Annex 12

INDICATOR-BASED ANALYSIS OF THE STATUS OF SHORTFIN MAKO SHARK IN THE NORTH PACIFIC OCEAN

REPORT OF THE SHARK WORKING GROUP

International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

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EXECUTIVE SUMMARY

1. Stock Identification and Distribution

Shortfin makos are distributed throughout the pelagic, temperate North Pacific. Nursery areas are found along the continental margins in both the western and eastern Pacific, and larger subadults and adults are observed in greater proportions in the Central Pacific. A single stock of shortfin mako sharks is assumed in the North Pacific Ocean based on evidence from genetics, tagging studies, and lower catch rates of shortfin makos near the equator than in temperate areas. However, within the North Pacific some regional substructure is apparent as the majority of tagged makos have been recaptured within the same region where they were originally tagged, and examination of catch records by size and sex demonstrates some regional and seasonal segregation across the North Pacific.

2. Catch

Catch was estimated for many fleets and nations based on the best available information. Catch estimates for each fishery were made based on effort, knowledge of the species composition of catch, estimated catch per effort, and scientific knowledge of the operations and catch history. These time series provide an idea of recent catch history for many of the main fleets, but estimates of total catch for shortfin mako sharks in the North Pacific are incomplete. Data are lacking for several significant fishing nations (e.g. Korea and China) and fleets (e.g. Taiwan small-scale longline, Japan deep-set longline and Japan training vessel fleets). Estimates are difficult to derive because discards are often not recorded and retained catch data are available with low quality. Given that trends in catch cannot be derived from the incomplete catch information provided, the catch time series were not considered for the purposes of providing stock status information.

3. Indicator Data and Analysis

Simulation analyses were conducted to examine the effects of CPUE time series of varying lengths and precision, of CPUE time series from predominately adult versus juvenile areas, and of the contribution of trends in mean size versus CPUE in determining stock status. Results from the simulations showed that time series of mean size are less informative regarding the current stock condition (*Bcur/Bmsy*) than CPUE indices. Simulation results also showed that CPUE indices that are derived from predominately adult areas provide better information on current stock status than CPUE indices from recruitment areas.

Four types of indicators were developed for the north Pacific shortfin mako shark: proportion of positive sets, abundance (CPUE) indices, sex-ratio and size compositions.

The proportion of positive sets, defined as set/trip where at least one shortfin mako sharks is caught, is calculated for major fisheries. The trends for proportion of positive sets varied across fisheries with the Japanese shallow-set longline fishery having the highest proportion of positive catch sets (approximately 75% in 2013, with the rate nearly tripling over the time series).

Indices of shortfin mako relative abundance were developed from eight fisheries or surveys ranging from 1985-2014 and covering different areas across most of the North Pacific. All indices were reviewed by the SHARKWG, and three were selected as the most plausible indicators of abundance based on their spatial and temporal coverage, size of sharks, data quality, and model diagnostics (Figure E1). The Japanese shallow-set longline index was considered to be the best abundance indicator candidate. The standardized index showed a flat or slightly increasing trend from 1994-2004, before a substantial increase from 2005-2013. Abundance indices developed from the Hawaii-based deep-set and shallow-set longline fisheries were also both considered to be plausible indicators of stock abundance. Trends in abundance showed some variability for the two fishery sectors between 2004 and 2012. The standardized CPUE trends moved in opposite directions, with the trend for the shallow-set sector showing a slight decrease, while the trend for the deep-set sector increased overtime.

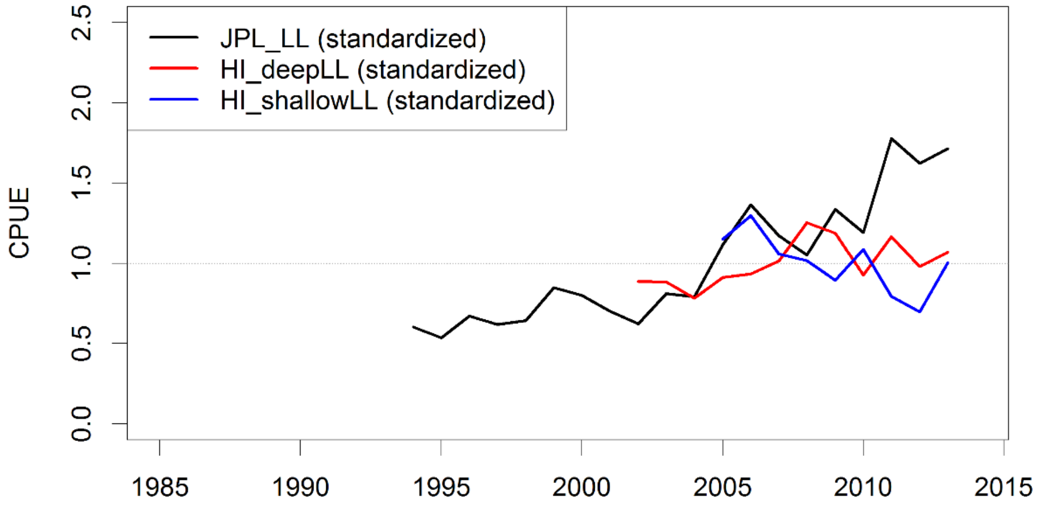

Figure E1. Standardized indices of abundance by fishery for shortfin mako sharks. While all of the available independent information was examined to draw conclusions about the stock, these three indices were considered to have the greatest value in determining stock status.

Overall, no trends in sex-ratio are apparent through time across fisheries, although sample sizes are generally low. It would probably be difficult to interpret any trends in sex-ratio because there is not a good understanding of population movement by size and sex through time. Thus, the SHARKWG considered sex-ratios to be of little value as indicators in this analysis of stock status.

The annual median and quartile percentiles of catch at size for shortfin mako sharks caught by the various fleets were examined. In general sizes remained relatively stable for all fleets. Larger sizes were recorded for the deep-set sector of the Hawaiian fleet and the Japan research and training longline vessels, while smaller individuals were more common in the U.S. juvenile longline survey, U.S. drift gillnet, and Japan longline survey.

4. Summary of Indicators

Although our knowledge about shortfin mako life history is not complete, a general picture of the dynamics of the assumed north Pacific stock has emerged: juvenile sharks are found in both the eastern and western areas of the Pacific Ocean near continental land masses while older sharks are found in greater numbers in the central Pacific. Like our knowledge of life history, our compilation of fishery data is also incomplete.

Effort for the fisheries examined that catch shortfin makos throughout the North Pacific seems to have declined overall, although effort estimates for several fisheries and nations were unavailable. Of the available indices of relative abundance (CPUE), the Japanese shallow-set longline and both Hawaiian longline indices (shallow- and deep-set) are considered good candidates for representing stock trends. All three indices cover a large part of the Pacific where mature sharks are found. Both the Japanese shallow-set and the Hawaiian deep-set indices indicate non-negative trends and the Hawaiian shallow-set a negative trend. Although the negative trend in the Hawaiian shallow-set should not be completely discounted, the variability in the annual length distributions from this fishery suggests that the index selectivity/catchability fluctuates which may invalidate the proportionality assumption. It should also be considered that the rate of population increase described by the Japanese shallow-set post 2000 is likely too steep to solely reflect the response of a Lamnidae species to a relaxation of fishing pressure.

5. Stock Status and Conservation Advice

Shortfin mako is a data poor species. Recognizing that information on important fisheries is missing, the untested validity of indicators for determining stock status, and conflicts in the available data, stock status (overfishing and overfished) could not be determined. Managers should consider the undetermined stock status of shortfin mako shark in the North Pacific when developing and implementing management measures.

The SHARKWG reviewed a suite of information to determine the stock status of shortfin mako shark in the North Pacific. Of the three indices considered to have the greatest value in providing stock status information, abundance trends in two of the series appear to be stable or increasing, while the abundance trend in the third series appears to be declining.

It is recommended that data for missing fleets be developed for use in the next stock assessment scheduled for 2018 and that available catch and CPUE data be monitored for changes in trends. It is further recommended that data collection programs be implemented or improved to provide species- specific shark catch data for fisheries in the North Pacific.

1 INTRODUCTION

The Shark Working Group (SHARKWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) was established in 2010 and is responsible for providing regular stock status assessments of pelagic sharks that interact with international tuna and billfish fisheries in the North Pacific Ocean. The focus of the SHARKWG to date has been on the two most commonly encountered pelagic sharks, the blue shark (*Prionace glauca*) and shortfin mako shark (*Isurus oxyrinchus*). In order to assess population status, SHARKWG members have been collecting biological and fisheries information on these key shark species in coordination and collaboration with regional fishery management organizations, national scientists and observers.

Shortfin mako shark is a highly migratory shark species and represents one of the largest and fastest of pelagic sharks. Unlike for commercially targeted species of higher value, such as tunas and billfish, a greater portion of shark fishing mortality is the result of bycatch or incidental catch. Due to a lower reproductive potential as a result of slower growth, larger adult size, later reproduction, and fewer offspring, sharks are generally more susceptible to overfishing than teleosts and higher fecundity species (Branstetter 1990; Hoenig and Gruber 1990; Au *et al.* 2008). As largely non-targeted species, records of shark catches (retained and discarded) are often of lower quality and quantity than for targeted species.

Without accurate recorded catch, it is difficult to produce traditional population dynamic stock assessment models. Data poor models, such as catch free (Porch *et al.* 2007; Trenkel 2008) and index free models (Dick and MacCall 2010), have been developed on the basis of strong assumptions and in some cases are not fully tested. Some regional management arenas have used simpler fishery indicator analyses to provide general stock status advice from data sources other than catch (Clarke *et al.* 2011a; Aires-da-Silva *et al.* 2014; Hinton *et al.* 2014; Francis *et al.* 2014).

The SHARKWG has analyzed several sources of data for shortfin mako shark including incomplete catch and effort data, size frequency data, fishery and survey relative abundance indices, and sex ratio data. Fishery indicators, defined to be time series each characterizing a single data source, were considered for their potential to provide information about the stock. Simulation testing was developed to select indicators that provide more information on the stock condition.

The nature of fishery indicator analyses is to consider all of the available independent information and draw a congruous conclusion based on the most meaningful signals present in the information. Based on results from the simulation analysis and the data themselves, the SHARKWG concluded that some indicators have little or no value to inform stock status, while others are meaningful in this regard. This report contains all the data that were taken into consideration to provide context about how the stock status determination was formed, but the conclusions are drawn from those indicators deemed to have the greatest value. Conclusions regarding stock status are limited in simple indicator-based analyses due to missing information on dynamic processes such as fishing mortality, selectivity and catchability. The results from the indicator analyses give a provisional identification of stock trends, however without the greater confidence associated with a traditional dynamic assessment model.

2 BIOLOGY BACKGROUND

2.1 Stock structure and movement

A single stock of shortfin mako sharks is assumed in the North Pacific Ocean based on evidence from genetics, tagging studies, and lower catch rates of shortfin makos near the equator than in temperate areas. All but one shortfin mako tagged in the northern and southern Pacific Ocean have been recaptured within the same hemisphere (Sippel *et al.* 2011; Urbisci *et al.* 2013; Bruce 2013), and there is a distinct signal in mitochondrial DNA heterogeneity between the North and South Pacific Ocean (Michaud *et al.* 2011; Taguchi *et al.* 2015). However, within the North Pacific Ocean some regional substructure is apparent as the lion's share of tagged makos have been recaptured within the same region where they were originally tagged, and examination of catch records by size and sex demonstrates some regional and seasonal segregation across the North Pacific Ocean (Semba and Yokawa 2011; Sippel *et al.* 2015).

There remain uncertainties about shortfin mako shark stock structure, however. Microsatellite DNA analyses reveal no differentiation between the North and South Pacific Ocean, although the results are still being examined in order to determine the significance of the findings with respect to population connectivity (Taguchi *et al.* 2015). In addition, one shortfin mako shark tagged in the southwestern Pacific Ocean off Australia was reportedly recaptured east of the Philippines (Bruce 2013). Given the preponderance of evidence currently supporting limited connection between North and South Pacific shortfin mako populations, the SHARKWG assumes distinct North and South Pacific stocks, although stock structure should be reconsidered provided further information supporting alternative hypotheses.

2.2 Habitat

Shortfin makos are distributed throughout the pelagic, temperate North Pacific Ocean, within which there are regions where young-of-the-year shortfin makos are more abundant, suggestive of pupping and/or nursery areas. These areas are distributed along the continental margins of the North Pacific Ocean, off the coast of U.S. and Mexico between about 27-35 degrees N in the eastern Pacific Ocean (Holts and Bedford 1993; Hanan *et al.* 1993; Sippel *et al.* 2015) and off the coast of Japan between about 30-40 degrees N (Semba and Yokawa 2011; Kai *et al.* 2015a; Sippel *et al.* 2015). Larger subadults and adults are observed in greater proportions in the Central Pacific Ocean (Sippel *et al.* 2015; Semba and Yokawa 2011). These observations are based on fishery data and the effect of gear selectivity on the size composition of the catch is unclear. Nevertheless, the data are suggestive that larger sharks tend to use more oceanic habitats in the central North Ocean where they may meet to reproduce, and that large females move toward the coastal areas to pup.

From the few electronic tagging studies conducted in the Pacific Ocean, shortfin makos appear to spend most of their time in epipelagic waters remaining predominately in the upper 100-150 m (Sepulveda *et al.* 2004; Musyl *et al.* 2011; Stevens *et al.* 2010; Abascal *et al.* 2011; Vetter *et al.* 2008; SWFSC unpublished) with occasional vertical excursions to beyond 500 m.

They exhibit diurnal behavior generally remaining closer to the surface at night. The majority of individuals studied have been juveniles and subadults.

2.3 Reproduction

The occurrence of reproductive sized shortfin mako sharks in fishery catch is rare, thus few studies of the reproductive biology of Pacific shortfin mako sharks have been conducted (Mollet *et al.* 2000; Joung and Hsu 2005; Semba *et al.* 2011). However, these studies have suggested they reproduce every two to three years, with an estimated gestation of 12 to 25 months (Mollet *et al.* 2000; Juong and Hsu 2005; Semba *et al.* 2011) followed by a "rest period" before the next pregnancy begins. In the northern hemisphere, shortfin makos are thought to pup from late winter to mid spring (Mollet *et al.* 2000; Juong and Hsu 2005; Semba *et al.* 2011; Kai *et al.* 2015a; Cailliet and Bedford 1983).

2.4 Growth

Age and growth studies have been limited by the scarcity of large specimens as well, which has made it difficult to reliably estimate growth rates, life span and age at maturity of shortfin mako sharks. In addition, for determining ages from vertebrae, there is uncertainty in the band pair deposition rates across regions, ages and sexes for North Pacific shortfin mako sharks. The periodicity of band pair deposition for shortfin mako in the Northeast Pacific Ocean up to age five has been validated at two band pairs per year based on oxytetracycline tagging (Wells *et al.* 2013) for sharks up to age 5, and one per year for a single adult male shark after age 5 (Kinney *et al.* 2014). Validation studies based on radio-bomb carbon suggest that one band pair is deposited in vertebrae per year (Ardizzone *et al.* 2006), but that the data are not inconsistent with a deposition rate of two per year for a few years.

Based on length frequency analysis and tag-recapture studies there is evidence of relatively rapid growth in shortfin makos, both in the north Pacific (Wells *et al.* 2013; Kai *et al.* 2015a), and elsewhere (Natanson *et al.* 2006; Bishop *et al.* 2006; Pratt and Casey 1983). In the northeast Pacific, growth has been estimated at 28-29 cm between the first and second summer and 19-21 cm between the second and third summer (Wells *et al.* 2013), and even more rapid in the northwest Pacific (Kai *et al.* 2015a). However, what may be the best growth models to use for north Pacific shortfin makos is still uncertain as studies are generally limited to smaller size classes, and results are not available for both sexes in all regions. The ISC SHARKWG is conducting a collaborative study to address shortfin mako growth which includes cross reading of reference vertebrae and a North Pacific-wide sampling plan to collect vertebrae from several regions and all age classes.

3 DATA AND METHODS

Four types of data were reviewed prior to the analyses: 1) fishery-specific catch; 2) fishing effort data; 3) relative indices of abundance; and 4) size and sex measurements. Data were either lacking or incomplete for several significant fisheries in the North Pacific. Data for the Taiwan small-scale longline fishery and for Korea's and China's longline fisheries were not available. For Japan's Research and Training Vessel (RTV) fishery and distant-water longline fishery, some data were provided, but not for all time series. Data sources and details of the data reviewed are presented below.

3.1 Catch

Catch was estimated for many fleets and nations based on the best available information. Catch estimates for each fishery were made based on effort, knowledge of the species composition of catch, estimated catch per effort, and scientific knowledge of the operations and catch history. Methods are presented in the working papers describing each fleet's/nation's catch. Estimated catch time series are available for the following nations/fleets and time periods (Figure 3.1): Japan – Kinkai shallow longline, 1994-2013 (Kai *et al.* 2015b); Mexico – artisanal gillnet and longline, medium size gillnet and longline, and large longline fleets, 1976-2013 (Sosa-Nishizaki *et al.* 2014); Taiwan – distant water longline, 1971-2012 (Tsai and Liu 2015); U.S.A. – Hawaii-based longline, California based-longline, pelagic drift gillnet, recreational and miscellaneous other, 1971-2013 (Sippel *et al.* 2014a).

These time series provide an idea of recent catch history for many of the main fleets, but estimates of total catch for shortfin mako sharks in the North Pacific Ocean are incomplete. Data are lacking for several significant fishing nations (e.g. Korea and China) and fleets (e.g. Taiwan small-scale longline, Japan distant-water longline and Japan RTV). Estimates are difficult to derive because discards are often not recorded and retained catch data are available with low quality. Shark species were typically not identified to the species level until recent years. Given that trends in catch cannot be derived from the incomplete catch information provided, the catch time series were not considered for the purposes of providing stock status information.

3.2 Fishing effort

Fishing effort data were compiled for major longline fisheries (Japan Kinkai shallow-set, Taiwan distant-water, Hawaii shallow- and deep-set), the U.S. West Coast drift gillnet fishery, U.S. West Coast longline survey, and Japan RTV longline. Estimated effort does not represent effort directed toward shortfin mako sharks, since the target species vary across fisheries, and further analyses are needed to estimate effective effort. Of the data examined, effort has changed over the years in the North Pacific Ocean (Figure 3.2). Note that effort data for China, Korea, Mexico and the small-scale longline fishery of Chinese Taipei were not available.

3.3 Indices of relative abundance

Catch and effort data were used to develop standardized catch-per-unit-of-effort (CPUE) time series, which were assumed to be proportional to population size and were used as relative indices of abundance. Catch-per-unit-of-effort was standardized for eight fisheries and surveys across the North Pacific Ocean. Details of sources of data used to derive the indices are described below and summarized in Table 3.1. The spatial extent of each fishery is shown in Figure 3.3.

An index for the western North Pacific Ocean was developed for 1994-2013 using logbook data from the Japanese shallow-set longline fishery. The fishery primarily catches juveniles and sub-adults (~60-200 cm precaudal length, PCL) in the western North Pacific Ocean (25-45°N and 137°E-160°W). The standardized index was developed after applying two filters, one that cross-checked the data against Japanese research and training vessel data and another that selected specific vessels was based on reliability of the proportion of positive catch (positive catch ratio) for each vessel. The standardization was conducted using a negative binomial model (Kai *et al.* 2015b).

An index was developed for a research survey in the western North Pacific Ocean (25-40° N, 140-150° E) for 2000-2013 using the data from chartered research trips conducted by NRIFSF (Ohshimo *et al.* 2014). Although the objectives of the survey were to develop and test mitigation measures to reduce seabird and sea turtle bycatch and mortality, a large number of subtropical and temperate pelagic sharks were caught. The size of shortfin makos caught in the fishery ranges from ~60-150 cm PCL. The standardized CPUE was calculated using a GLM with negative binomial errors.

For the Taiwanese distant water longline fishery which operates throughout most of the North Pacific Ocean, logbook records for the period 2005-2012 were used to develop a relative abundance index (Tsai and Liu 2015). The fishery predominately catches sub-adult and adult sharks from ~100-280 cm PCL. Due to the high frequency of zero shortfin mako shark catch sets, the index was standardized using a delta lognormal model, which included set type (shallow- or deep-set) as a model factor (Tsai and Liu 2014; Tsai and Liu 2015). The final models reviewed by the Working Group showed unsatisfactory diagnostics believed to be due to differences in effort across the regions stratified. Therefore, for the indicator analyses, the SHARKWG used the nominal CPUE time series for the two regions in the central North Pacific that had the greatest and most consistent effort over time.

The Hawaii-based pelagic longline fishery operates in the central North Pacific Ocean, with shallow-set operations targeting swordfish in more temperate areas and deep-set operations targeting bigeye tuna in more subtropical areas. An abundance index was developed for the deep-set fishery from 2002-2013 and for the shallow-set fishery from 2005-2013. The deep-set fishery catches sub-adults and adults (~125-220 cm PCL) and the shallow-set fishery catches juveniles and subadults (~65-210 cm PCL). Although the fisheries have been operating in the North Pacific since the early 1990s, these datasets were truncated because observer coverage was not adequately representative of the deep-set fishery prior to 2002 (Sippel *et al.* 2014b) and the shallow-set fishery was heavily impacted by changes in operations and a fishery closure during 2001-2004. Indices of abundance for both fisheries were standardized with delta lognormal models (Carvalho and DiNardo 2014).

Set-by-set logbook data from a large mesh drift gillnet fishery targeting swordfish along the coast of California were used to develop a relative abundance index for 1985-2012. The fishery catches primarily juveniles and subadults (~65-160 cm PCL). Due to bycatch concerns, regulations have changed fishing operations substantially (annual effort, spatial extent and fishing season) since logbook requirements were implemented in 1980. As result of these operational changes, the index was split into two periods (1985-2000; 2001-2012), and due to the high frequency of zero shortfin mako catch sets, the index was developed using a delta lognormal model (Lee *et al.* 2014).

Set-by-set data from an annual fishery-independent survey of juvenile sharks (~65-145 cm PCL) for the 1994-2013 period were used to develop an index of relative abundance. The survey is conducted in the Southern California Bight, covering a relatively limited area off Southern California known to be a nursery area for shortfin makos. The index was developed using a general linear model (Runcie *et al.* 2014).

Observer data from Mexico's longline fishery operating off the coast of Baja California were used to develop a juvenile and subadult (~60-170 cm PCL) abundance index for 2006-2014 (González-Ania *et al.* 2014). The primary target of the fishery is swordfish, and although the fishery began as a drift gillnet fishery, it is now exclusively a longline fishery due to a ban on gillnetting imposed in 2009. The index was based on the longline component of the fishery that operates off the states of Baja California and Baja California Sur and was standardized using a delta lognormal model due to the high frequency of zero mako catch sets (González-Ania *et al.* 2014).

3.4 Size frequency data

Spatially-explicit sex-specific size frequency data in precaudal length (PCL; cm) were compiled from major longline fisheries (Japan, U.S.A.), a regional longline survey (Mexico), a small-scale U.S. West Coast drift gillnet fishery and U.S.A. longline survey, which altogether cover much of the North Pacific Ocean (Sippel *et al*. 2015). The SHARKWG reviewed spatio-temporal analyses conducted on juvenile size and sex distribution. Sharks were sampled from Japanese shallow-set longline and coastal driftnet fisheries in the western and central North Pacific (Kai *et al.* 2015a) and across most of the North Pacific Ocean from Japanese shallow- and deep-set longline fisheries, Hawaiian shallow- and deep-set longline fisheries, Mexican longline, the U.S.A. large mesh drift gillnet fishery and small-scale domestic longline survey (Sippel *et al.* 2015).

Additional size data that were neither spatially-explicit nor sex-specific were also reviewed by the SHARKWG. These data were aggregated with the spatially explicit data described above to investigate size trends by fishery through time and are provided in the results of this report. The biological sampling programs that collected size data varied in scope and design.

Size data for the Hawaiian longline fisheries were collected through the Hawaiian observer program. The observer program has been in operation since 1995, but through 2000 sampling may have been biased due to low coverage rates and non-random assignment of observers to fishing vessels. However, the program was redesigned in 2001 with increased coverage rates and randomized design, thereby minimizing or removing potential sampling biases (Sippel *et al.* 2014b). The shallow-set fishery has always operated with 100% observer coverage, and all sharks are measured, so sampling has been considered representative of the fishery catch. Biological sampling for the U.S. West Coast drift gillnet fishery was conducted by port samplers between 1980-1990 (Childers and Halko 1994) and thereafter by observers following a statistically designed sampling program.

Mexico's size data come from their observer program that was first implemented in 2006 and has operated in both the longline and drift gillnet fisheries (Castillo-Géniz *et al.* 2014). The assignment of observers to trips is not designated through a randomized design and coverage rates have not been consistent through time, so sampling biases may occur.

Japanese size and sex data come from two fisheries. One is the Japanese shallow-set longline fishery which operates primarily in the western and central North Pacific Ocean and the size data are collected by port samplers (Ohshimo *et al.* 2014; Kai *et al.* 2015a). The second source is from onboard size measurements taken in the Japan RTV fishery which operates primarily around Hawaiian waters using deep-set longline gear (Clarke *et al*. 2011b).

Taiwan collects biological data from its longline fisheries through both onboard observers as well as port sampling. While the quality of data collected by observers should be reliable, sample sizes were low and protocols for at-sea sampling (e.g. randomization) were not described, so caution should be exercised with respect to representativeness of these data. Taiwanese port samples came from processed catch (frozen and with head, fins, and tail removed) unloaded at docks.

3.5 Prioritization of data components using simulation analyses

The use of simulation analyses assisted in the prioritization of the data available to be used as stock status indicators. Results from the simulation showed that time series of mean length are less informative regarding the current stock condition (*Bcur/Bmsy*) than CPUE indices of abundance (Lee *et al.* 2015).

3.6 Prioritization of CPUE indices

The simulation analyses showed that the effectiveness of CPUE as a stock status indicator depends on the length of the time series as well as the precision of the estimates (Lee *et al.* 2015). The prediction power of any CPUE time series increases as the length of time between the start of the time series and the unfished state decreases and when year to year variability is lower. Relatively short CPUE time series (e.g. 5 years) seem to have almost no information regarding the current stock status. Simulation results also showed that CPUE indices that are derived from predominately adult areas provide better information on current stock status than CPUE indices from recruitment areas.

4 RESULTS OF INDICATOR-BASED ANLYSES

Four types of indicators were developed for the North Pacific shortfin mako shark: proportion of positive sets, abundance indices, sex-ratio and size compositions. These indicators are presented here as annual time series and assessed for their utility in describing population trends.

4.1 Proportion of positive sets

The proportion of positive sets, defined as each set/trip where at least one shortfin mako sharks was caught, was calculated for major fisheries. Summarizing the trends of this indicator from multiple fisheries over space and time may indicate high abundance areas and/or efficiency of fleets. However, this indicator should be interpreted with caution because it is confounded with catchability and selectivity.

The trends for proportion of positive sets varied across fisheries and are shown in Figure 4.1. The proportion of positive sets increased steadily from 1994-2013 in the Japanese shallow-set longline fishery; was variable without trend from 1992-2007 before declining from 2008-2013 in the Japanese research and training vessel fishery; was variable without trend from 1995-2004 before increasing from 2005-2012 in the Hawaii deep-set longline fishery; was flat without trend from 1995-2000 before nearly doubling then slightly declining from 2005-2012 in the Hawaii shallow-set longline fishery; was variable without trend from 1980-2012 U.S. West Coast drift gillnet fishery; and increased steadily in Mexico's longline fishery off Baja California from 2006-2014. Across these fisheries, the Japanese shallow-set longline fishery has the highest proportion of positive catch sets (approximately 75% in 2013, with the rate nearly tripling over the time series).

4.2 Indices of relative abundance

Indices of shortfin mako relative abundance were developed from eight fisheries or surveys ranging from 1985-2014 and covering different areas across most of the North Pacific (Figure 4.2). All indices were reviewed by the SHARKWG, and three were selected as the most plausible indicators of abundance based on their spatial and temporal coverage, size of sharks, data quality, and model diagnostics. A summary of characteristics of the abundance indices reviewed by the SHARKWG is in Table 3.1.

The Japanese shallow-set longline index was considered to be the best abundance indicator candidate because of the large spatio-temporal coverage of the dataset, consistent catchability through time, and the acceptable diagnostics of zero-inflated negative binomial model. The standardized index showed a flat or slightly increasing trend from 1994-2004, before a substantial increase from 2005-2013.

Abundance indices developed from the Hawaii-based longline fisheries were also both considered to be plausible indicators of abundance. Data quality was considered to be good as both indices were developed from data collected by onboard observers, with 100% observer coverage in the shallow-set fishery over the 2005-2013, and ~20% coverage in the deep-set fishery during the 2002-2013. The SHARKWG deemed model diagnostics to be acceptable for both indices. Both fisheries cover medium spatial extents when compared to the other indices examined, although catchability may not have been constant in the shallow-set fishery because bycatch mitigation measures imposed in 2006 and 2011 may have changed fishery behavior. Trends in abundance showed some variability for the two fishery sectors between 2004 and 2012. The standardized CPUE trends moved in opposite directions, with the trend for the shallow-set sector showing a slight decrease, while the trend for the deep-set sector increased overtime.

An index produced from the relatively small-scale Japanese longline survey in the Northwest Pacific for 2000-2014 was considered to be less informative as a stock indicator. Although the quality of data were considered good because it was a research survey, sample size was fairly low with only 650 makos caught from a single vessel over the survey period. The index indicated a mostly flat, but variable trend from 2000-2012, with a steep increase over 2013 and 2014.

The index developed for the U.S. West Coast drift gillnet fishery, 1985-2013, was also considered to be less informative as a stock indicator. The time-series was split into two time periods because bycatch mitigation regulations implemented in 2001 substantially changed the spatio-temporal distribution and amount of effort in the fishery, thus catchability was likely greatly affected. The fishery also catches primarily immature shortfin makos with only the occasional larger adult. The index was derived from logbook data, with nearly 100% coverage and verification through an observer program since 1990, so there was high confidence in data quality. The resulting index indicated a slight overall increasing trend from 1985-2013 with several brief increases and decreases over time.

The Taiwan distant-water longline fleet index for 2005-2012 was not considered a reliable abundance index at this time, although the nominal CPUE data for two spatial areas were believed to provide some useful information. The SHARKWG expressed some concerns about the statistical soundness of the complete standardized model based on departures from normality of model residuals and the low observed effort for certain areas and times. The overall fishery does cover the largest spatial area of all fisheries however, and catchability was not thought to have changed much through time. The non-uniform effort across the 4 spatial areas used in the standardization led to consideration of the data and nominal CPUE trends for areas 1 and 3 only for the stock indicator analysis. The nominal CPUE for area 3 showed a noisy but overall declining abundance trend from 2005-2012, whereas the nominal CPUE in area 1 showed an increasing trend from 2008-2012.

The abundance index developed for the Mexico longline fishery, 2006-2014, was deemed to be less informative as a stock indicator as well. The time series is rather short, the fishery occurs over a relatively small region of the EPO, and the catches are primarily juvenile shortfin makos. The observer program from which the data came was not of a balanced design and likely not representative of the overall fishery for all years (Castillo-Géniz *et al.* 2014). Furthermore, changes in fishery management may have led to changing catchability through time. No clear trend was apparent from the index due to its highly variable (noisy) pattern.

The SHARKWG reviewed an index from a fishery-independent survey of juvenile sharks conducted off California in the EPO, 1994-2013. The index was not considered to be a reasonable indicator of stock abundance and was not used in indicator analyses. The survey covers the smallest area of all indices presented and targets juvenile sharks on a known nursery area. The total number of sets was low. Although the data quality is good, the apparent variability in catch rates is believed to reflect the changing distribution in space and time of juveniles within the nursery that may only adequately be addressed with a larger scale or adaptive survey.

4.3 Sex ratio

The proportion of females is between 50-60% in the northwest Pacific Ocean, ranges from 20-60% in the central Pacific, with a small core of 50-60% east of the Hawaiian Islands, and ranges from approximately 40-60% along the west coast of North America (Sippel *et al.* 2015). Overall, no trends in sex-ratio are apparent through time across fisheries, although sample sizes are generally low (Figure 4.3). It would probably be difficult to interpret any trends in sex-ratio because there is not a good understanding of the dynamics of the population by size and sex through time. Thus, the SHARKWG considered sex-ratios to be of little value as indicators in this analysis of stock status.

4.4 Size

Length measurements can be made quickly and easily and could provide useful stock status indicators if collected in an unbiased manner across fisheries. In general, higher exploitation rates result in removals of fish before they have a chance to reach larger sizes, therefore generate a substantial reduction in the average and/or median size of fish being caught.

The annual median and quartile percentiles of catch at size in PCL (cm) for shortfin mako sharks caught by the various fleets in the North Pacific Ocean are presented in Figure 4.4. In general sizes remained relatively stable for all fleets. Larger sizes were recorded for the deep-set sector of the Hawaiian fleet and the Japan research and training longline vessels, while smaller individuals were more common in the U.S. juvenile longline survey, U.S. drift gillnet, and Japan juvenile longline survey. High variability in the median sizes observed in many cases could be due to small sample sizes. For example, median sizes for the Japan longline survey and U.S. juvenile longline survey are variable and mainly represent just a few juvenile age classes. For other fleets, like Taiwan's distant-water longline and Hawaii's shallow-set longline, median sizes are also variable across years.

5 STOCK STATUS

5.1 Synthesis of indicators

Although our knowledge about shortfin mako life history is not complete, a general picture of the dynamics of the assumed north Pacific stock has emerged. Juvenile sharks are found in both the eastern and western areas of the Pacific Ocean near continental land masses. Older sharks are increasingly found in the central Pacific where mating likely takes place. Under this hypothesis, fisheries operating near the Japan and North America coastlines take young sharks while those fisheries from the central Pacific catch older ages. Like other large pelagic sharks, shortfin mako produce relatively few offspring, mature at older ages and are thus less resilient/more susceptible to fishing pressure than the typical teleost.

Like our knowledge of life history, our compilation of fishery data is also incomplete. However, a general conclusion regarding stock condition is also emerging from the information examined. Effort for the fisheries examined that catch shortfin makos throughout the North Pacific seems to have declined overall, although effort estimates for several fisheries and nations were unavailable. Of the available indices of relative abundance (CPUE), only the Japanese shallow-set longline and both Hawaiian longline indices (shallow- and deep-set) are considered good candidates for representing stock trends. All three indices cover a large part of the Pacific where mature sharks are found. Both the Japanese shallow-set and the Hawaiian deep-set indices indicate non-negative trends and the Hawaiian shallow-set a negative trend. Although the negative trend in the Hawaiian shallow-set should not be completely discounted, the variability in the annual length distributions from this fishery suggests that the index selectivity/catchability fluctuates which may invalidate the proportionality assumption. It should also be considered that the rate of population increase described by the Japanese shallow-set post 2000 is likely too steep to solely reflect the response of a Lamnidae species to a relaxation of fishing pressure (Smith *et al.* 1998). The recent targeting of blue shark by this fleet may be affecting the catch rates of shortfin mako, and analytical attempts to factor out this effect have not been fully explored..

Simulation work has shown that time series of mean fish length are a poor predictor of stock condition, but that indices of abundance that are proportional to stock size may be a good predictor depending on the length of series (how close to unfished) and the precision of the estimate. Therefore we consider the CPUE series as the best fishery indicators of stock condition. However, all of the indices examined start at a time period far from the unfished condition, making interpretation of these data regarding stock condition uncertain.

5.2 Stock Status and Conservation Advice

Shortfin mako is a data poor species. Recognizing that information on important fisheries is missing, the untested validity of indicators for determining stock status, and conflicts in the available data, stock status (overfishing and overfished) could not be determined. Managers should consider the undetermined stock status of shortfin mako shark in the North Pacific when developing and implementing management measures.

The SHARKWG reviewed a suite of information to determine the stock status of shortfin mako shark in the North Pacific. Of the three indices considered to have the greatest value in providing stock status information, abundance trends in two of the series appear to be stable or increasing, while the abundance trend in the third series appears to be declining.

It is recommended that data for missing fleets be developed for use in the next stock assessment scheduled for 2018 and that available catch and CPUE data be monitored for changes in trends. It is further recommended that data collection programs be implemented or improved to provide species- specific shark catch data for fisheries in the North Pacific.

6 RESEARCH RECOMMENDATIONS

The SHARKWG offers the following priority research recommendations. Advice is given in two sections: 1) recommendations to improve subsequent indicator analyses, and 2) recommendations to move toward a more quantitative integrative stock assessment.

<u>Improve future indicator analyses</u>

1. Improve data filtering and standardization for all CPUE indices. Improvements could help explain some of the implausible rates of change in currently accepted series. Other important series (notably the Taiwanese distant-water longline) could be considered as suitable indicators with better statistical treatment of the data.
2. Improved summarization of indicator series. For CPUE data, investigate using state space modeling to characterize trends. For size composition data, investigate indicators (beyond average size) or methods of using the data for providing information on stock condition.

<u>Improve data compilation/collection to be able to conduct a full assessment</u>

1. Full accounting of all catch and discarded mortality.
2. Explore methods to provide estimates of data from the historical period.
3. Continue to improve knowledge of the life history (e.g. age and growth, spawner-recruit relationship, etc.) to move towards an age-structured assessment model.

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TABLES

Table 3.1. Characteristics of the relative abundance indices of shortfin mako sharks in the North Pacific Ocean.

Nation	USA	USA	USA	USA	Mexico	Taiwan	Japan	Japan
Fishery	**Hawaii longline - Deep set**	**Hawaii longline - Shallow set**	**West Coast Large-mesh drift gillnet**	**Southern California Bight fishery-independent longline survey**	**Mid-size Longline**	**Large-scale longline**	**Fishery-independent longline survey**	**Shallow set longline**
Type/Quality of Observations	Good because using observer data and has 10-20% coverage and discards recorded.	Good because using observer data with 100% coverage and discards recorded.	Good because using logbook data with good coverage and discards are recorded. Verified with observer data since 1990.	Research survey with good data collection but sample size is low (total 460 sets).	Observer data, but coverage varies in space and time.	CPUE based on the logbook data and coverage is not known. Size data is based on the observer data. Subset of data verified with observer data.	Research survey with good data collection, but sample size is low. Total 650 mako sharks were caught.	logbook data, filtered based on verification with research trips, shallow and Tohoku and Hokkaido fleets only: considered most reliable data for index
Spatial Coverage	Medium: 5 - 30 N, 140 - 175 W	Medium: 20 - 40 N, 135 - 175 W	Small: 32 - 45 N, 117 - 125 W	Small: 32 - 34 N, 117 - 120 W	Small: 15 - 32 N, 105 - 120 W	Large: 0 - 45 N, 140 E - 100 W	Small: 28 - 40 N, 140 - 150 E	Large: 24-45 N, 137 E-160 W
Size range (cm PCL) of 90% of catch	(F) 126-217; (M) 127-205	(F) 65-200; (M) 70-214	(F) 69-160; (M) 70-158	(F) 70-144; (M) 70-146	(F) 71-161; (M) 71-172	105-200	(F) 64-148; (M) 64-152	(F) 92-180; (M) 100-190
Median size (PCL)	(F) 168; (M) 164	(F) 101; (M) 144	(F) 105; (M) 106	(F) 95; (M) 98	(F) 112; (M) 113	135	(F) 109; (M) 110	(F) 130; (M) 140
Predominant age classes	Adult	Subadult	Juvenile	Juvenile	Juvenile	Subadult/Adult	Juvenile	All sizes
Statistical soundness	Reasonable based on diagnostics provided.	Reasonable based on diagnostics provided.	Reasonable based on diagnostics provided.	Reasonable based on diagnostics provided.	Reasonable based on diagnostics provided.	Some concerns. Residual pattern of lognormal part deviates from normal.	Reasonable based on diagnostics provided.	Reasonable based on diagnostics provided.
Time series length	12 yrs (2002-2013)	9 yrs (2005-2013)	16 yrs (1985-2000); 12 yrs (2001-2012)	18 yrs (1994-2013)	9 yrs (2006-2014)	8 yrs (2005-2012)	13 yrs (2000-2014)	20 yrs (1994-2013)
Q Changes (due to management, fishing practices, etc.)	No major regulatory and fishery changes after the ban on finning in 2000. Slight increase of effort for region 5 (20-30 N, 135 - 160W).	Likely due to the regulatory requirements upon reaching turtle take caps in 2006 and 2011.	Multiple regulatory changes across entire time period (Q probably changed through time).	No change in operation of survey. If population distribution is correlated to the environment, then Q may vary.	Gillnet closed in 2009 and may affect the longline effort and size structure. Summer time shark closure since 2012.	Q is relatively stable.	No change in operation of survey. If population distribution is correlated to the environment, the Q may vary. Standaridzation includes location information so should account for that.	No change overtime that may affect mako catch (non-target species); potential change in discard ratio over time.
Average Observation CV	0.18	0.17	0.17 (early); 0.10 (late)	0.07	0.21	0.12	0.36	0.12
CV based on smoother	0.18	0.17	0.17(early); 0.26 (late)	0.2	0.21	0.12	0.36	0.12
Value of index	High	High	Low	Not used	Low	Low (nominal areas 1 and 3 only)	Low	High
Comments	Diagnostics are reasonable. Coverage area is relatively small in the North Pacific.	Diagnostics are reasonable. Coverage area is relatively small in the North Pacific and the fishery has some regulatory changes that may affect CPUE.	Large change in fishing area over time and covers a relatively small area in the North Pacific. Fishery operates in a nursery area. Time series is quite long compared to other indices.	Survey operates in a nursery area and is very small in spatial scale. Survey design may not be adequate given the variable distribution over space and time of the juveniles.	The index with just the Ensenada fleet was recalculated. Diagnostics considered reasonable. Second index with Mazatlan fleet and historical large longline may be possible.	Effort may differ across regions and time. Standardized index for all areas combined not considered useful due to an apparent time x area effect and shifts in relative effort between areas. Effort in areas A and C is higher than in B and D. Nominal area specific indices for areas A and C are considered useful at the "low" value category.	Small area but operates in Japan's core mako fishing ground.	4 areas with CPUE estimated for each and as combined index. Combined index considered useful for stock determination.

FIGURES

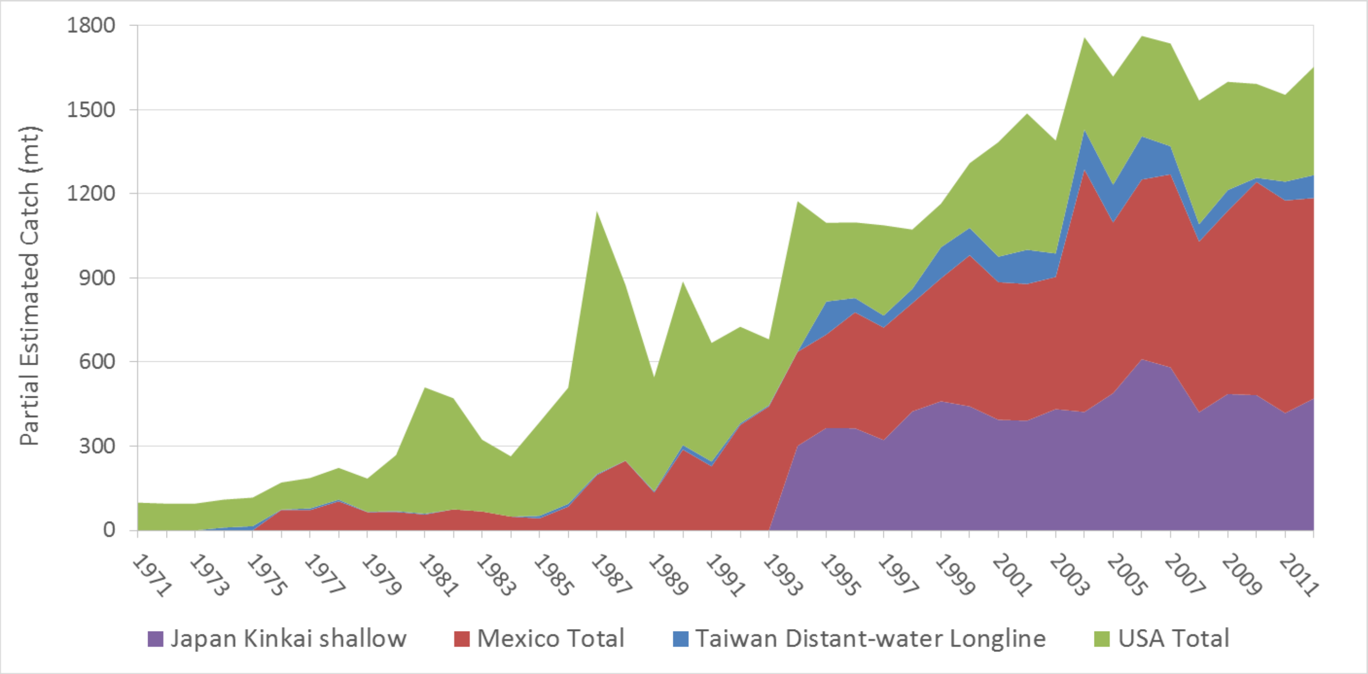


Figure 3.1. Partial catch estimates of shortfin mako shark for several fleets/nations operating in the North Pacific Ocean. Catch estimates are not available for some major fisheries including Taiwan small-scale longline, Japan distant-water longline, and China's and Korea's longline fleets. Trends in shortfin mako catch cannot be derived from the data provided given the data are incomplete and for individual fisheries/nations they may not reflect the entire history of the fishery.

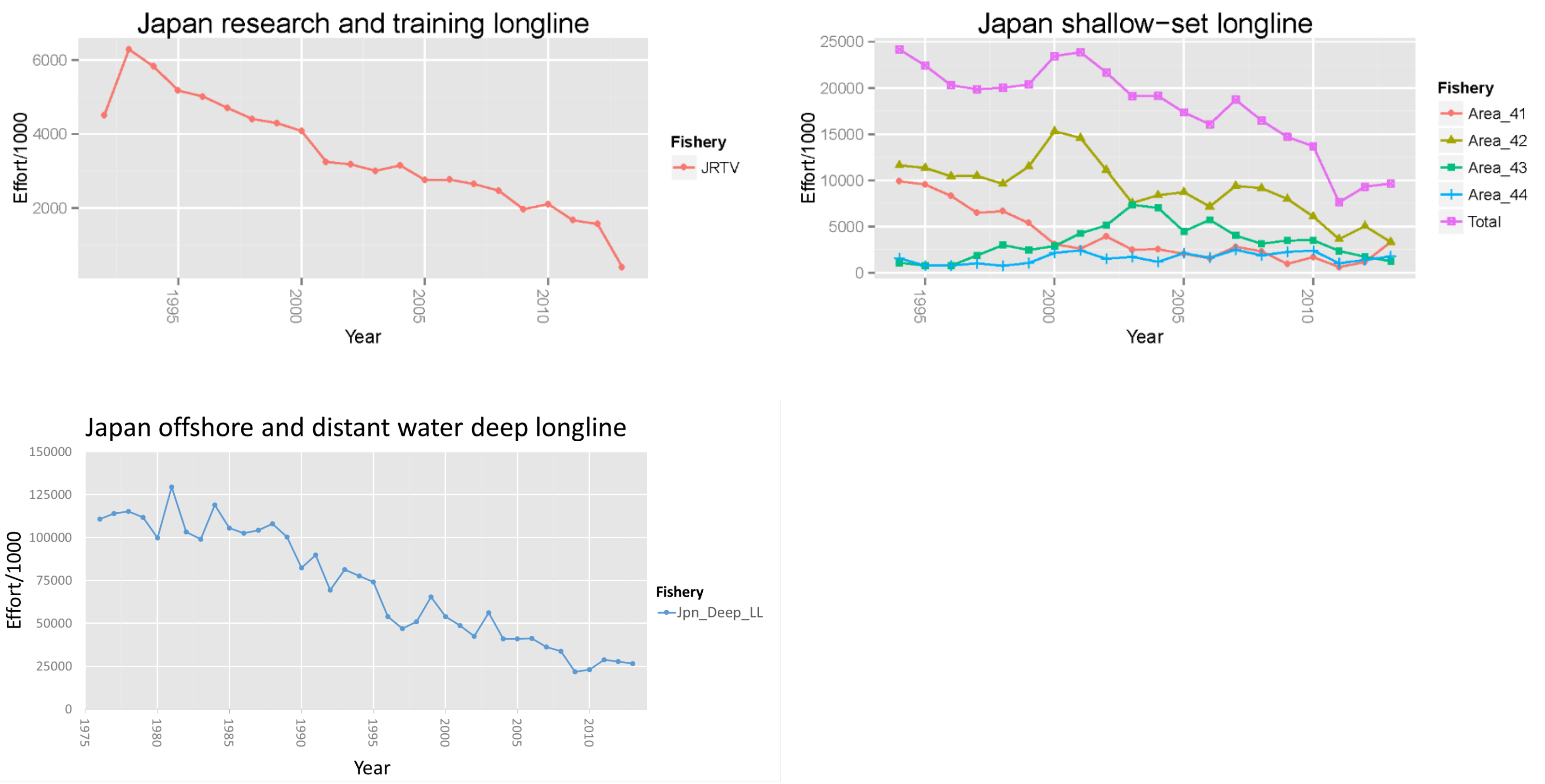


Figure 3.2. Fishing effort by fishery of shortfin mako sharks in the North Pacific Ocean. Units of effort are number of 1,000 hooks and number of sets for longline fishery and drift gillnet fishery, respectively.

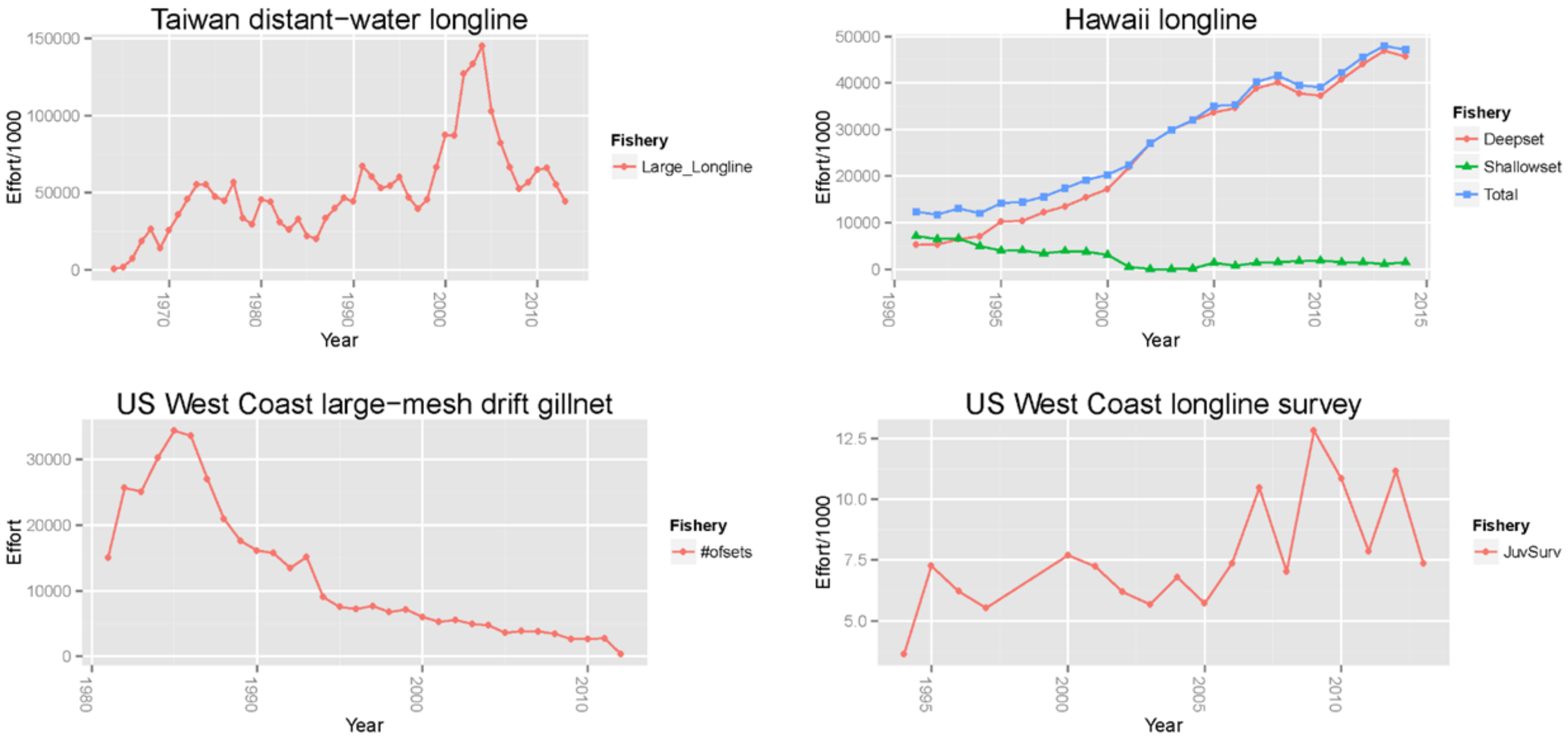


Figure 3.2 continued.

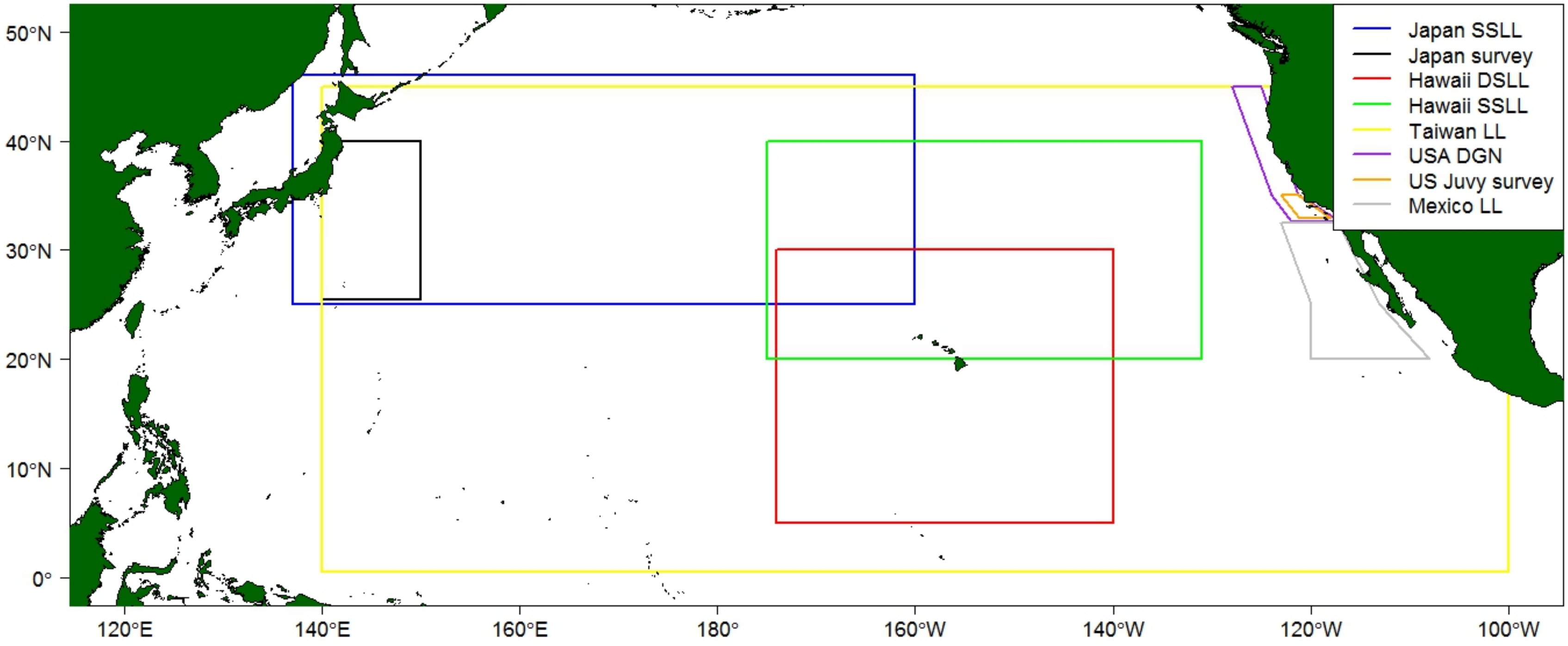


Figure 3.3. Spatial extent of the fisheries for which CPUE time series were developed. Fisheries include Japan shallow-set longline (Japan SSLL), Japan longline survey (Japan survey), Hawaii-based deep-set longline (Hawaii DSLL), Hawaii-based shallow-set longline (Hawaii SSLL), Taiwan distant water longline (Taiwan LL), U.S. west coast large-mesh drift gillnet (USA DGN), U.S. juvenile shark longline survey (US Juvy survey), and Mexico longline (Mexico LL).

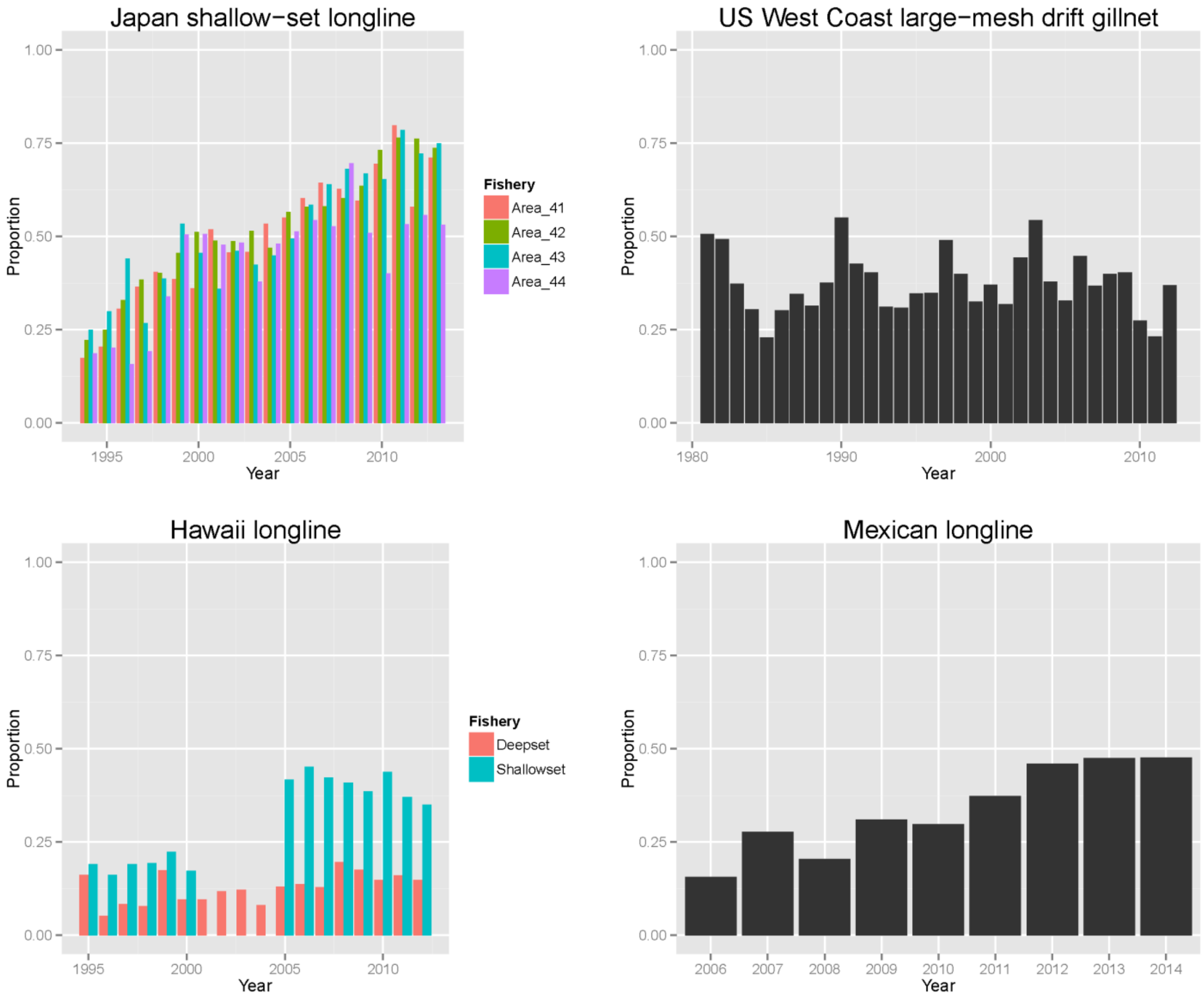


Figure 4.1. Proportion of positive sets by fishery of shortfin mako sharks in the North Pacific Ocean.

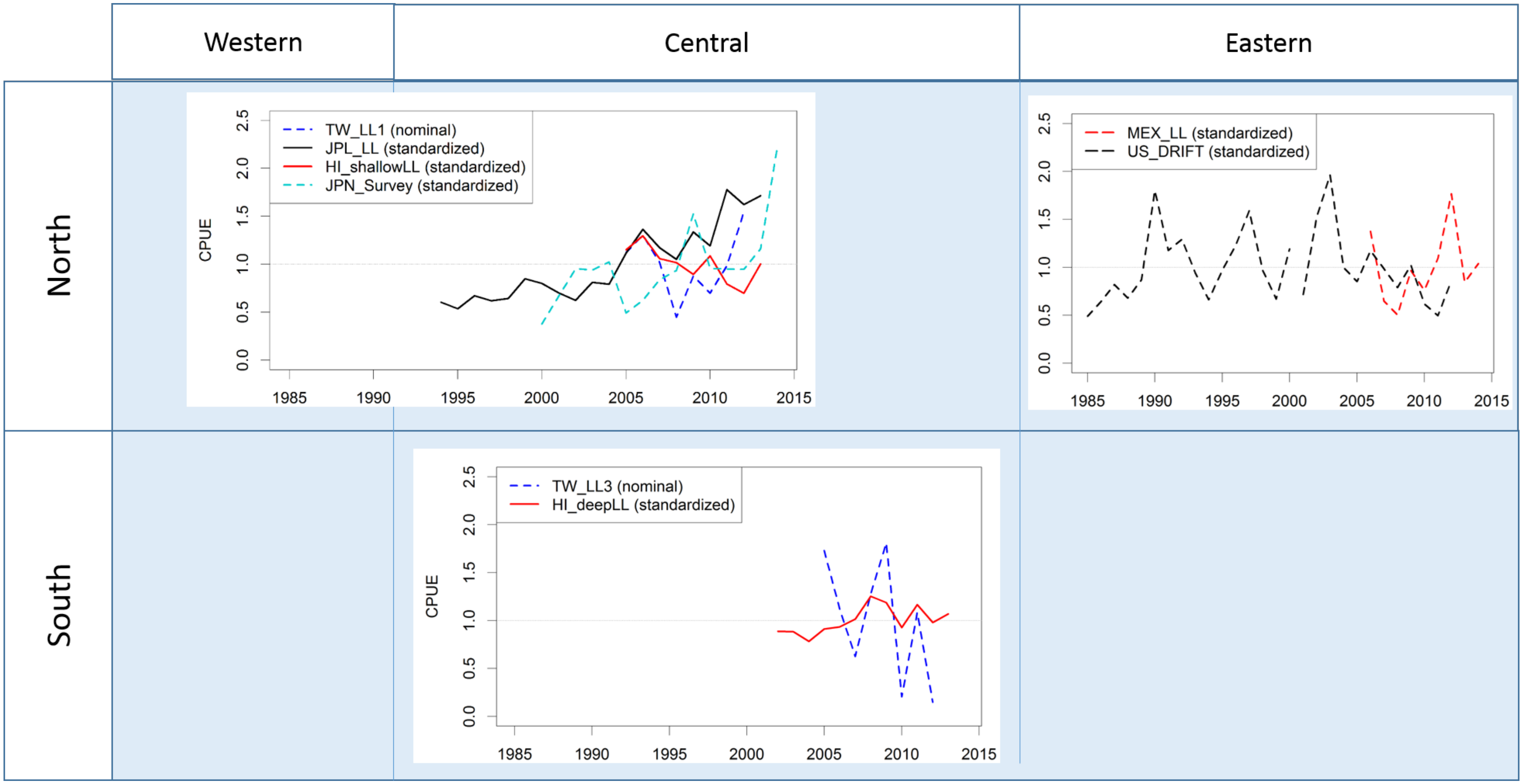


Figure 4.2. Plots of CPUE by fishery for shortfin mako sharks in the North Pacific Ocean. Indices considered to have the greatest value in determining stock status are shown with solid lines.

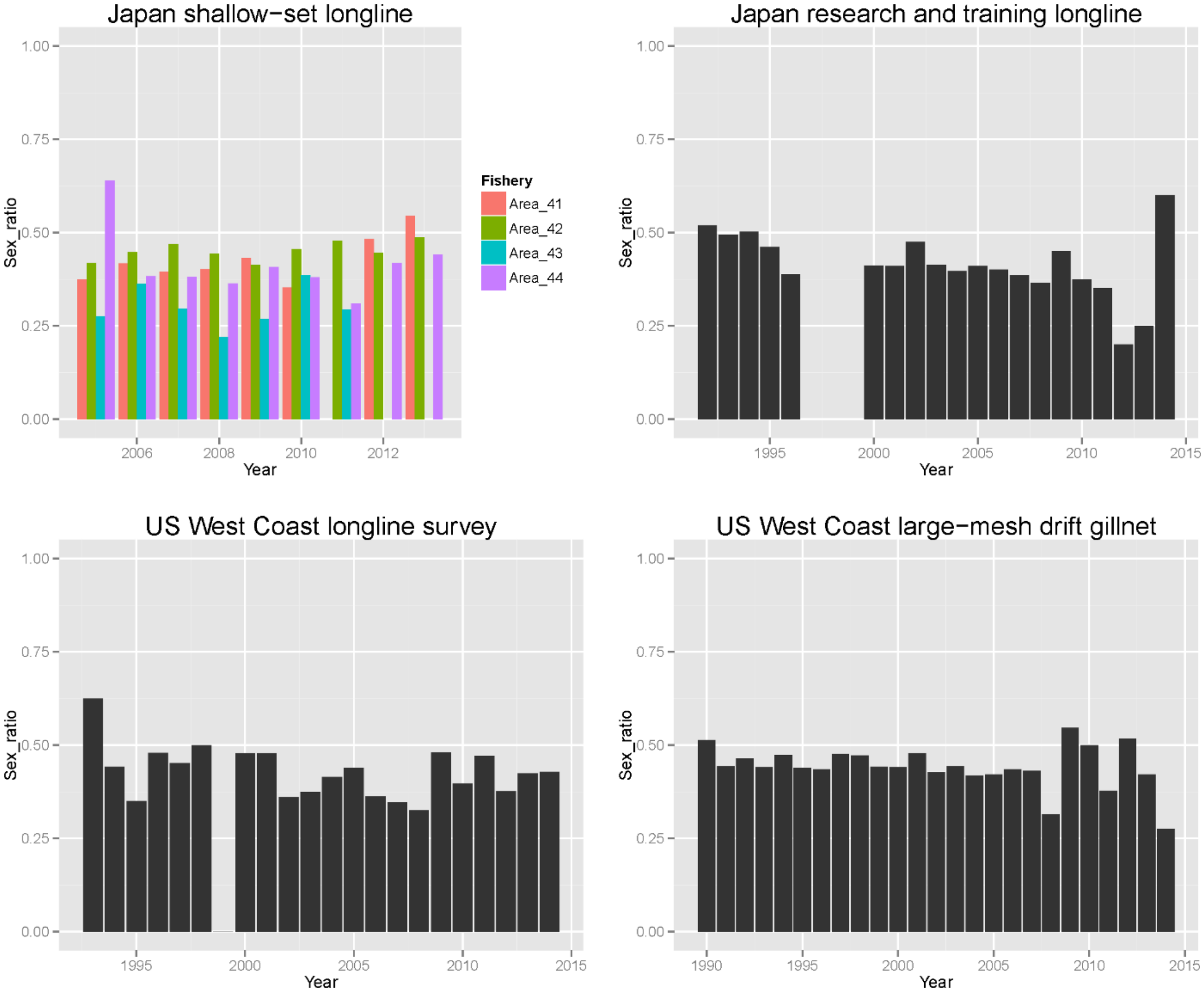


Figure 4.3. Sex ratio (proportion of females) by fishery of shortfin mako sharks in the North Pacific Ocean.

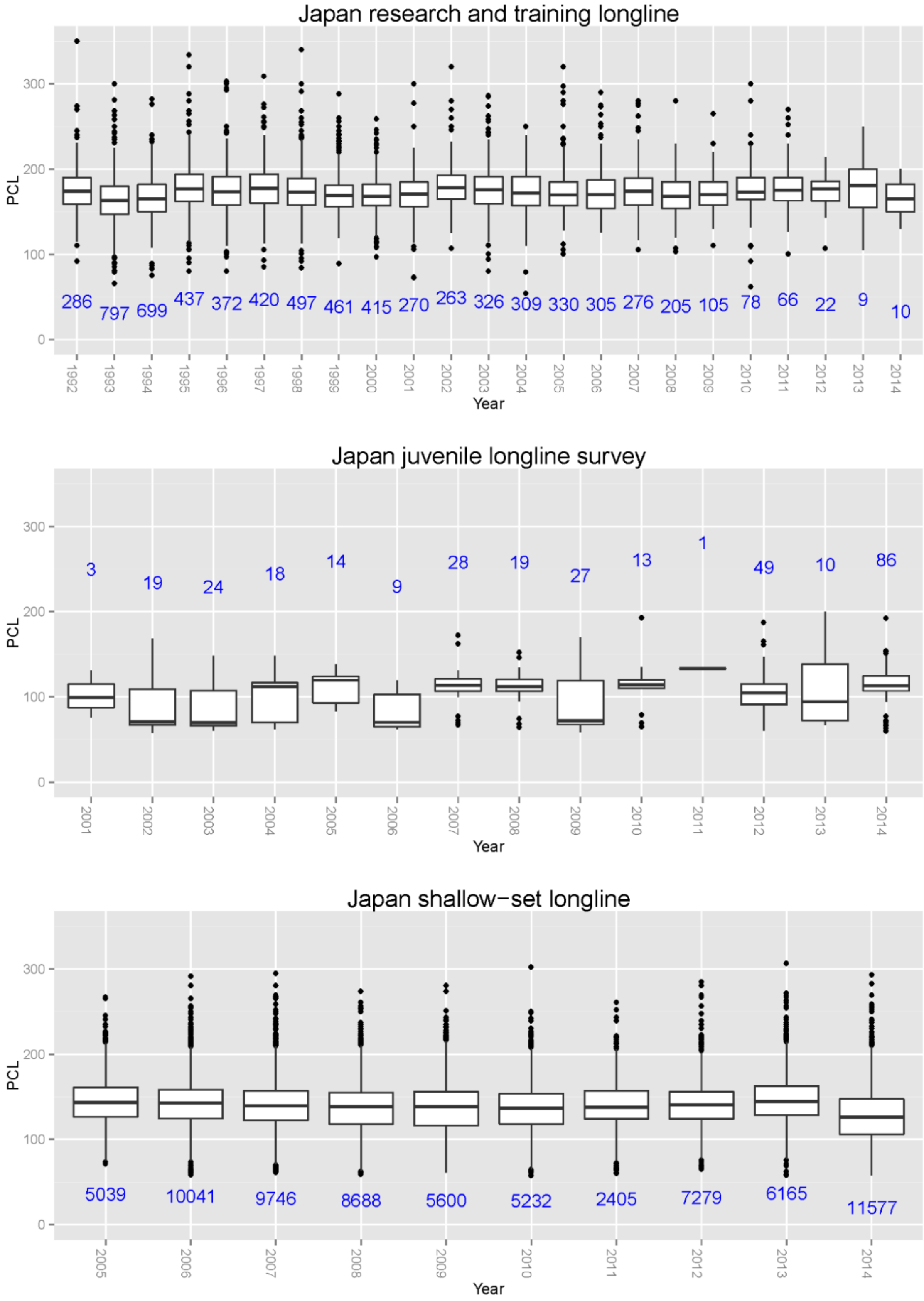
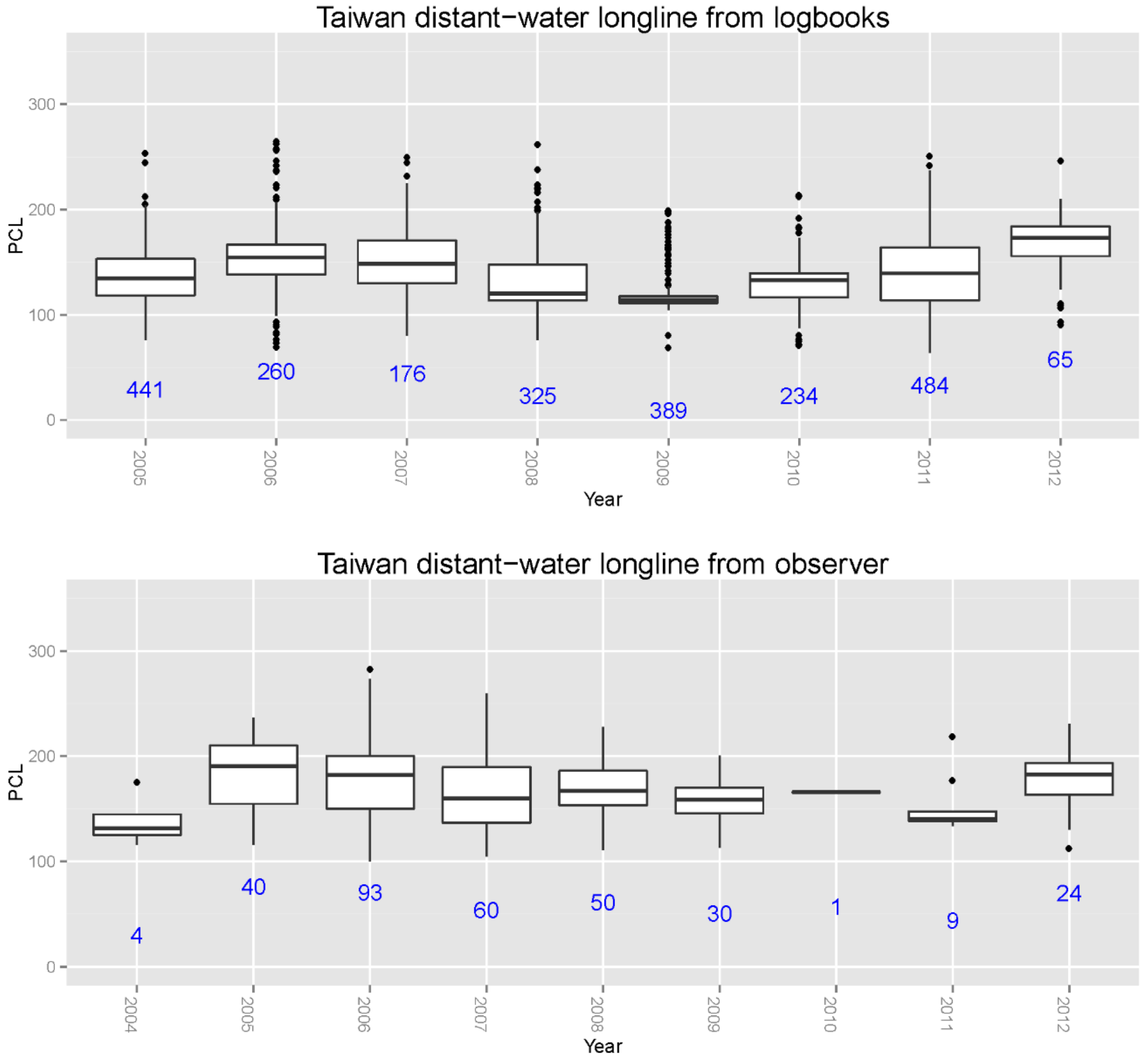


Figure 4.4. Boxplots (showing medians, interquartile ranges, 1.5 times the interquartile ranges, and outliers) of the annual sizes of shortfin mako sharks caught in North Pacific surveys and fisheries.


Taiwan distant−water longline from logbooks

Taiwan distant−water longline from observer

Figure 4.4 continued.

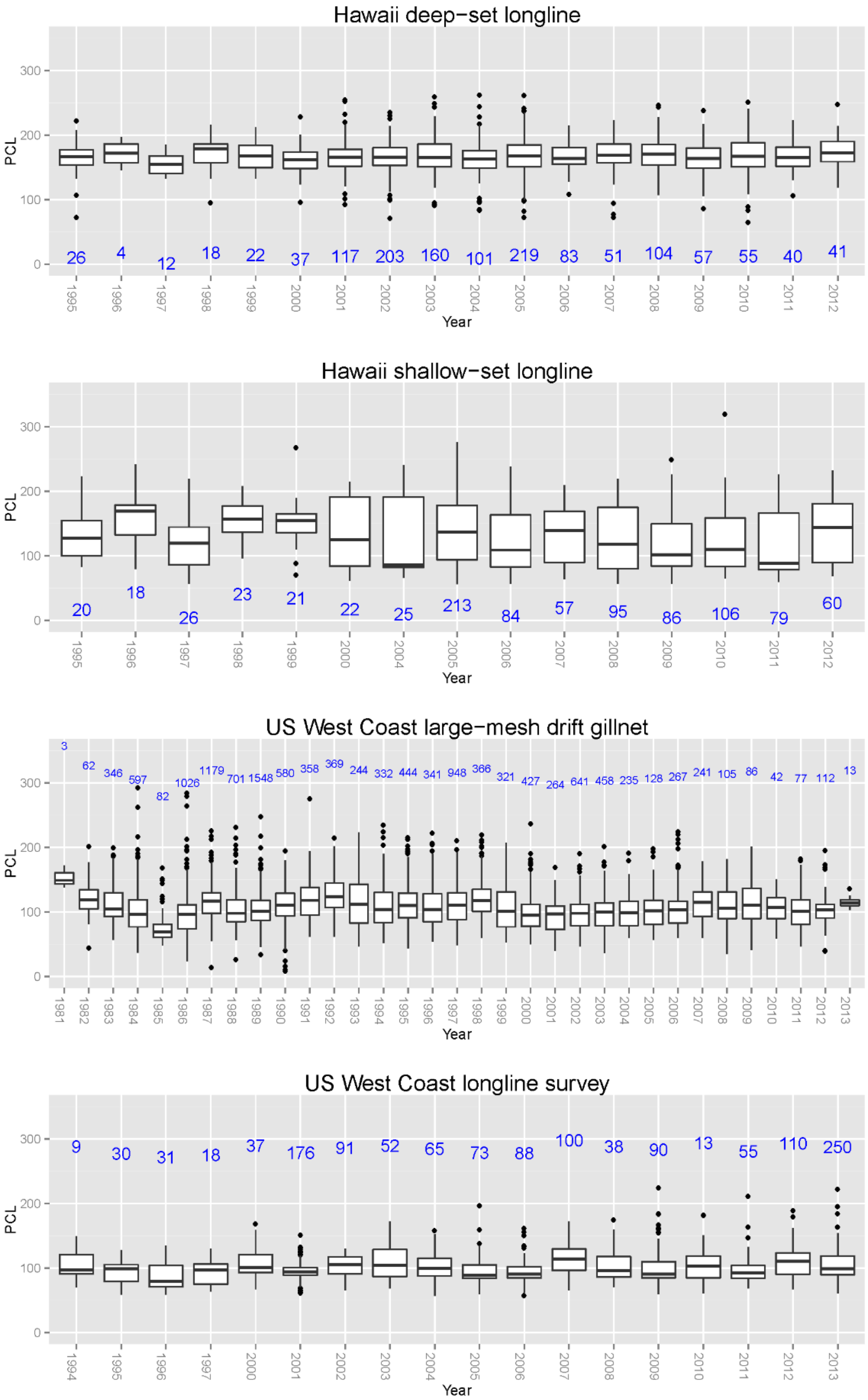


Figure 4.4 continued.