CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES
OF WILD FAUNA AND FLORA

Sixteenth meeting of the Conference of the Parties
Bangkok (Thailand), 3-14 March 2013

POPULATION TRENDS IN PACIFIC OCEANIC SHARKS AND THE UTILITY OF REGULATIONS ON SHARK FINNING

The attached document has been submitted by the United States of America at the request of Shark Advocates International, the Project AWARE Foundation and Humane Society International, in relation to amendment proposal CoP16 Prop. 42 on the ocean whitetip chark (*Carcharhinus longimanus*).*

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Population Trends in Pacific Oceanic Sharks and the Utility of Regulations on Shark Finning

SHELLEY C. CLARKE,* SHELTON J. HARLEY, SIMON D. HOYLE, AND JOEL S. RICE

Oceanic Fisheries Program, Secretariat of the Pacific Community, B.P. D5,98848, Nouméa CEDEX, New Caledonia

Abstract: *Accurate assessment of shark population status is essential for conservation but is often constrained by limited and unreliable data. To provide a basis for improved management of shark resources, we analyzed a long-term record of species-specific catches, sizes, and sexes of sharks collected by onboard observers in the western and central Pacific Ocean from 1995 to 2010. Using generalized linear models, we estimated population-status indicators on the basis of catch rate and biological indicators of fishing pressure on the basis of median size to identify trends for blue (*Prionace glauca*), mako (*Isurus *spp.), oceanic whitetip (*Carcharhinus longimanus*), and silky (*Carcharhinus falciformis*) sharks. Standardized catch rates of longline fleets declined significantly for blue sharks in the North Pacific (by 5% per year [CI 2% to 8%]), for mako sharks in the North Pacific (by 7% per year [CI 3% to 11%]), and for oceanic whitetip sharks in tropical waters (by 17% per year [CI 14% to 20%]). Median lengths of silky and oceanic whitetip sharks decreased significantly in their core habitat, and almost all sampled silky sharks were immature. Our results are consistent with results of analyses of similar data sets. Combined, these results and evidence of targeted fishing for sharks in some regional fisheries heighten concerns for sustainable utilization, particularly for oceanic whitetip and North Pacific blue sharks. Regional regulations that prohibit shark finning (removal of fins and discarding of the carcass) were enacted in 2007 and are in many cases the only form of control on shark catches. However, there is little evidence of a reduction of finning in longline fisheries. In addition, silky and oceanic whitetip sharks are more frequently retained than finned, which suggests that even full implementation of and adherence to a finning prohibition may not substantially reduce mortality rates for these species. We argue that finning prohibitions divert attention from assessing whether catch levels are sustainable and that the need for management of sharks should not be addressed by measures that are simple to implement but complex to enforce and evaluate.*

Keywords: indicator, mortality, sustainability

Tendencias Poblacionales de Tiburones del Océano Pacífico y la Utilidad de Regulaciones sobre Cercenamiento de Aletas

Resumen: *La evaluación precisa del estatus de las poblaciones de tiburón es esencial para la conservación pero a menudo es constreñida por datos limitados y poco confiables. Para proporcionar una base para un mejor manejo del recurso tiburón, analizamos un registro de largo plazo sobre la captura de especies, tamaños y sexos de tiburón recolectados por observadores a bordo de embarcaciones en el Pacífico occidental y central de 1995 a 2010. Utilizando modelos lineales generalizados, estimamos indicadores del estatus de la población con base en la tasa de captura e indicadores biológicos de la presión de pesca con base en tamaño medio para identificar tendencias para* Prionace glauca*,* Isurus *spp.,* Carcharhinus longimanus *y* Carcharhinus falciformis*. Las tasas de captura estandarizadas declinaron significativamente para* P. glauca *en el Pacífico Norte (5% por año [IC 2% a 8%]), para* I. *spp. en el Pacífico Norte (7% por año [IC 3% a 11%] y para* C. longimanus *en aguas tropicales (17% por año [IC 14% a 20%]). Los tamaños medios de* C. falciformis *y* C. longimanus *decrecieron significativamente en su hábitat núcleo, y casi todos los individuos de* C. falciformis *eran inmaduros. Nuestros resultados son consistentes con los análisis de conjuntos de datos similares. Combinados, estos resultados y evidencia de la pesca de tiburones en algunas pesquerías regionales*

**email scc@sasama.info*

Paper submitted February 9, 2012; revised manuscript accepted July 3, 2012.

Conservation Biology, Volume 00, No. 0, 1–13

DOI: 10.1111/j.1523-1739.2012.01943.x

aumentan la preoocupación por el uso sustentable de tiburones, particularmente de C. longimanus *y* P. glauca, *no son sustentables. En 2007 se decretaron regulaciones regionales que prohíben el cercenamiento de aletas de tiburón (remoción de aletas y eliminación del cuerpo) y en muchos casos son la única forma de control de la captura de tiburones. Sin embargo, hay poca evidencia de la reducción del cercenamiento en las pesquerías. Adicionalmente,* C. longimanus *y* P. glauca *son retenidos más frecuentemente que cercenados, lo que sugiere que aun con la implementación plena de y la adhesión a una prohibición de cercenamiento puede que no se reduzcan sustancialmente las tasas de mortalidad de estas especies. Argumentamos que las prohibiciones de cercenamiento desvían la atención de la evaluación de la sustentabilidad de los niveles de captura y que la necesidad del manejo de tiburones no debe ser abordada con medidas que son sencillas de implementar pero complejas de aplicar y evaluar.*

Palabras Clave: indicador, mortalidad, sustentabilidad

Introduction

In the decade following the UN Food and Agriculture Organization's International Plan of Action for the Conservation and Management of Sharks (FAO 1999) and the first listing of shark species by the Convention on Trade in Endangered Species in 2001, several steps have been taken to protect vulnerable oceanic shark species. These range from listings by international treaty organizations, such as the Convention on Migratory Species, to banning the trade and possession of shark fin products by several U.S. states and territories and to establishing shark "sanctuaries" in Pacific Island countries, such as Palau and the Marshall Islands. In general, however, international fisheries managers continue to view sharks as bycatch rather than target species requiring management (Gilman et al. 2008; Camhi et al. 2009), despite the fact that the high value of shark fins is widely acknowledged as a major driver of shark mortality (Clarke et al. 2006; Clarke et al. 2007).

Absence of data is an important factor in the low level of fisheries management for oceanic sharks. Due to their differing life histories and expected susceptibilities to fishing gear, shark species vary in their vulnerability to overexploitation (Cortés 2002; Cortés et al. 2010). Because shark catches (i.e., quantity of sharks killed as a result of fishing activities) are often not reported or are underreported in fishery statistics and species identifications are often lacking or unreliable, species-specific data analyses have been limited largely to a few locations and fleets: western North Atlantic (Baum et al. 2003; Baum & Myers 2004; Myers et al. 2007; Aires-de-Silva et al. 2008; Hayes et al. 2009), Hawaii (Polovina et al. 2009; Walsh et al. 2009), Japan (Matsunaga & Nakano 1999), and New Zealand (Francis et al. 2001). Not all of these studies show significant abundance trends, and some that do have been challenged on the basis of the data sets and methods researchers used (Burgess et al. 2005; Grubbs et al. 2011). Regional assessments of shark stocks have also been limited by data quantity and quality. Assessments of blue, shortfin mako (*Isurus oxyrinchus*), and porbeagle (*Lamna nasus*) sharks have had limited success in determining whether stocks are depleted or are being fished at rates that will deplete them (ICCAT 2009; Kleiber et al. 2009).

The Western and Central Pacific Fisheries Commission (WCPFC) is a regional fisheries management organization responsible for managing 2.4 million t of tuna (*Thunnus* spp. and *Katsuwonus pelamis*) catches in over 100 million km^2: 84% of the Pacific and 60% of the global tuna catch. The total shark catch in the WCPFC area is highly uncertain due to non- and underreporting of sharks in vessel logbooks, but a recent estimate, which was based on WCPFC observer data, suggests catches of a group of 5 so-called key species (blue, makos [*I. oxyrinchus* or *paucus*], oceanic whitetip [*Carcharhinus longimanus*], and silky [*Carcharhinus falciformis*]) of sharks have averaged 2 million individuals annually since the mid-1990s (Lawson 2011).

The WCPFC conservation and management measure for sharks (CMM 2010–07), first agreed to in 2007, seeks to prohibit finning by calling on members to ensure they "have on board fins that total no more than 5% of the weight of sharks on board up to the first point of landing." This wording is designed to ensure that carcasses are not disposed of at sea while fins are retained, but it sets no other limits on shark catches or mortality. Also, the appropriateness of applying a single ratio, whether 5% or another figure, to a range of species and fleets has been questioned (Hareide et al. 2007). The WCPFC Shark Research Plan calls for analyses of WCPFC observer records since 1995 to produce indicators of fishing pressures on the key shark species. Although longline observer coverage in all tuna regional fisheries management organizations is generally low (typically <5% of all operations), unlike the tuna management organizations in other oceans, WCPFC holds observer data covering a wide geographic range and multiple fleets. Analyses of these data may provide the most robust characterization to date of the status of shark populations.

We analyzed WCPFC observer data sets from longline and purse-seine fisheries to assess the status of shark populations and to examine the effects of a prohibition on shark finning. We also compared our results with results from other Pacific data sets for the same species.

Methods

Data Sources

Prior to February 2011 the WCPFC did not require members to submit catch data for sharks. Thus, many members reported no shark catches or reported them only in an undifferentiated shark category. Species-specific data on shark catches are however available in the form of detailed records kept by onboard observers in longline and purse-seine fisheries. Although these observer data are extremely useful, coverage rates are variable and not representative of effort in the fishery as a whole.

In the longline fishery, which accounts for 10% of the western and central Pacific Ocean (WCPO) tuna catch, annual average observer coverage levels from 2005 to 2008 were <1%. Furthermore, although the longline fishery is broadly distributed between 45°N and S across the WCPO, most observed fishing (80% from 1995 to 2009) occurred in exclusive economic zones (EEZs), where observers are a condition of fishing licenses for foreign-flagged vessels (Fig. 1a). As a corollary, there is little or no information on the shark catches of major fleets belonging to China, Taiwan, Japan, and Korea when they fish in their own EEZs or on the high seas (Fig. 1b).

The purse-seine fishery, which comprises 75% of the WCPO tuna catch, is concentrated in waters between 5°N and 10°S, predominantly within EEZs (Fig. 1c). From 1995 to 2009, 85% of observed purse-seine sets occurred in national waters. Annual average observer coverage ranged from 13% to 16% from 2005 to 2009; coverage was higher in some EEZs such as Papua New Guinea (Fig. 1d).

In addition to the WCPFC data set, we conducted a comparative analyses with data from other studies of sharks in the WCPO: Japanese commercial longline catches for region 1 (JPLL1, 1994–2008 for blue and mako sharks and 2001–2008 for oceanic whitetip sharks [Clarke et al. 2011]); catches from Japanese research and training vessels in regions 2 and 4 (1993–2008 [Clarke et al. 2011]); and outcomes of 2 models of Hawaiian longline catches (1995–2010 for oceanic whitetip and silky sharks only [Walsh & Clarke 2011]). Walsh and Clarke (2011) used data sets that partially overlapped the WCPFC data for years prior to 2005; therefore, we could not consider the trends estimated from this study completely independent.

For most analyses, the observer data sets were partitioned into the 6 regions of the WCPFC bigeye tuna (*Thunnus obesus*) stock assessments. Bigeye tuna are targeted with longlines, and longlines are the primary gear type that catches sharks in WCPFC's area of jurisdiction (Lawson 2011). Therefore, these regions provide a reasonable starting point for analyses. The original boundary between regions 1 and 2 was fixed at 170°E, but some Japanese vessels operate eastward to 180°E (Clarke et al. 2011); thus, we moved the boundary to 180°E (Figs. 1a–c).

We analyzed data on blue, oceanic whitetip, and silky sharks by species and data on mako sharks by genus due to a lack of species-specific observer data in the early part of the time series and the possibility of misidentification.

Catch-Rate Analyses

Catch rate is one of the most commonly used indicators of population status in fisheries science and is an important input to most stock-assessment models (Hilborn & Walters 1992). If catch rate is proportional to stock size, catch rate can be used as a fishery-dependent indicator of abundance. There are, however, instances in which this proportionality does not hold, such as when catch rates are stable but abundance is decreasing (an example of hyperstability) or when catch rates are declining but abundance is stable (an example of hyperdepletion) (Hilborn & Walters 1992). Because such effects are more likely to occur with nominal catch rates (i.e., catch per species ÷ number of hooks fished), standardization models are often used to address biases by accounting for changes in fishing practices (e.g., shifts to different areas, depths, or seasons; changes in target species; or use of different gear types or setting practices) (Maunder & Punt 2004; Maunder et al. 2006).

We used standardization models to predict annual values of catch rate and confidence intervals that when plotted as a time series indicated the population trajectory. Exploratory plots of nominal annual catch rates by 10° latitudinal bands showed different patterns in northern and southern hemispheres for the primarily temperate blue and mako sharks, so we divided data sets for these species at the equator and ran models separately. We ran models for the tropical and semitropical silky and oceanic whitetip sharks for the WCPO as a whole.

We modeled catch rates with overdispersed (quasi-) Poisson models in generalized linear form (Zuur et al. 2009). The Poisson-distributed response variable was the number of sharks caught per set, but overdispersion occurred in the data because variance among catches tends to be higher than the mean and there were multiple zero-catch records. We structured initial covariates (Table 1) as factors (categorical variables), except for latitude and longitude, which were linear, and total number of hooks that was specified as a spline with 5 df on the basis of the distribution of hook data. Modeling hook effect as a spline rather than an offset allowed for the possibility that catch rate does not vary linearly with increasing numbers of hooks and for saturation (i.e., shark catch per hook declines in sets with more hooks) to be modeled.

We evaluated this base model for collinearity by means of variance inflation factors. We also undertook marginal testing using analysis of variance to determine which covariates were significant without being highly

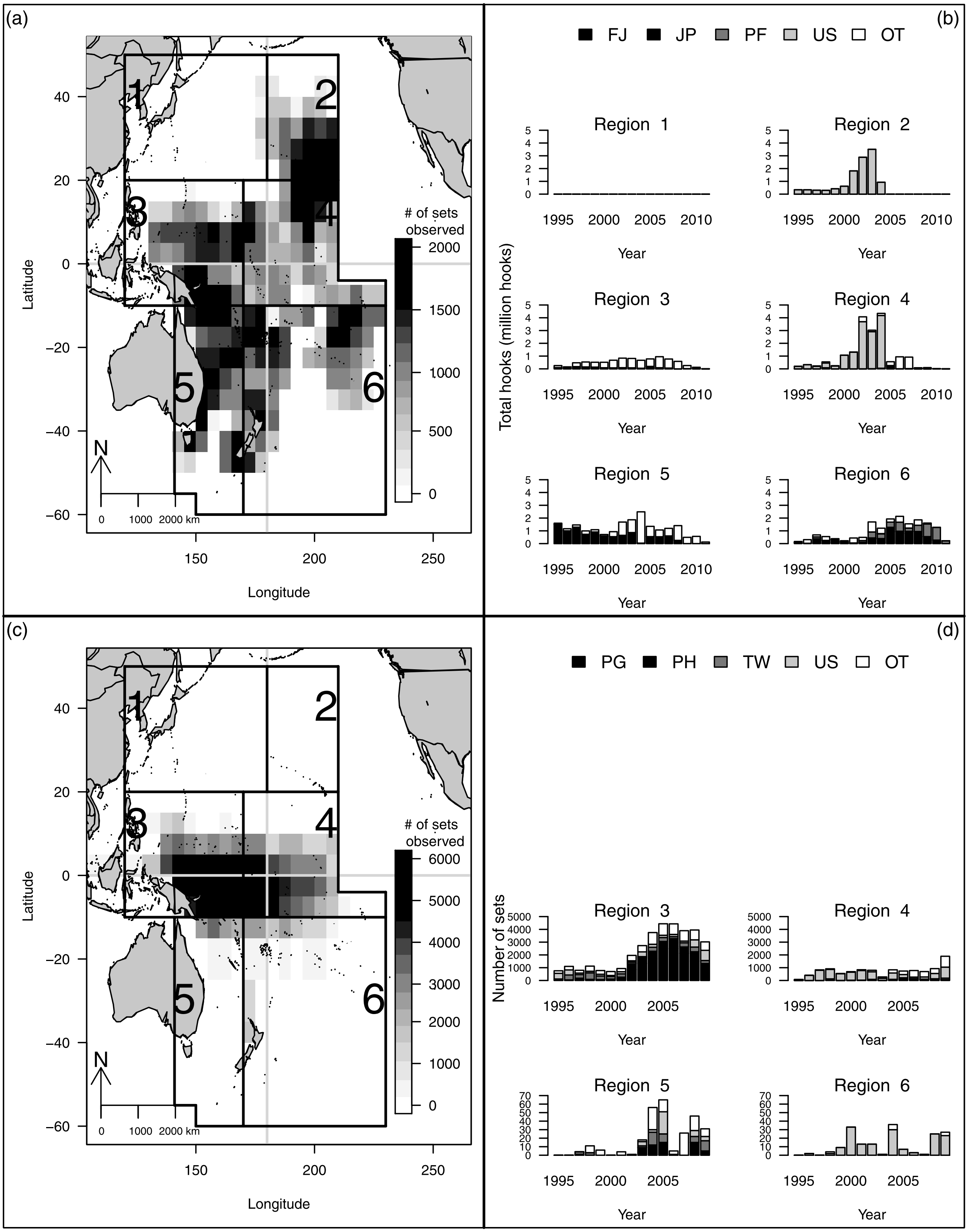

Figure 1. Locations and number of sets monitored in (a) longline (n = 37,774) and (c) purse- seine sets (n = 46,061) in the western and central Pacific Ocean from which data on shark catches were collected. Year of data collection (1995–2010) and country fishing by region relative to (b) number of hooks monitored and (d) number of sets monitored (regions shown on maps in [a] and [c]: FJ, Fiji; JP, Japan; PF, French Polynesia; US, United States; OT, other; PG, Papua New Guinea; PH, Philippines; and TW, Taiwan).

Table 1. Covariates[a] of shark catch rate based on Bromhead et al. (2012) (rows 1–12) and diagnostics from the quasi-Poisson generalized linear models applied to standardize longline-observer catch data (rows 13–15).

Covariates	*Blue shark, north*	*Blue shark, south*	*Mako, north*	*Mako, south*	*Oceanic whitetip*	*Silky*
Year	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
Month	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
Hook depth	≤0.001	≤0.05			≤0.001	≤0.001
Vessel flag state	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
Time of day	≤0.001	≤0.001	≤0.001	>0.05	≤0.001	≤0.001
Shark lines	≤0.001				≤0.001	≤0.001
Shark bait		≤0.01			≤0.001	≤0.001
Shark targeting				≤0.01	≤0.001	≤0.001
Latitude	≤0.001	≤0.001	≤0.001	≤0.01	≤0.001	>0.05
Longitude	≤0.001	≤0.05	≤0.001	≤0.001	≤0.001	≤0.001
Lat × lon interaction	≤0.001	≤0.001	>0.05	≤0.001	≤0.001	≤0.001
Number of hooks fished	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
Overdispersion	4.84	11.55	1.39	2.14	2.26	4.66
Null deviance explained (%)	39	61	7	22	42	78
Null deviance df	18,212	19,228	18,212	19,228	37,773	37,773

[a] *Covariates significant in the model for each shark–region combination are indicated by their p value (rows 1–12).*

correlated with other covariates. We then refined the model so it would iteratively select the most appropriate combination of covariates. Annual mean catch rates were predicted by fixing the covariates at median or otherwise common (i.e., for factors) values and the number of hooks at 1000. We evaluated model performance for each species–region combination by examining the residuals diagnostics, the percentage of null deviance explained, and the significance of terms in the model (Table 1). We used R software with the car package to conduct these analyses.

The standardization model specified individual year effects because such effects provided a better fit to the data than a continuous variable for time. To summarize the time trend and produce a catch-rate (abundance) trajectory, we fitted a linear model to the logarithm of catch rate against the individual year effects from the standardization model and calculated the time trend as equal to $e^{\text{slope parameter}} - 1$. This approach avoided biasing the trend toward years with more data. This summarization generalizes the direction and magnitude of the time trend over the entire time series, so a catch rate that rises and then falls may be characterized as having no trend over time.

We analyzed purse-seine catch rates in nominal (unstandardized) form due to the lack of data and methods available to standardize effort in this fishery. Nominal catch rates for each of the 6 regions were calculated as the number of sharks per set, per associated set (sets on floating objects), and per unassociated set (free-swimming tuna schools).

Shark catch-rate indicators from our study and the 5 other studies described earlier were summarized and plotted such that points below zero indicated a decrease in catch rate and abundance over time. We arranged species along the abscissa from low to high productivity on the basis of their intrinsic rate of increase (Cortés et al. 2010). A steep decline in catch rate for a low-productivity shark would in theory be of greater concern than the same decline observed for a higher-productivity shark.

Size-Indicator Analyses

Trends in a standardized measure of fish size can indicate changes in the age and size composition of the population. In particular, size is expected to decrease in harvested populations (Goodyear 2003). The magnitude of such change can, in theory, provide information on the level of exploitation of a fish stock (Francis & Smith 1995). In addition to calculating median size as an annual indicator, we compared this median size to the length at which 50% of the population reached full maturity (referred to hereafter as length at maturity) from the literature (Supporting Information). This comparison indicated whether the majority of captured sharks of each species were being caught before they were able to reproduce.

We converted data on total length (i.e., tail tip) to tail fork length (an alternative body length measurement method) with conversion factors from the literature (Supporting Information). We analyzed longline data separately for males and females to avoid sampling biases associated with sexual segregation that occurs in some shark populations (Mucientes et al. 2009). In the purse-seine data set, sexes were not usually recorded; therefore, all individuals were combined in a single analysis.

We standardized length data from longlines to account for potential changes in the spatial distribution of sampling effort. A generalized linear model was fitted to fork length by region (regions 3–6 only) and sex for each shark species (factors year and 5° × 5° latitudinal–longitudinal cells); we assumed a normal distribution. Cells with fewer than 20 individuals were removed from the analyses. We used this standardization model to predict shark lengths for each year for an arbitrarily chosen cell at the center of each region. We summarized time trends as described earlier for catch rates, except that we did not log transform the lengths; thus, the model was linear. Sample sizes of purse-seine data were too small for robust model fitting; therefore, we determined trends on the basis of nominal annual median sizes.

Shark size indicators were compared to similar data collected on Japanese research and training vessels (Clarke et al. 2011) by plotting increases and decreases in length for each species arranged along the abscissa from low to high productivity on the basis of their intrinsic rate of increase (Cortés et al. 2010). A steep decline in size for a low-productivity shark would in theory be of greater concern than the same decline observed for a higher-productivity shark.

Fate of Observed Sharks

Observers record the fate of sharks under a large number of codes (21 for purse-seine fisheries and 26 for longline fisheries) that we aggregated into 5 categories: retained, finned, discarded, escaped, and unknown. We excluded sharks in the unknown category from analyses. Although the WCPFC finning prohibition was agreed on in 2007, a simple before and after comparison was not possible because the prohibition is being phased in gradually through regulatory processes undertaken independently by each member.

Results

Catch Rate

Longline catch rates of blue sharks in the northern hemisphere (Fig. 2a) decreased by >50% from 1996 to 2009. In the southern hemisphere, catch rates increased from 2004 to 2008 and then declined sharply in 2009. Catch rates for blue sharks declined by 5% (95% CI 2% to 8%) per year for the north but did not change significantly in the south.

For makos in both hemispheres, the longline catch rates were highest early in the time series and declined to a variable but lower level in the late 2000s (Fig. 2b). Catch rates of mako sharks in the North Pacific declined significantly by 7% (95% CI 3% to 11%) per year. In the South Pacific, changes in abundance in mako sharks were not significant. The performance of the standardization model for mako sharks (north and south) was poorer than for the other studied shark species; thus, estimated trends for mako sharks were less reliable.

Longline catch rates for oceanic whitetip shark declined consistently: annual values decreased by 90% from 1996 to 2009 and uncertainty in the estimates was low (Fig. 2c). Longline catch rates of silky sharks increased in the first half of the time series and then declined in the second half such that the starting and ending annual catch rates were similar (Fig. 2c). In both species, the increase in the late 1990s may have been due to progressively more species-specific recording during this period resulting from improved observer training. Oceanic whitetip sharks declined significantly by 17% (95% CI 14% to 20%) per year, whereas changes in abundance in silky sharks were not significant.

Purse-seine catch rates in regions 3 and 4 combined (20°N to 10°S) could not be standardized and are presented for comparative purposes only. The only 2 species frequently caught in this fishery, oceanic whitetip and silky sharks, exhibited declines that resembled those in the longline fishery (Fig. 2d). Analyses for these sharks by set type (not shown) indicated associated sets' catch rates were approximately double those of unassociated sets.

Size

Significant declining size trends were found in 11 of 36 analyzed combinations of species, region, sex, and fishery (Supporting Information). Two of the 36 combinations, female blue sharks in region 4 and female mako sharks in region 3, increased significantly in median length. The length of female oceanic whitetip sharks from the longline fishery declined in their core tropical habitat (both regions 3 and 4), whereas males and females from the purse-seine fishery declined only in region 3. Male and female silky sharks from the longline fishery declined in length in their core tropical habitat (region 3) and in region 5, and they declined in length in the purse-seine fishery in region 3. In their core habitat, where sample size was largest (region 3), almost all silky sharks sampled by longline and purse-seine fisheries observers were below length at maturity. All oceanic whitetip sharks sampled from purse-seine fisheries since 2000 were also immature (Supporting Information).

Comparison of Indicator Trends

The only shark with consistent catch-rate trends across all studies was the oceanic whitetip, which exhibits intermediate productivity. This species declined, often significantly (95% CI does not include zero) (Fig. 3a). In contrast, the catch rate for higher-productivity blue sharks and lower-productivity mako sharks varied widely across studies. The catch rate for silky sharks also varied among studies but over a narrower range than for the other species. Increasing catch rate at the beginning of the study contrasted with decreasing catch rate in recent years. Catch rates of blue sharks in the North Pacific declined the most of any species; these trends were observed both in our data set and in the Japanese research and training vessel data for region 2 (Clarke et al. 2011).

As for catch rate, the more productive blue and less productive mako sharks showed a range of positive and

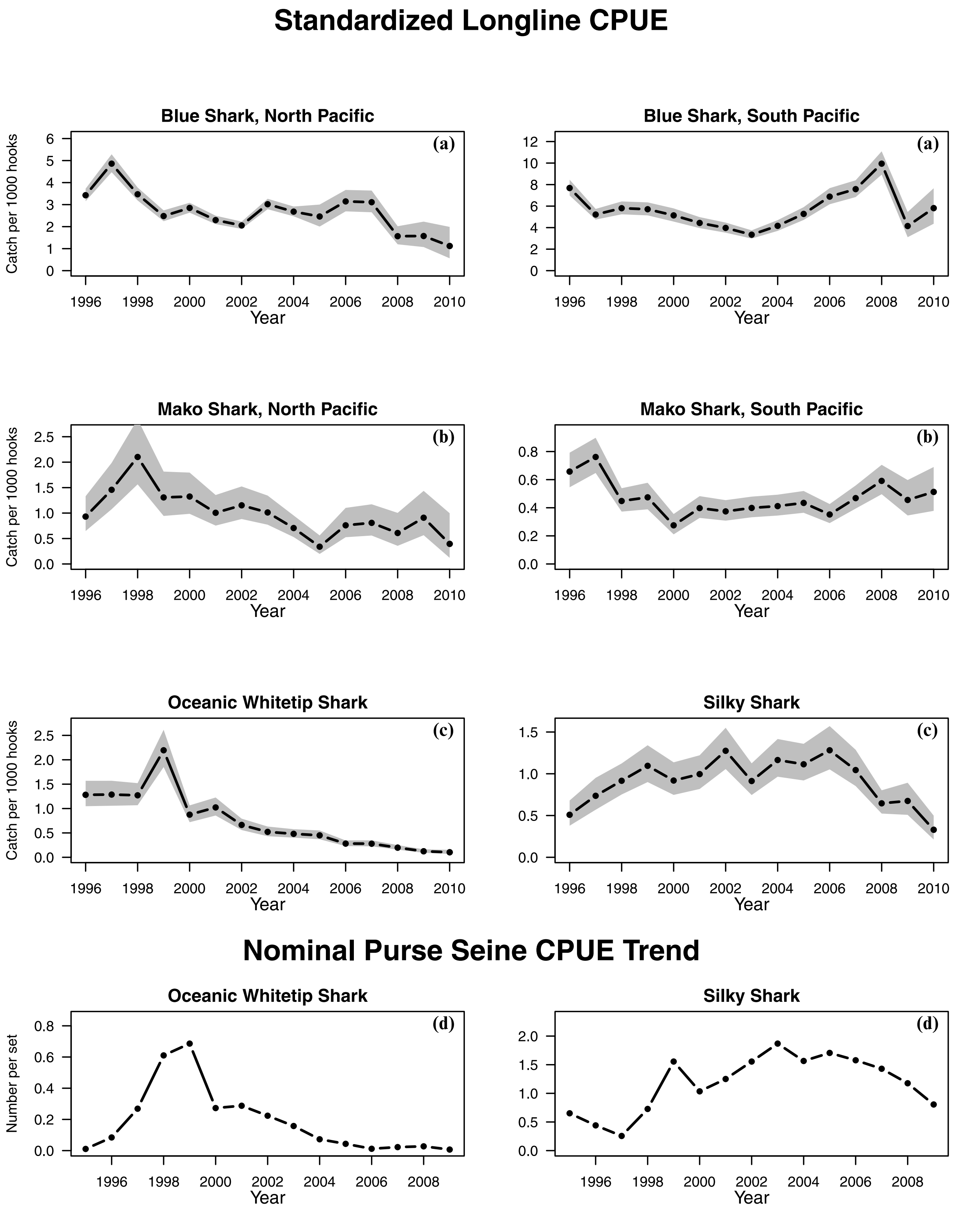

Figure 2. Catch rates for (a) blue, (b) mako, and (c) oceanic whitetip and silky sharks (standardized with a quasi-Poisson formulation of a generalized linear model; see Table 1) for longlines and (d) oceanic whitetip and silky sharks for purse seines (unstandardized [i.e., nominal]) in the western and central Pacific Ocean, 1996–2009 (95% CIs shown for standardized series only).

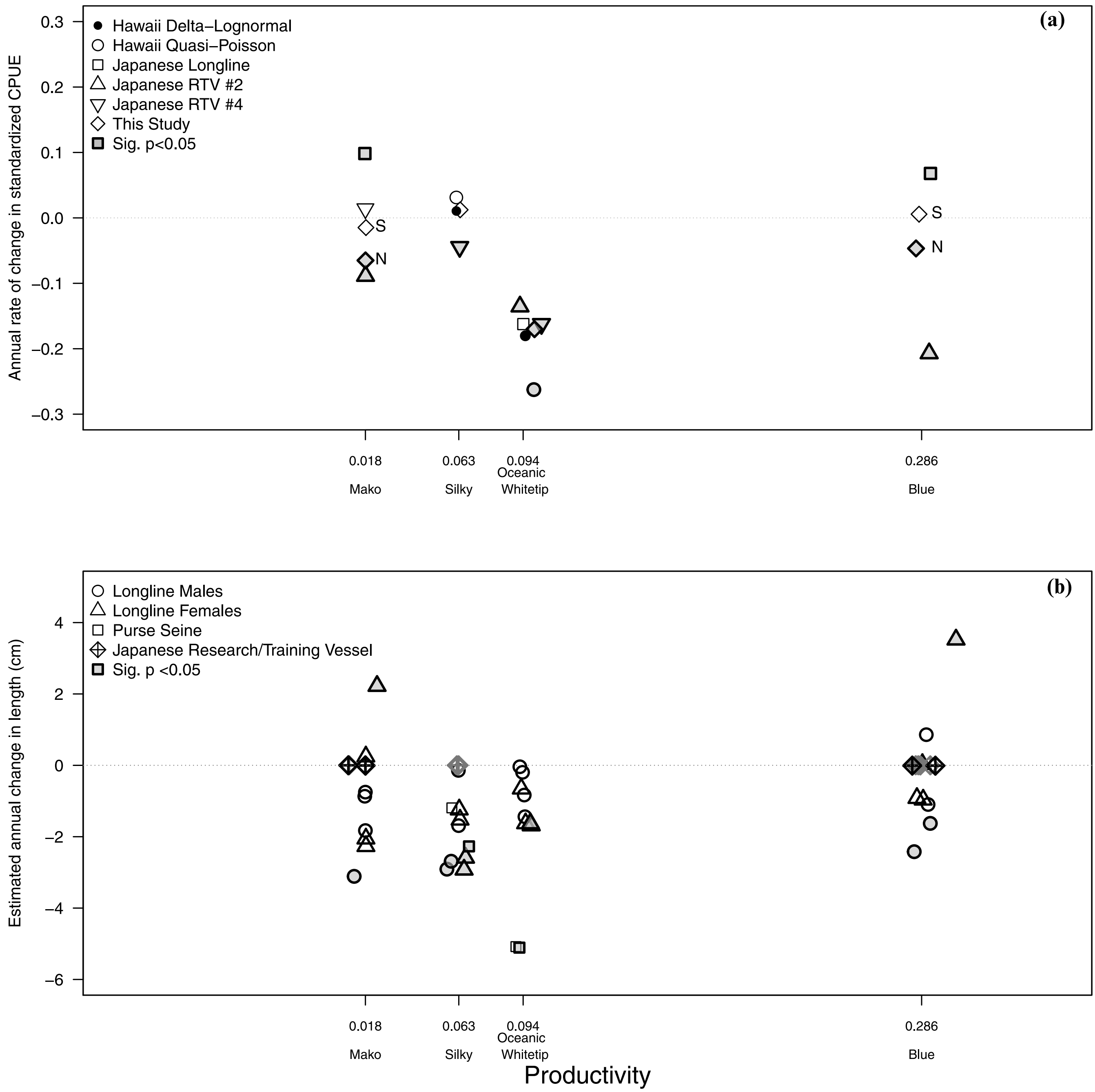

Figure 3. Trends in (a) catch rate (N, Northern Hemisphere; S, Southern Hemisphere) and (b) size of Pacific oceanic sharks relative to their reproductive productivity (intrinsic rate of increase). In (b) size data are standardized for longline, unstandardized for purse-seine, and standardized for Japanese research and training vessel (RTV) catches (regions 1–2 and 4 annual values for 1993–2008 from Clarke et al. [2011]).

negative size trends (Fig. 3b). For both species size varied by sex, females had the largest significant increases in size and males had the largest significant decreases in size. For these species, neither purse-seine data nor data from Japanese research and training vessels showed significant trends. The only significant size trends were for intermediate productivity oceanic whitetip and silky sharks (they decreased in size).

Fate

The proportion of sharks finned in the longline fishery in 2008 (48%), the first full year after the WCPFC finning prohibition was agreed on, was lower than 2007 (53%) but higher than 2006 (40%), the year before the measure was agreed on (Fig. 4a). In 2009 and 2010, observer coverage in the longline fishery was considerably less than

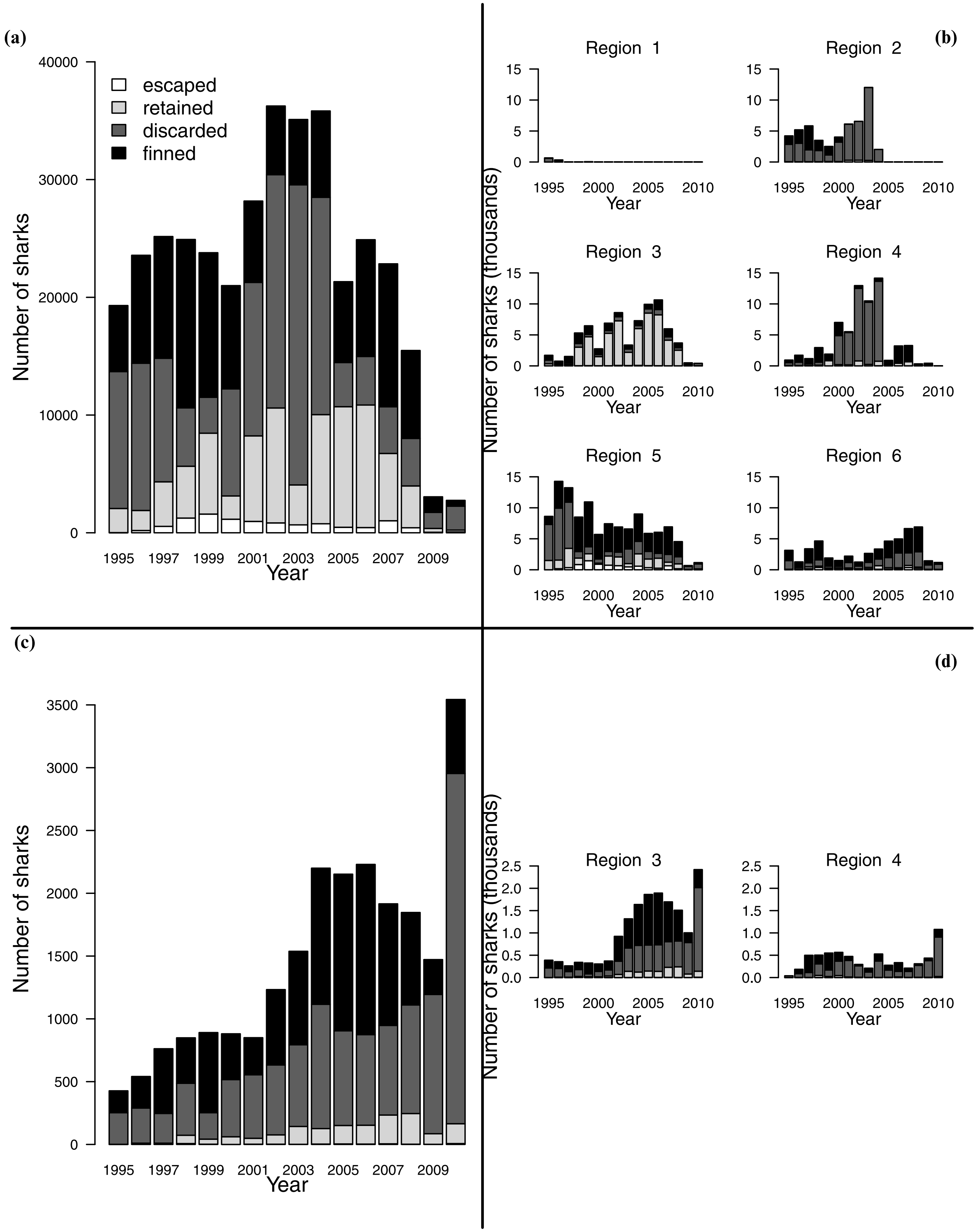

Figure 4. Fate of sharks as recorded by observers from 1995 through 2010 for longline (a–b) and purse-seine (c–d) fisheries in the western and central Pacific Ocean (a, c) as a whole and (b, d) by region (see Fig. 1 for location of regions).

in previous years and resulted in a much-reduced sample size. Data for 2009, suggest finned sharks accounted for 43% of sharks that were recorded by observers. In 2010 less finning was recorded but shark retention (keeping dead sharks in whole form) increased such that overall mortality remained stable. Plotting the same data on shark fate by region revealed higher proportions of discarded sharks in regions 2 and 4 through 2004 (Fig. 4b), most likely because shark-finning prohibitions were enacted by the United States in 2000 (Walsh et al. 2009). The absence of the U.S. observer data after 2004 due to confidentiality restrictions has reduced the number of discarded sharks in the WCPFC database in recent years. In region 3, where silky sharks dominate the catch, notably higher proportions of retained sharks were recorded. In regions 5 and 6 in 1998–2008, the percentage of sharks finned remained between 45% and 70%.

For the purse-seine fishery, the proportion of sharks finned decreased each year since 2006 (61%, 51%, 40%, 19%, 17%) and the proportion of sharks discarded increased (32%, 37%, 47%, 75%, 79%) (Fig. 4c). The much larger number of sharks observed in 2010 results from the new requirement for 100% observer coverage. Observer data from the purse-seine fishery suggested that the proportion of sharks finned did not vary appreciably between regions 3 and 4 (Fig. 4d).

Shark fate by species from 1995 to 2010 indicated different patterns by species within a fishery (e.g., blue vs. silky sharks in the longline fishery) and between fisheries for a given species (e.g., silky sharks in the longline vs. purse-seine fisheries) (Fig. 5). In the longline fishery silky sharks were usually retained, but in the purse-seine fishery they were usually finned and rarely retained. The fate patterns for oceanic whitetip sharks were similar to those of silky sharks. Makos were commonly retained, and blue sharks were commonly discarded.

Discussion

We documented declines in abundance in 2 populations of Pacific sharks: oceanic whitetip sharks and blue sharks in the North Pacific. All standardized catch-rate trends for the oceanic whitetip from Pacific longline and purse-seine fisheries we analyzed were consistent, steep, and downward. Congruent declines to near-zero catch rates in other data sets from Japan and Hawaii over the same period (Clarke et al. 2011; Walsh & Clarke 2011) and the significantly smaller sizes of sharks we and others (Clarke et al. 2011) found confirm the depleted state of the oceanic whitetip population in the WCPO. North Pacific blue sharks are also of conservation concern on the basis of significant, continuous, and substantial declines in abundance of $\geq$5% per year in 2 independent data sets (ours and that of Clarke et al. [2011]). Polovina et al. (2009) found a declining catch rate for blue sharks of 3% per year (1996–2006) in deep fishing sets by the Hawaii-based longline fishery. Although Kleiber et al. (2009), on the basis of data through 2002, concluded that North Pacific blue sharks are above their maximum sustainable yield biomass reference point, our more recent data suggest this conclusion may no longer be valid. Because both oceanic whitetip and blue sharks are valuable components of the global trade in shark fins (Clarke et al. 2006), blue sharks are targeted by a large commercial fleet operating in the North Pacific (Clarke et al. 2011), and there are few known methods for avoiding shark catches (Gilman et al. 2008), it is highly unlikely that declining abundance reflects intentional shifts in fishing effort away from these species.

Silky sharks are restricted to tropical waters (Camhi et al. 2009), but within this range they dominate both longline and purse-seine catches. Many of the catch-rate trends for silky sharks were not significant, but in some cases this was due to contrasting rising and falling catch rates in the early and late portions of the time series. Improved species identification may explain the increase in catch rates during the early period. The recent declines in catch rates cannot be easily explained by sampling bias and are consistent with decreasing and often significant size trends for both sexes in several data sets from the core tropical habitat of silky sharks. These findings indicate a need for close, ongoing monitoring of this species.

Under its convention, the WCPFC is required to maintain or restore populations of nontarget species above levels at which their reproduction may become seriously threatened. Prior to 2012, the only WCPFC shark conservation and management measure was a prohibition on finning. This measure is designed to apply to all waters under the WCPFC's jurisdiction; however, coastal states, where most of the observer coverage is concentrated, can apply alternative measures in national waters. As of October 2010, of the 32 WCPFC members only half had confirmed they were fully implementing the finning prohibition. Only 11 provided specific confirmation of either implementation of the 5% fins-to-carcass rule or an alternative measure, and few of these reported the degree of compliance. Because it is thus possible that only a small amount of the observer data reflects full implementation of current WCPFC finning prohibitions, it is not surprising that although some reduction in the proportion of sharks finned appears to have occurred in the purse-seine fishery, there is little evidence that the proportion of sharks finned in the longline fishery has been reduced since the WCPFC measure was adopted. Another issue with the WCPFC prohibition on finning is that even if it were fully implemented it would not necessarily lead to a reduction in shark mortality. Our results showed that oceanic whitetip, silky, and mako sharks in longline fisheries are more likely to be retained than finned. As a result, even a fully effective prohibition on

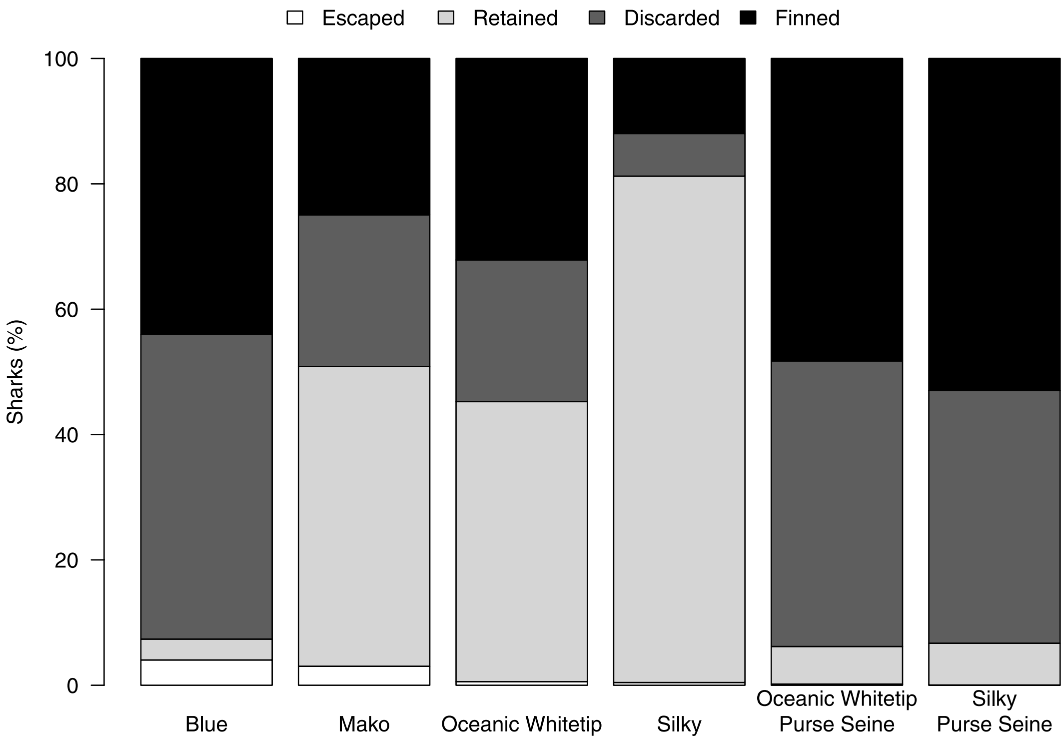

Figure 5. Fate of sharks by species as recorded by observers from 1995 through 2010 for the western and central Pacific Ocean as a whole for longline (left 4 bars) and purse-seine (right 2 bars) fisheries.

finning would not address the primary source of mortality to these species.

Reduction of shark mortality by prohibiting retention was the focus of recent measures adopted by the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Inter-American Tropical Tuna Commission (IATTC) for oceanic whitetip and silky sharks. A similar measure was adopted by WCPFC for oceanic whitetip sharks in March 2012. Although these measures, which prohibit retention of these sharks in any form (i.e., parts or whole), are likely to reduce shark mortality to a greater extent than finning prohibitions, gear-retrieval practices can have a large effect on shark mortality (Gilman et al. 2008). In longline fisheries, the likelihood of asphyxia or depredation before the gear is retrieved and mortality after release as a result of onboard handling and hook-removal techniques varies among species (Campana et al. 2009). In purse-seine fisheries, the potential for live release of sharks depends on the length of time they have been confined in the net, water temperature, individual species tolerance of stress, position in the brailer (i.e., the dip net used to scoop fish from the purse seine), and many other factors (Itano & Restrepo 2011). It would therefore not be correct to assume that no retention will result in no mortality, and in some cases mortality rates would be expected to remain high (e.g., 69% of the silky shark catch was found dead at gear retrieval in the Atlantic longline fishery [Beerkircher et al. 2008]).

Prohibitions on shark finning divert management focus toward shark handling and utilization practices and away from assessing whether current catch levels are sustainable. Prohibitions on shark retention are unlikely to be adopted for species that are economically important (e.g., North Pacific blue sharks). Both finning and retention prohibitions fail to acknowledge that in many fisheries across the Pacific sharks form an economically valuable component of the catch that can and should be sustainably managed. Furthermore, in many fleets, shark catches are less likely to be accurately recorded if they are discarded due to finning or retention prohibitions.

The increasingly clear need for management of shark resources should not be addressed by measures that are simple to implement but complex to enforce and evaluate. Instead, we suggest management measures be accompanied by specific monitoring requirements that allow ongoing assessment of a measure's effectiveness. For example, if a no-retention measure is adopted it should be accompanied by mandatory, periodic review of the degree to which total shark mortality has decreased. This review should be based on observer coverage above a minimum threshold and studies of post-release mortality in specific fleets. If total mortality does not decline significantly after implementation, consideration of other measures, such as catch limits, should be triggered. Conversely, if mortality levels are considered acceptable, some retention may then be allowed. Such evaluation and adaptive management would accelerate progress toward regulating mortality rather than utilization and thus help ensure the sustainability of shark populations.

Acknowledgments

This research was conducted by the Oceanic Fisheries Programme of the Secretariat of the Pacific Community on behalf of the WCPFC. Technical assistance for data management and modeling was provided by D. Bromhead, T. Lawson, and P. Williams of SPC. W. Walsh of the University of Hawaii's Joint Institute of Marine and Atmospheric Research generously shared his ideas and methodologies.

Supporting Information

Information on length conversion factors and length at maturity (Appendix S1), observed changes in shark lengths by species, sex, and region (Appendix S2), and median fork lengths for oceanic whitetip and silky sharks in their core habitat, 1995–2009 (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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