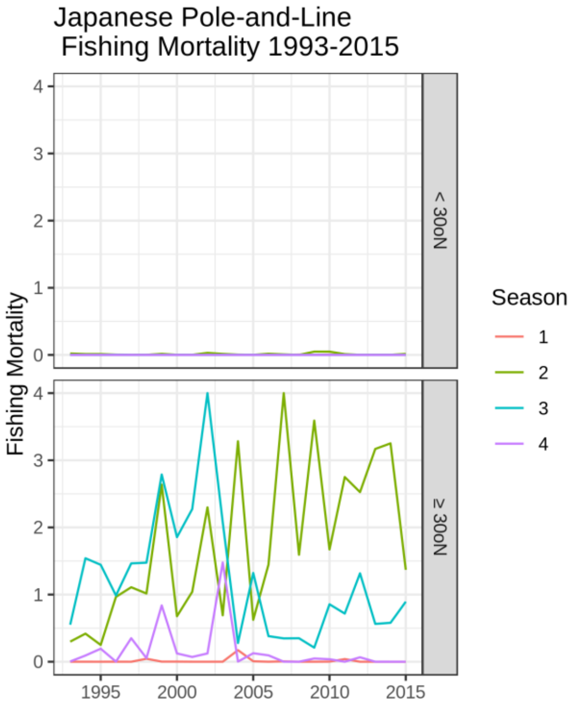

Figure 6. Trends in the effort (number of hooks) and fleet capacity (number of vessels) for the Japanese longline fleet.

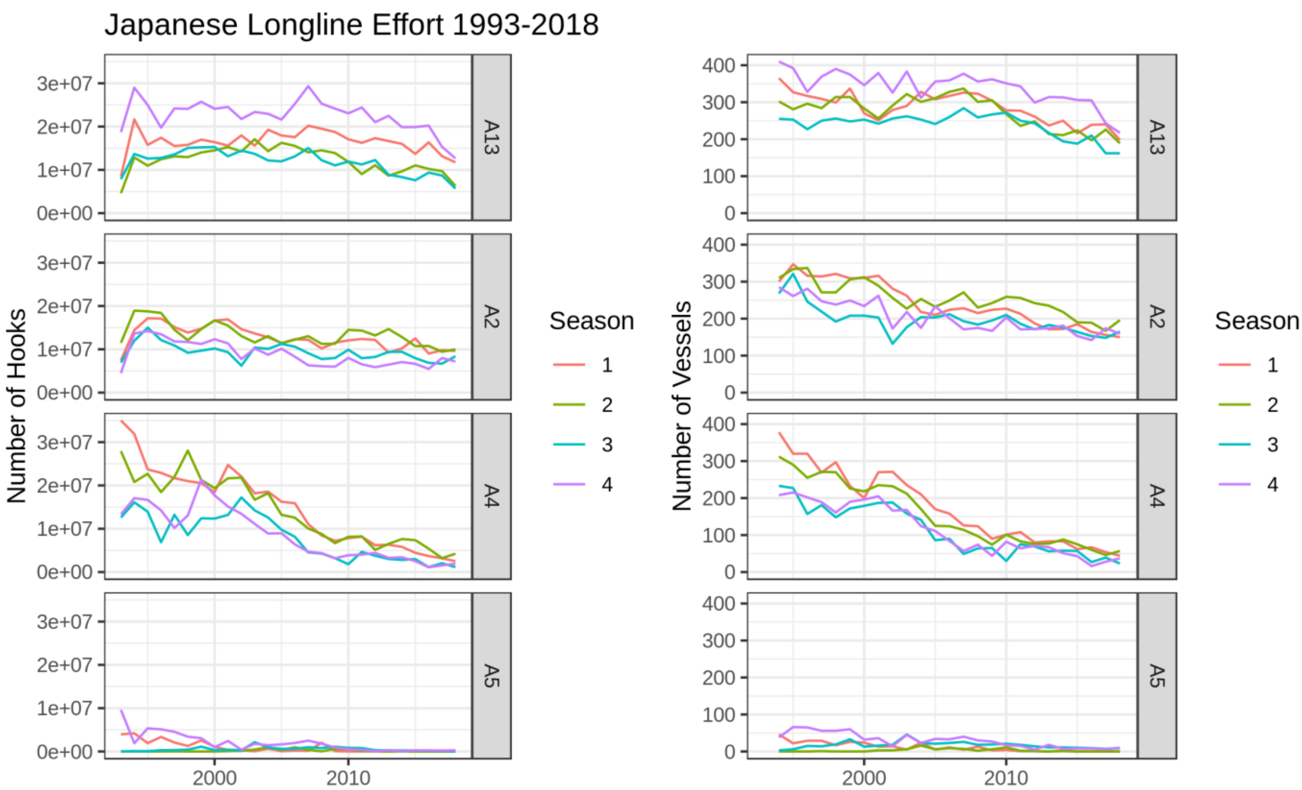

Figure 7. Trends in fishing mortality for the Japanese longline fleet.

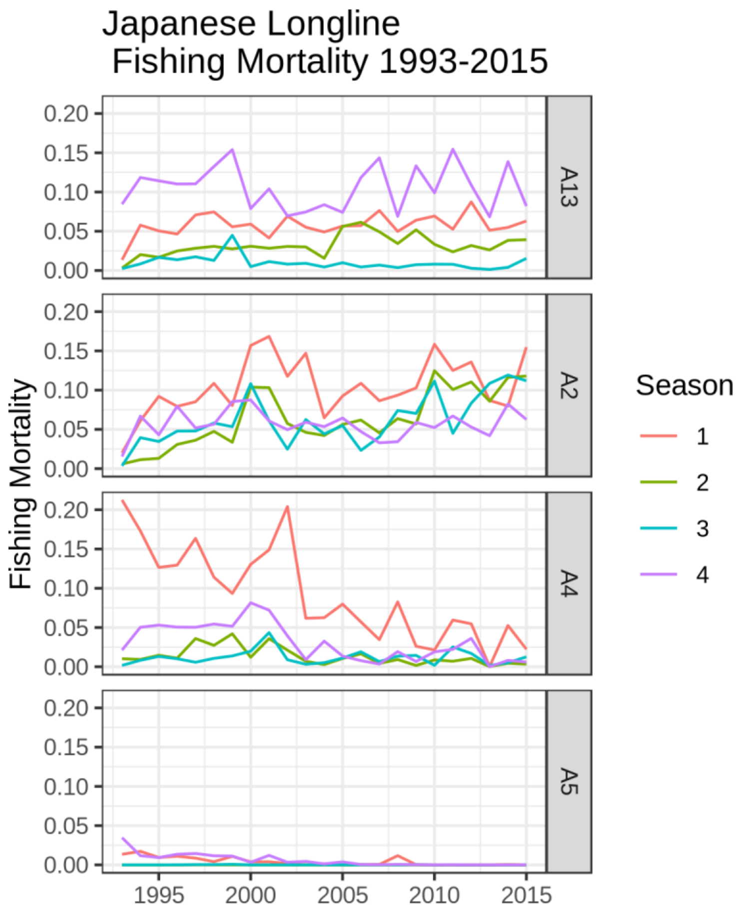

Figure 8. Fishing mortality against fishing effort (number of hooks) for the Japanese longline fleet operating in Area 5.

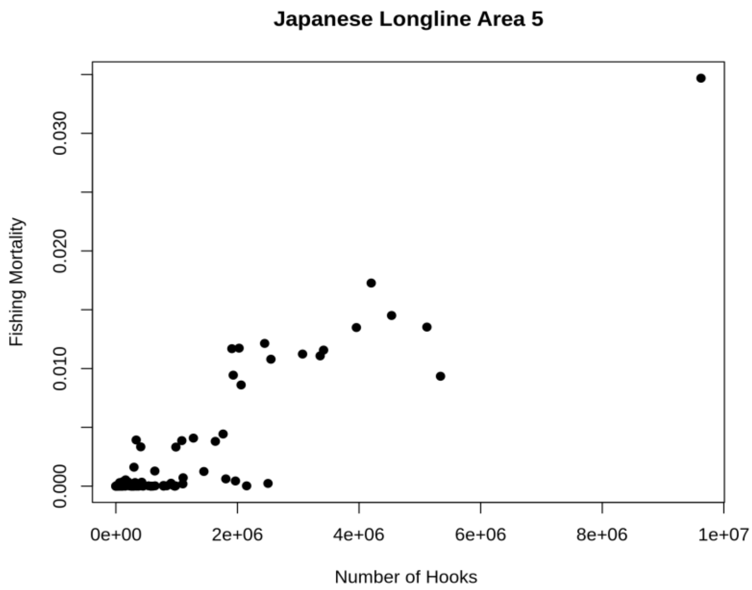

Figure 9. Trends in the effort (number of hooks) and fleet capacity (number of vessels) for the USA longline fleet.

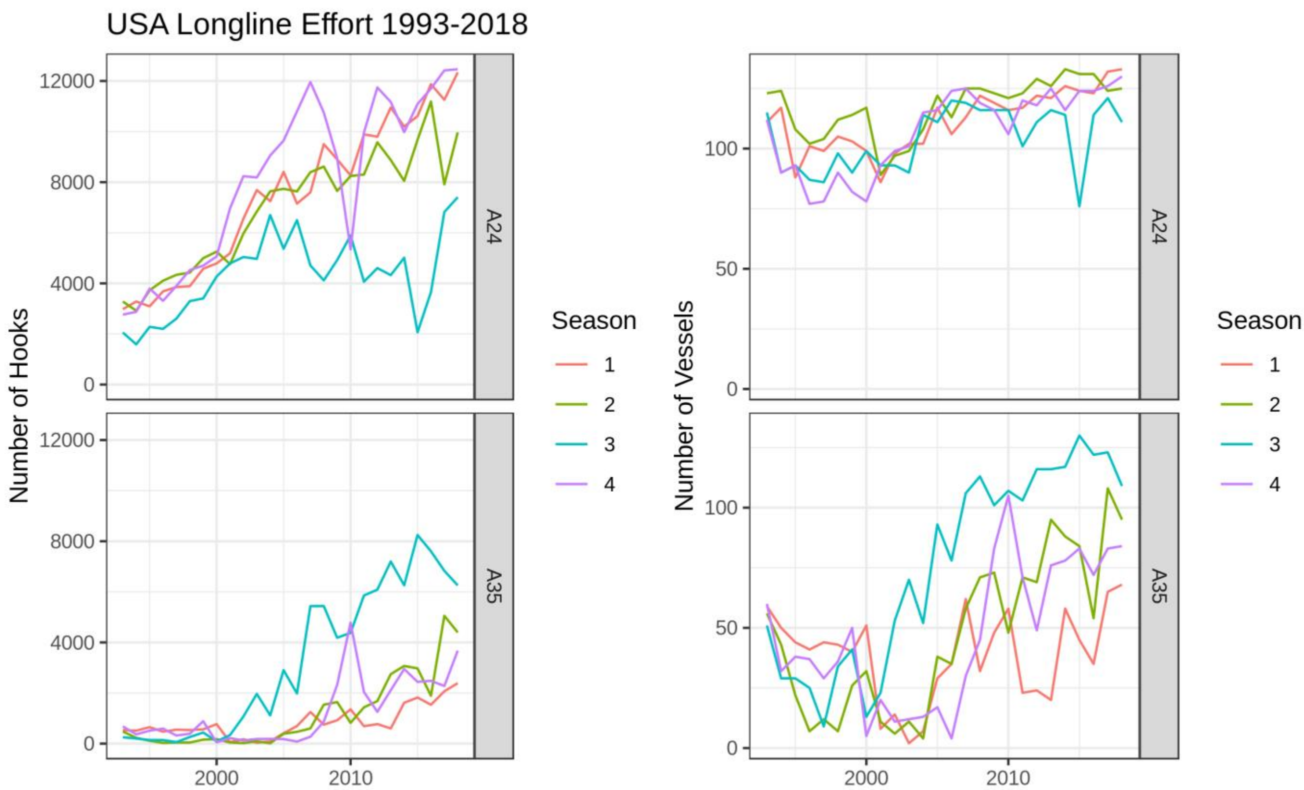

Figure 10. Trends in fishing mortality for the USA longline fleet.

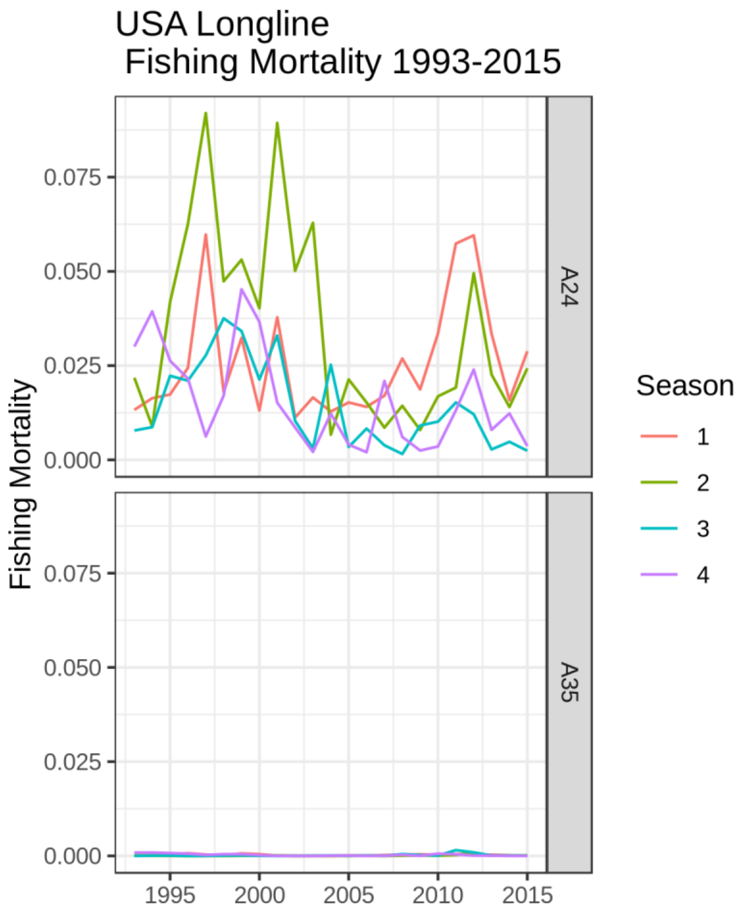

Figure 11. Trends in the effort (number of hooks) and fleet capacity (number of vessels) for the Chinese-Taipei longline fleet.

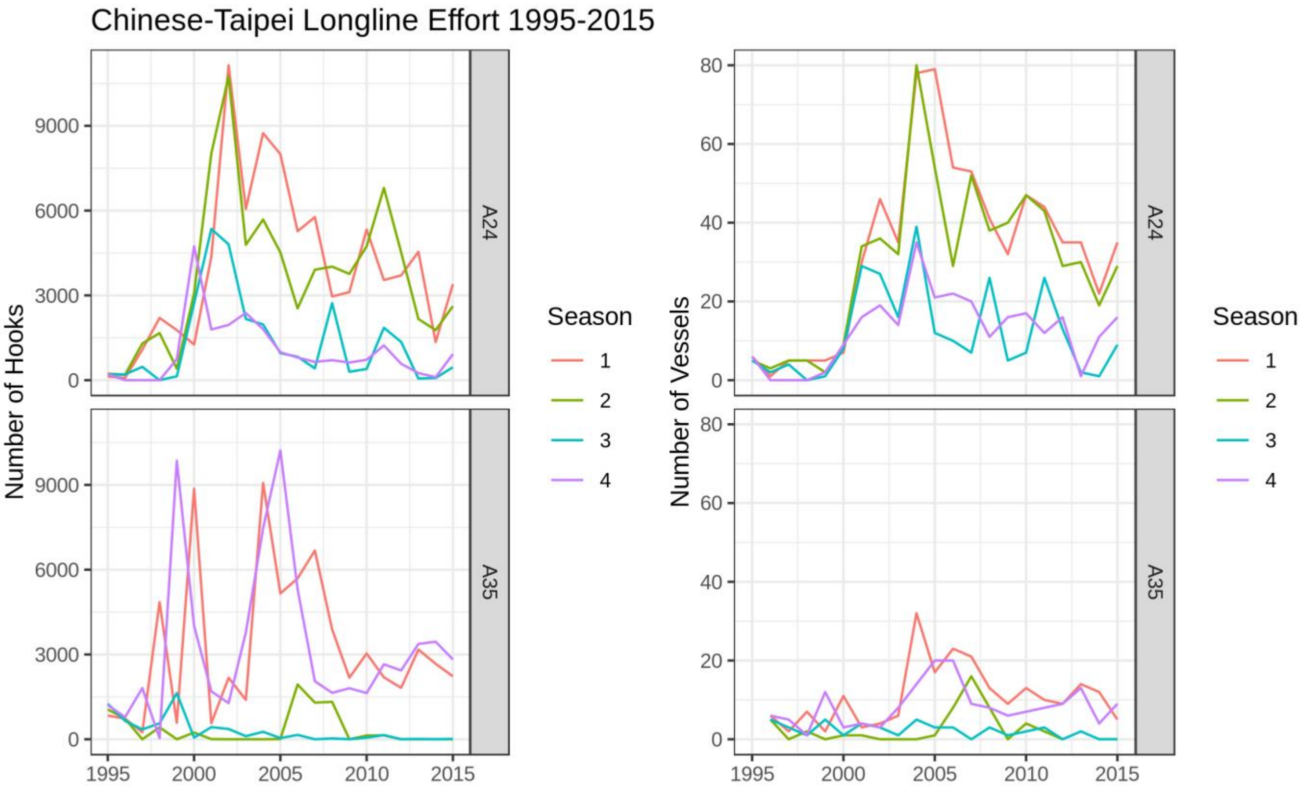

Figure 12. Trends in fishing mortality for the Chinese-Taipei longline fleet.

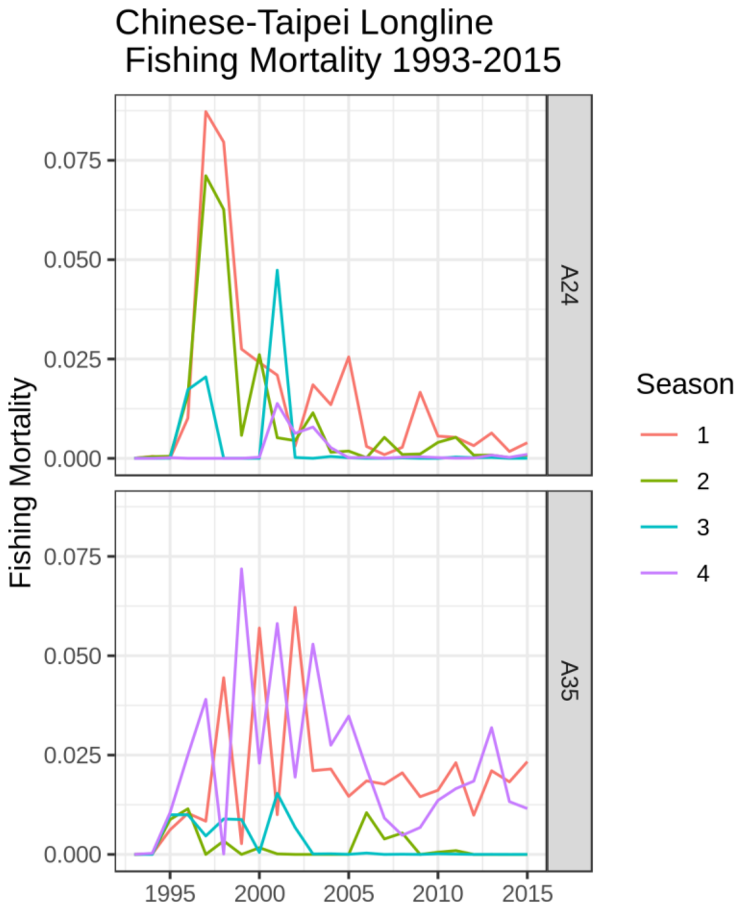

Figure 13. Trends in the effort (number of hooks) and fleet capacity (number of vessels) for the Korean longline fleet.

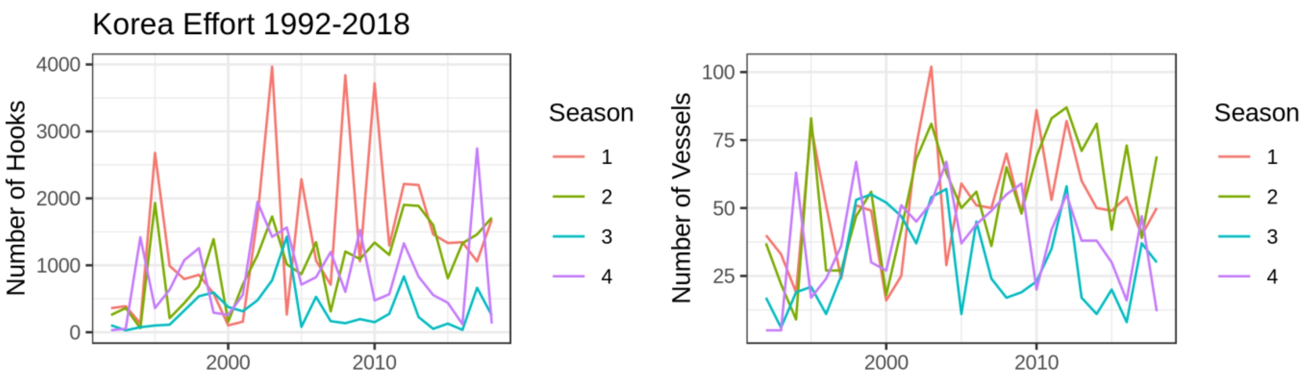

Figure 14. Trends in fishing mortality for the Korean longline fleet.

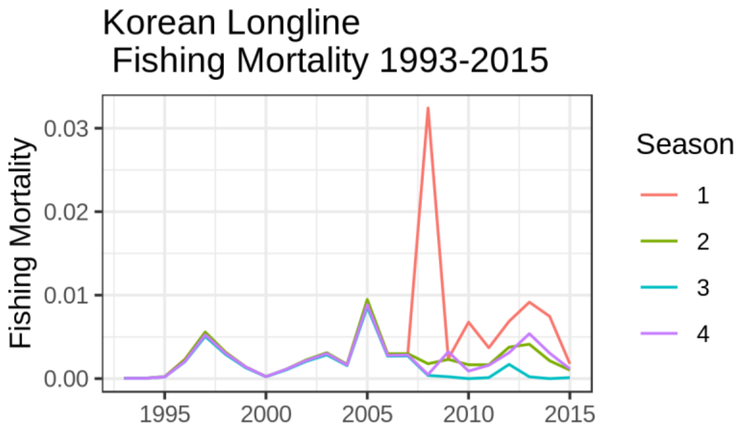

Figure 15. Trends in the effort (number of hooks) and fleet capacity (number of vessels) for the Chinese longline fleet.

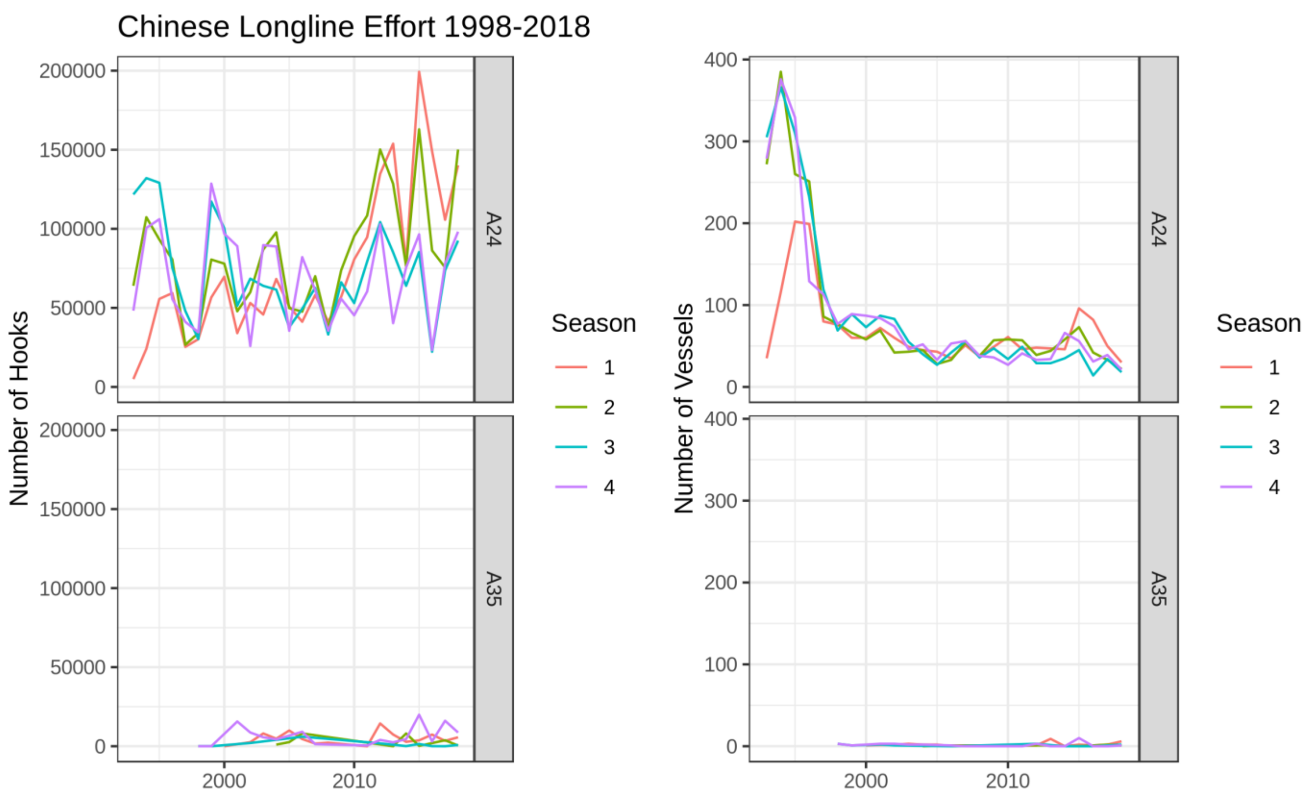

Figure 16. Trends in fishing mortality for the Chinese longline fleet.

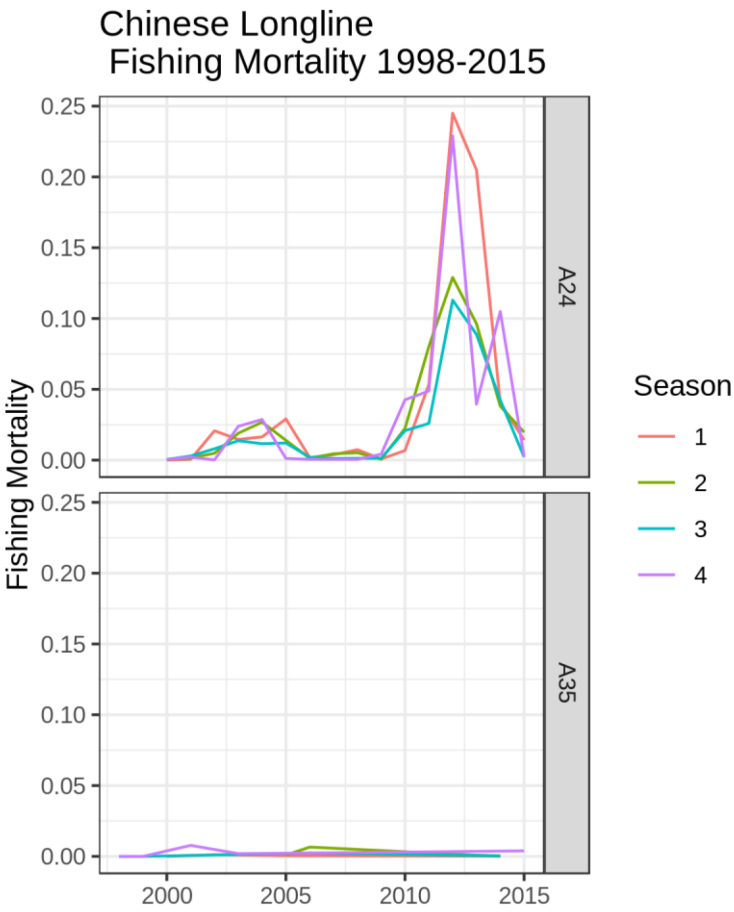

Figure 17. Trends in the effort (number of hooks) and fleet capacity (number of vessels) for the Vanuatu longline fleet.

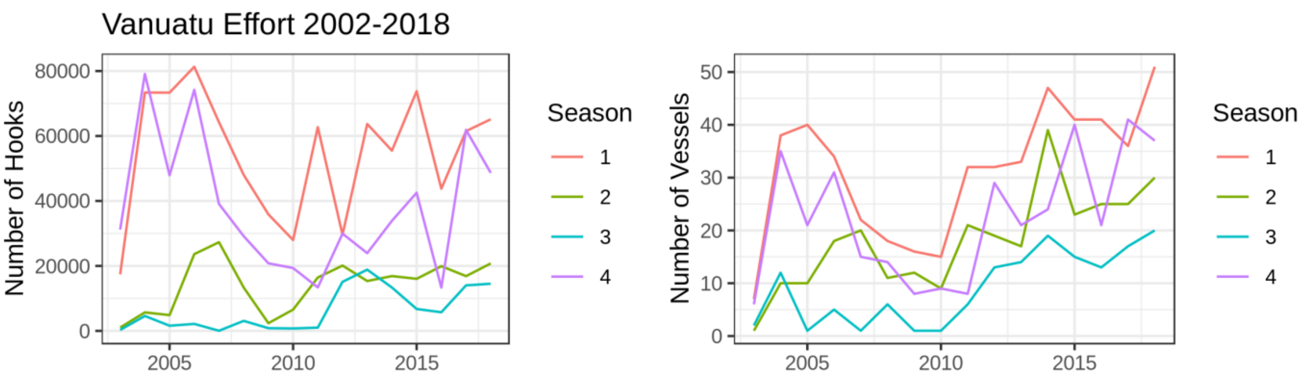

Figure 18. Trends in fishing mortality for the Vanuatu longline fleet.