

FEATURE ARTICLE



# Temporal and spatial dynamics of 'trophy'-sized demersal fishes off the California (USA) coast, 1966 to 2013

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**ABSTRACT:** California (USA) recreational fisheries are biologically and economically important, and depend heavily on demersal fish species, especially during winter and spring months. While many of these species have shown signs of population decline, the size-selective nature of fishing generally impacts population size structure before population declines are evident. However, long-term size-specific information, especially for the largest size classes, is rare. Our ability to gain an early warning of fishery overexploitation is thus limited. We developed the Western Outdoor News (WON) database, which consists of a long-term (1966–2013) time series of trophy-sized fishes caught along the California coast and Baja California, Mexico. Sixteen demersal species, with a total of 25 943 records, were the focus of this study. Twelve of the 16 species showed signs of long-term decline in trophy size, but 9 of these 12 showed signs of transition to either stabilization or initial recovery in the most recent years. The more progressive state fisheries management actions adopted since 2001 have likely contributed to this apparent shift in trends, and the new coastal marine protected area (MPA) networks may benefit these populations even more in the future. Trophy size increased with distance from home port, and the distance required to reach maximum trophy sizes increased over time, especially for the rockfishes, which suggests that declines were due to overfishing. Trophy sizes of fishes caught specifically within the Northern Channel Islands region showed long-term declines through the early 2000s, but also showed signs of stabilization or initial recovery for some species since the 2003 implementation of the Northern Channel Islands network of MPAs.

**KEY WORDS:** Historical ecology · Trophy fish · Demersal · Marine protected area · Northern Channel Islands



Six cowcod *Sebastes levis* caught aboard the 'Patrician' with Capt. M. Thompson in the 1970s. The anglers, from left to right, are R. Wasserman, T. Holland, S. McDainels, and D. Wilson.

Photo: courtesy of [www.sportfishinghistory.com](http://www.sportfishinghistory.com)

## INTRODUCTION

Marine recreational fisheries in California (USA) contribute significantly to the state economy (Lovell et al. 2013), support coastal communities and cultural heritage (Scholz et al. 2004), and account for a significant portion of total landings for a number of fish species (Hill & Schneider 1999, Schroeder & Love 2002, Dotson & Charter 2003). These fisheries are highly dynamic, with a primary focus on pelagic species (e.g. Pacific bluefin and yellowfin tunas) during the summer months. However, the recreational fishing industry is sustained by demersal species (e.g. rockfishes) during the rest of the year. Prior to 2001, commercial rockfish fisheries were more prevalent, and recreational rockfish fishery regulations prima-

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rily consisted of individual bag limits for most species, size limits for some species, and seasonal closures for only a few species. Under both of these fisheries, populations of many fished demersal species showed signs of decline (Dayton et al. 1998). For example, several rockfishes (*Sebastes* spp.) were declared overfished after exhibiting declines in recreational catch per unit effort and size structure, as well as changes in species composition in both southern California (Love et al. 1998) and central California (Mason 1998). In response, the state of California established progressive regulatory policies beginning in 2001 in an effort to restore and retain healthy fish stocks. For instance, the state established cowcod conservation areas in an effort to recover particularly hard-hit cowcod *S. levis* stocks (Butler et al. 2003). Moratoriums were implemented for multiple rockfishes, such as cowcod, yelloweye *S. ruberrimus*, canary *S. pinniger*, and bocaccio *S. paucispinis* (since re-opened with lower daily bag limits). Additional regulations followed, including broad fishing depth restrictions, seasonal and depth closures, and networks of marine protected areas (MPAs) along the mainland coast as well as the northern and southern Channel Islands.

While these new policies were contentious among marine stakeholders, fisheries adapted quickly after implementation, and positive signs of recovery have emerged since. For example, cowcod were initially projected to rebuild by 2068 (Dick et al. 2007), but the population increased more rapidly than expected, and may be rebuilt as soon as 2020 (Dick & MacCall 2013). In addition, Field et al. (2010) showed that bocaccio are in a rebuilding state following an earlier conclusion that stocks were severely depleted (MacCall & He 2002), and Hamel et al. (2009) found that in recent years, lingcod *Ophiodon elongatus* stocks have been rebuilding. In general, after a decade of more progressive fisheries management and a few years of strong recruitment (Love et al. 2012), rockfish and other groundfish populations are showing signs of recovery (Sewell et al. 2013, Miller et al. 2014).

It is thus clear that declining trends among demersal species in California can be reversed if the necessary temporal and spatial data are available to assess stock status and inform appropriate and effective management action. However, while some species are showing positive signs in recent years, many species (e.g. several rockfishes) are still considered data-poor (Wilson-Vandenberg et al. 2014). We still have limited continuous long-term time-series metrics other than total landings, such as size-specific

information for many other species. This hinders the development of informative assessments of their stock status, and ultimately, effective fisheries management. This is especially important in California fisheries due to their often size-selective nature.

Impacts of size-selective fishing on fish populations are broad, and have been the subject of numerous studies during the last several decades (since Beverton & Holt 1957). Many of these impacts occur after sustained size-selective fishing over long time periods. For example, Hamilton et al. (2007) found that changes in life history characteristics of California sheephead *Semicossyphus pulcher* largely depended on levels of site-specific fishing pressure over a 2 to 3 decade period. However, some impacts can be measured on short-term scales. Demographic effects, such as decreased age and size structure (e.g. Schroeder & Love 2002), are often the first sign of fishing impacts (Laugen et al. 2014). Such decreases in the abundance of both large individuals and large species (e.g. McClenahan 2009a,b, Powers et al. 2013) can occur even before declines in total catch frequencies (Froese 2004). Population size structure time series data can thus provide a sensitive metric for fisheries impacts to targeted populations (Shin et al. 2005). This is particularly true for size structure data that accurately characterize changes in the size of the largest ('trophy size') individuals in a population (Gislason & Rice 1998, Pauly et al. 2002, DeMartini et al. 2008, Sandin et al. 2008).

In addition to size-specific data gaps, California fisheries datasets are limited with respect to spatially explicit information at any detail greater than coarse  $10 \times 10$  min blocks (approx. 300 km<sup>2</sup> resolution in this region). Greater spatial detail in fish population demographics is essential to understanding the influence of fishing and management on population characteristics. For example, isolated areas tend to receive less fishing pressure, thus allowing demographic analyses across a gradient of fishing effort (e.g. DeMartini et al. 2008, Weijerman et al. 2013). In California, a state-wide MPA network was recently implemented along the entire mainland coast, including the local islands. The state of California implemented this network on a regional basis, first in the Northern Channel Islands (effective 9 April 2003), followed by the central marine region (21 September 2007), north-central marine region (1 May 2010), southern marine region (1 January 2012), and lastly the northern marine region (19 December 2012). Fine-scale spatial information specific to coastal fisheries can allow measurements of how these MPAs function under varying ages and levels of protec-

tion, and studies have recently been implemented to quantify baseline metrics for these MPAs (e.g. Hovel et al. 2015). Hamilton et al. (2010) found that commonly targeted fish species showed increased densities and biomass inside the boundaries of the Northern Channel Islands MPAs after 5 yr of protection, indicating that population benefits can be realized on short time scales within local reserve boundaries. Caselle et al. (2015) measured increased fish biomass both inside and outside the boundaries of these same MPAs 10 yr after implementation. This indicates that fish populations have continued to increase inside the MPA boundaries, and suggests that spillover to adjacent areas has occurred. Kay et al. (2012) measured significant increases in population abundance of spiny lobsters *Panulirus interruptus* within the Northern Channel Islands MPA boundaries after 6 yr of protection, which also suggests the potential for future larval/adult spillover. However, while a growing amount of evidence suggests that MPAs can improve adjacent populations and fisheries, no study has yet empirically linked increased fisheries yields to a reserve effect following the implementation of MPAs in California (De Leo & Micheli 2015).

To address current limitations in spatially explicit and size-specific fisheries data in California, we generated a new trophy size database (Bellquist 2015) from a regional fishing newspaper, Western Outdoor News (WON). On a weekly basis, this publication lists all of the largest fish caught at each sportfishing landing along the California coast from 1966 to present, including the approximate location of catch. We entered these records into a database to assess the temporal and spatial trends in trophy size dynamics for demersal species in California. Specifically, we evaluated the long-term (48 yr) trends in trophy sizes of demersal species, both separately and in aggregate. In an effort to gain insight regarding the mechanism driving the apparent trends, we also evaluated patterns in the spatial distribution of trophy catch locations relative to angler home port. Our assumption is that, if fishing pressure is the primary mechanism driving trends in the size of trophy fish through time, increasing fishing pressure will require anglers to travel farther to reach regions with trophy fish. Finally, we used the spatial distribution of trophy catches through time to explore whether the implementation of an MPA network in southern California coincides with changes in the trophy sizes of target species. Trophy-sized fishes have proven to be a particularly good metric for assessing the effects of marine reserves on adjacent fisheries (Roberts et al. 2001); we therefore leveraged a before-after-control-

impact (BACI) style analysis of trophy catches at the Northern Channel Islands MPA network to assess support for the influence of short-term (decadal) effects of trophy-sized catch in areas adjacent to newly established MPAs.

## METHODS

The WON database contains 48 750 demersal species records from 1966 to 2013, ranging from southern Baja California to the California–Oregon border, but the area of interest for this study was the California coast in general, as well as the Northern Channel Islands region of southern California (Fig. 1A). We focused on the top 16 demersal species in terms of reporting frequency (14 teleosts and 2 elasmobranchs; Table 1), which account for 25 943 records, or 53.2% of the database. We did not include data from long-range fishing trips in the analysis because they are not considered representative of California coastal populations (see ‘Spatial analysis: distance from home port’ section below). Each WON record consists of the largest fish reported in a given week at each sportfishing landing. These records come from all legal recreational fishing methods, including spearfishing and shore-based angling, but most records are from trips aboard commercial passenger fishing vessels (CPFVs). Typically there is 1 ‘jackpot’ fish per vessel trip, and each WON record represents the largest (heaviest) of these ‘jackpot’ fish each week. However, because long-range offshore trips frequently return with large tunas that would cancel out locally-caught inshore species reports, there is often 1 offshore pelagic species and 1 inshore species reported per week. Almost all records contained at least a general catch location, and most contained specific catch locations. Specific catch locations were those that could be assigned latitude–longitude coordinates accurate to within approx. 3 km. For example, we could assign a single set of coordinates for a white sturgeon *Acipenser transmontanus* with a ‘Roe Island’ catch location because this is a specific place in the San Joaquin–Sacramento Delta where white sturgeon are sometimes caught. Conversely, a catch location reported as ‘Catalina Island’ is too broad for specific coordinates due to the size of the island. Linear distance from home port to specific catch locations could then be calculated between latitude–longitude coordinates. This approach assumes that catch locations were reported truthfully and accurately, but unfortunately we cannot measure the degree of spatial accuracy. This assumption of accurate reporting

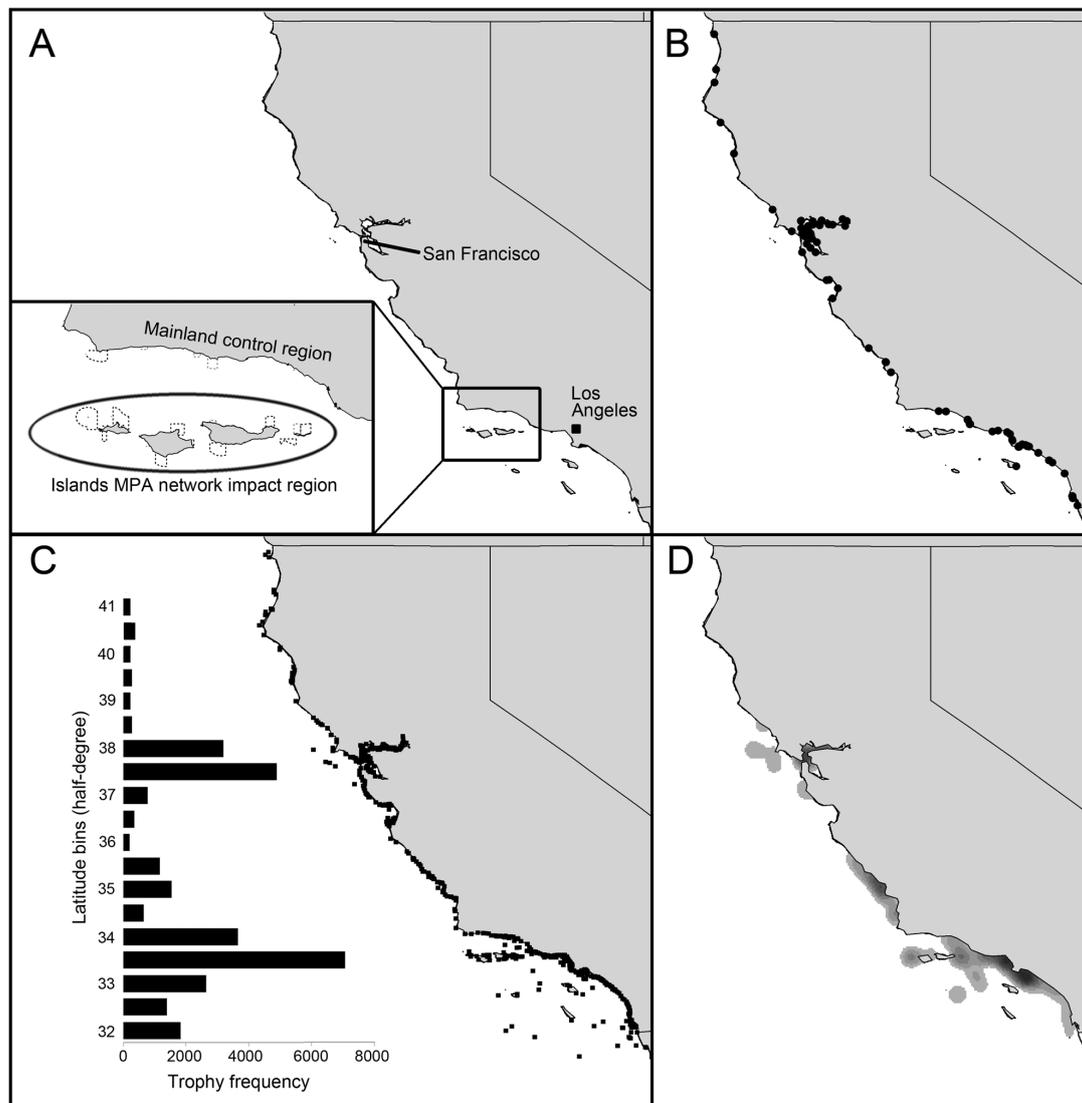


Fig. 1. (A) California coast, USA, with inset showing the Santa Barbara mainland coast (outside the island marine protected area [MPA] impact region) and the Northern Channel Islands (inside the MPA network impact region). Dotted lines represent MPA boundaries. (B) Sportfishing port locations (black dots). (C) All 25 943 individual trophy fish catch locations (black dots) with latitudinal frequency distribution of trophy records from 32 to 41° N latitude. (D) 95 % (shaded light grey) kernel utilization distribution (KUD) of trophy catch locations, with shaded core 50 % (medium grey) and 10 % (dark grey) KUDs included

is nonetheless consistent with the current 'faith-based' system accepted by the state in recreational CPFV logbook catch reports.

#### Time-series analysis of trends in trophy sizes

We modeled the temporal trends in trophy sizes through time using a Bayesian auto-regressive state-space approach, where reported sizes were assumed to represent sampled values from a true (unobserved) average trophy size per unit time. We used this

model-fitting approach (as opposed to other smoothing methods such as general additive models) because it is explicitly auto-regressive, and because it allows us to easily incorporate hierarchical structure. Our species-specific model formulation was thus:

$$x_{t,s} = x_{t-1,s} + u_s + w_{t,s}, \text{ where } w_{t,s} = N(0, Q_s) \quad (1)$$

$$y_{i,t,s} = x_{t,s} + v_{t,s}, \text{ where } v_{t,s} = N(0, R_s) \quad (2)$$

Eq. (1) is the state equation, where  $x_{t,s}$  represents the log of species-specific ( $s$ ) true average trophy size per year ( $t$ ),  $u_s$  represents the annual species-specific growth rate, and  $w_{t,s}$  represents annual species-

Table 1. Species, temporal extent, and sample sizes (n; total number of records) of the 16 most commonly reported demersal fish species in the Western Outdoor News database

Species	Scientific name	Years	n
Lingcod	<i>Ophiodon elongatus</i>	1966–2013	7884
California halibut	<i>Paralichthys californicus</i>	1966–2013	7729
White sturgeon	<i>Acipenser transmontanus</i>	1984–2013	2877
Cowcod	<i>Sebastes levis</i>	1966–2009	2535
Vermilion rockfish	<i>Sebastes miniatus</i>	1968–2013	1083
California sheephead	<i>Semicossyphus pulcher</i>	1968–2013	1036
Kelp bass	<i>Paralabrax clathratus</i>	1966–2013	866
Barred sand bass	<i>Paralabrax nebulifer</i>	1966–2013	556
Bocaccio	<i>Sebastes paucispinis</i>	1966–2013	364
Giant seabass	<i>Stereolepis gigas</i>	1966–2008	231
Yelloweye rockfish	<i>Sebastes ruberrimus</i>	1977–2001	195
Cabezon	<i>Scorpaenichthys marmoratus</i>	1969–2013	192
Sevengill shark	<i>Notorynchus cepedianus</i>	1985–2013	148
Leopard shark	<i>Triakis semifasciata</i>	1984–2012	105
Copper rockfish	<i>Sebastes caurinus</i>	1973–2013	72
Ocean whitefish	<i>Caulolatilus princeps</i>	1969–2012	70
Total			25943

specific process error with variance  $Q_s$ . Eq. (2) presents the observation equation, where  $y_{t,s}$  represents the log of the  $i^{\text{th}}$  trophy size report for species  $s$  in year  $t$ . These logged observations are assumed to be normally distributed around the true average species- and time-specific trophy size  $x_{t,s}$  with observation variance  $R_s$ . We visually inspected residual plots to confirm that the reported log trophy sizes  $y_{i,t,s}$  were normally distributed around the model estimated average annual log trophy size  $x_{t,s}$ . All terms in the above equations are estimated within the modeling framework, with the exception of the  $y_{t,s}$  observations.

We also modeled the hierarchical, temporal trend in the *Sebastes* spp. complex (across all species within the complex). In this case, we established and fit a slight variant to the existing model, such that:

$$x_t = x_{t-1} + u + w_t, \text{ where } w_t = N(0, Q) \quad (3)$$

$$r_{t,s} = x_t + u_{t,s}, \text{ where } u_{t,s} = N(0, Z_s) \quad (4)$$

$$y_{i,t,s} = r_s + v_{t,s}, \text{ where } v_{t,s} = N(0, R_s) \quad (5)$$

Here  $x_t$  represents the estimated average of all species-specific mean rockfish trophy sizes per year ( $r_{t,s}$ ). All  $r_{t,s}$  are thus assumed to be normally distributed around  $x_t$  with variance  $Z_s$ ,  $u$  represents the growth rate and  $w_t$  represents the annual process error with variance  $Q$ . Observations  $y_{i,t,s}$  for each rockfish species ( $s$ ) in each year ( $t$ ) are assumed to be normally distributed around the species-specific yearly mean ( $r_{t,s}$ ) with observation variance  $R_s$ . In both models above, all estimated parameters were

given uninformative (broad) uniform priors. Specifically, each of the variance terms was given a uniform prior interval between 0 and 10, while the remaining parameters were given the uniform prior interval between  $-10$  and 10.

All models were estimated using ‘Just Another Gibbs Sampler’ (JAGS; Plummer 2003) and the R statistical software environment (Ihaka & Gentleman 1996). We assessed model convergence by visually inspecting parameter trace plots and generating Gelman-Rubin potential scale reduction factors ( $R_{\text{hat}}$ , Gelman & Rubin 1992) using the CODA package in R (Plummer et al. 2006). In all model instances, we carried out sufficient iterations and thinning to ensure  $R_{\text{hat}}$  values of  $<1.05$  (adequate chain mixing and parameter convergence). All

model outputs were overlaid onto boxplots of annual weight across the time series to allow visual comparison of model results with the distribution of the raw data.

### Spatial analysis: distance from home port

We first analyzed spatial patterns in trophy size with respect to the degree of isolation of catch locations relative to vessel home port. Our intent was to look for evidence that anglers had to travel farther to catch similar sized trophy fish across time. If true, the expected size of a particular trophy fish would be a function of both the distance from home port, when the fish was caught, and the interaction between distance and timing of catch. However, we expected that the relationships between trophy size, location, and timing of catch vary as a function of the species considered. For instance, declines in cowcod through time were dramatically different than more sustainably managed fisheries, such as California halibut *Paralichthys californicus*; we therefore used the R package lme4 (Bates et al. 2013) to develop and test a linear mixed effects model of the form:

$$\begin{aligned} \text{Log}(\text{Weight}_{kg}) \sim \\ \text{DOY} + \text{Distance\_km} + \text{DOY}:\text{Distance\_km} + \\ (1 + \text{DOY} + \text{Distance\_km})\text{Species} \end{aligned} \quad (6)$$

In the above model specification, effects for the timing of catch (day of year,  $DOY$ ) and distance from

home port (*Distance\_km*) are assumed to be random across targeted species (*Species*) while the interaction between these effects (*DOY:Distance\_km*) is assumed to be fixed. We logged the response variable  $Weight_{kg}$  in order to approximate normality, based on residual plots of the un-logged version of the model, and after visually inspecting histograms of the response variable. To evaluate the significance of the model that includes the interaction term, i.e. the term that specifies a relationship between date captured and distance from home port in predicting trophy size, we specified and fit a separate null model that was identical to the prior model in all but the inclusion of the *DOY:Distance\_km* interaction. We then used a likelihood ratio test to evaluate relative model performance. Prior to conducting this analysis, we included only trips <200 km from home port. This range of distances generally encompasses the overall range of CPFVs and private vessels that operate locally for demersal species, which combined represent the majority of California recreational landings for demersal species. For the purposes of this study, this includes ½-day, ¾-day, overnight, and 1½-day CPFV trips as well as most private vessel trips. Some of the 16 species considered had too few catch location coordinates assigned for robust analysis, and were thus not included in the results. Species included in the analysis were kelp bass *Paralabrax clathratus*, barred sand bass *P. nebulifer*, California halibut, California sheephead, bocaccio, vermilion rockfish *S. miniatus*, cowcod, yelloweye rockfish, lingcod, and cabezon *Scorpaenichthys marmoratus*. In order to provide a simple graphical representation of the presumed relationship between trophy fish sizes, distance from home port, and capture date, we binned data into 3 distance bins and 2 temporal bins, and generated species- and bin-specific boxplots of trophy sizes. Note, however, that for the above statistical analysis, distance from home port and capture data were treated as continuous variables.

### **Spatial analysis: BACI design for Northern Channel Islands MPA network effects**

Because our trophy size database spans the 2003 implementation of a network of MPAs within the Northern Channel Islands National Marine Sanctuary off the coast of Santa Barbara and Ventura Counties, we used a BACI-style analysis comparing 2 regions (islands and mainland) to explore for evidence that these MPAs have influenced the size of trophies caught at the Northern Channel Islands.

Trophy size data for demersal species were split into the periods before and after the 2003 implementation of the Northern Channel Islands MPA network. The 'before' period was defined for 2 time intervals: 1966–2002 (i.e. all 'before' data) and 1990–2002 (only the more recent period before 2003). Trophy size data were also separated spatially into catch location records from the islands region, which we assume to be inside the MPA network impact zone (but outside the actual MPA boundaries), and the mainland region, which we assume to be outside the MPA network impact zone. To assess the effect of the regional reserve network on trophy sizes, we fit a linear fixed effects model for each species that included an effect for time period (before, after) reserve proximity (within network: Channel Islands; outside network: coastal), and the interaction between time period and reserve proximity. This interaction term represents the reserve 'impact' on trophy catch within the reserve network (but outside of specific MPAs).

## **RESULTS**

### **Temporal analyses**

Temporal trends show declines in trophy weight for most of the species considered during the study period, although most of these long-term declines appear to show a period of stabilization in the most recent years (since the early 2000s). This is especially true for the groundfishes in this study, including most of the rockfishes in the genus *Sebastes*. Cowcod (Fig. 2A) showed a consistent decline in size until the fishery was closed in 2001, after which time almost no records of catch were reported. Vermilion rockfish (Fig. 2B) showed a decline during the 1990s, but the decline stabilized after approx. 2002. Bocaccio (Fig. 2C) were slightly more variable, but showed a gradual decline during the study period that stabilized beginning in 2004. Copper rockfish *Sebastes caurinus* (Fig. 2D) were reported at a much lower frequency than other species, but this frequency increased over time, showing a decline in trophy size since the mid-1990s. Yelloweye rockfish (Fig. 2E) were only reported from the late 1970s until the fishery was closed in 2001, but the limited data showed a slight decrease in trophy size. Fig. 2F shows the *Sebastes* complex combined, with the exception of cowcod, which were excluded due to the significant influence of such a large species on the overall outcome. Even with cowcod excluded, the *Sebastes* complex showed an obvious and steady decline until

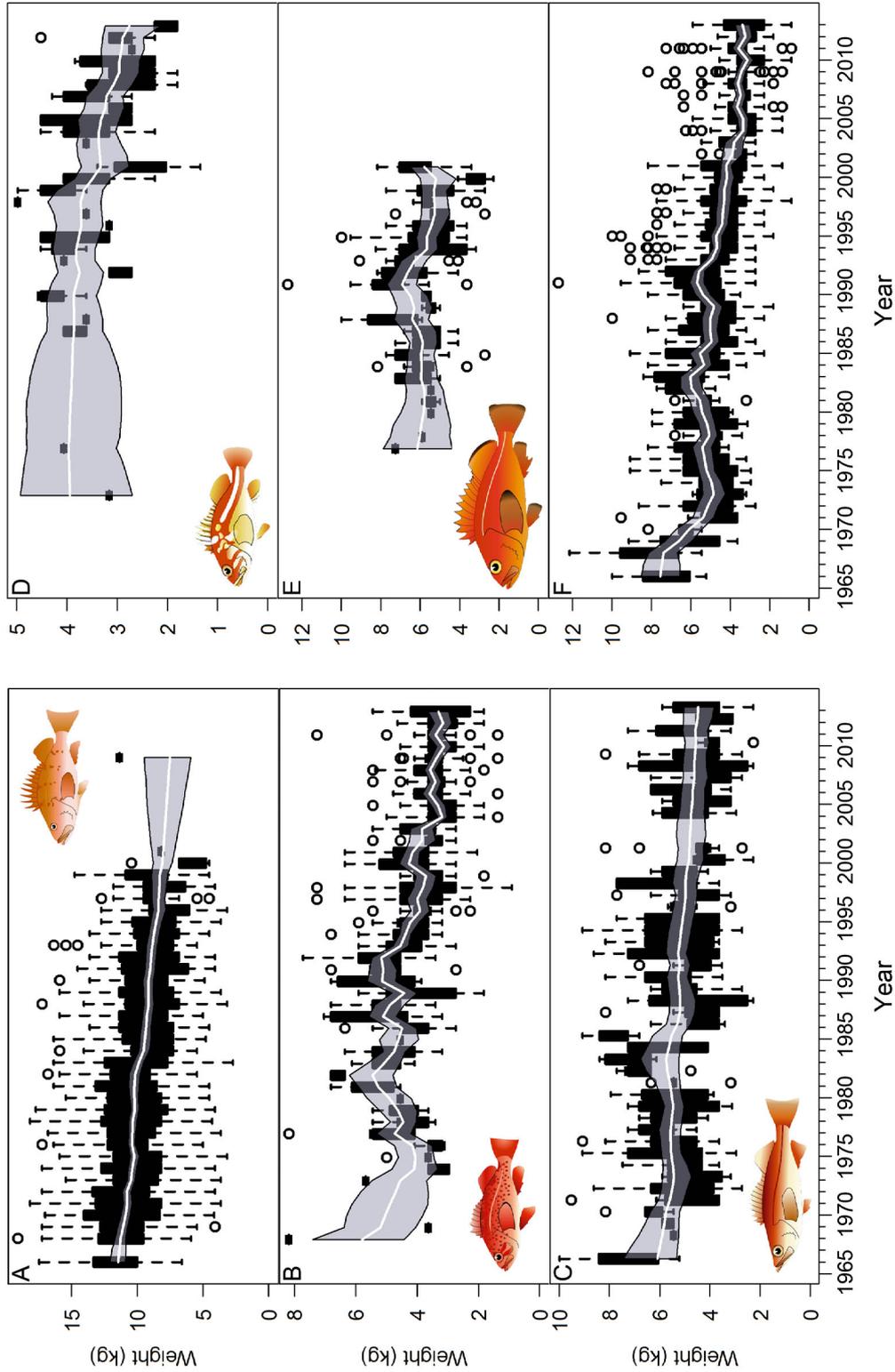


Fig. 2. Time series plots of annual model estimated trophy fish weight (median posterior value, white line) and uncertainty (95 % confidence intervals, grey region) overlaid onto boxplots of the raw data for (A) cowcod (n = 2535), (B) vermilion rockfish (n = 1083), (C) bocaccio (n = 364), (D) copper rockfish (n = 72), (E) yelloweye rockfish (n = 195), and (F) all *Sebastes* spp., excluding cowcod (n = 1787). Species binomials are given in Table 1. Boxplots show inter-quartile range (IQR, boxes), with outliers (circles) greater than  $1.5 \times$  IQR (whiskers) below or above the first and third quartiles, respectively

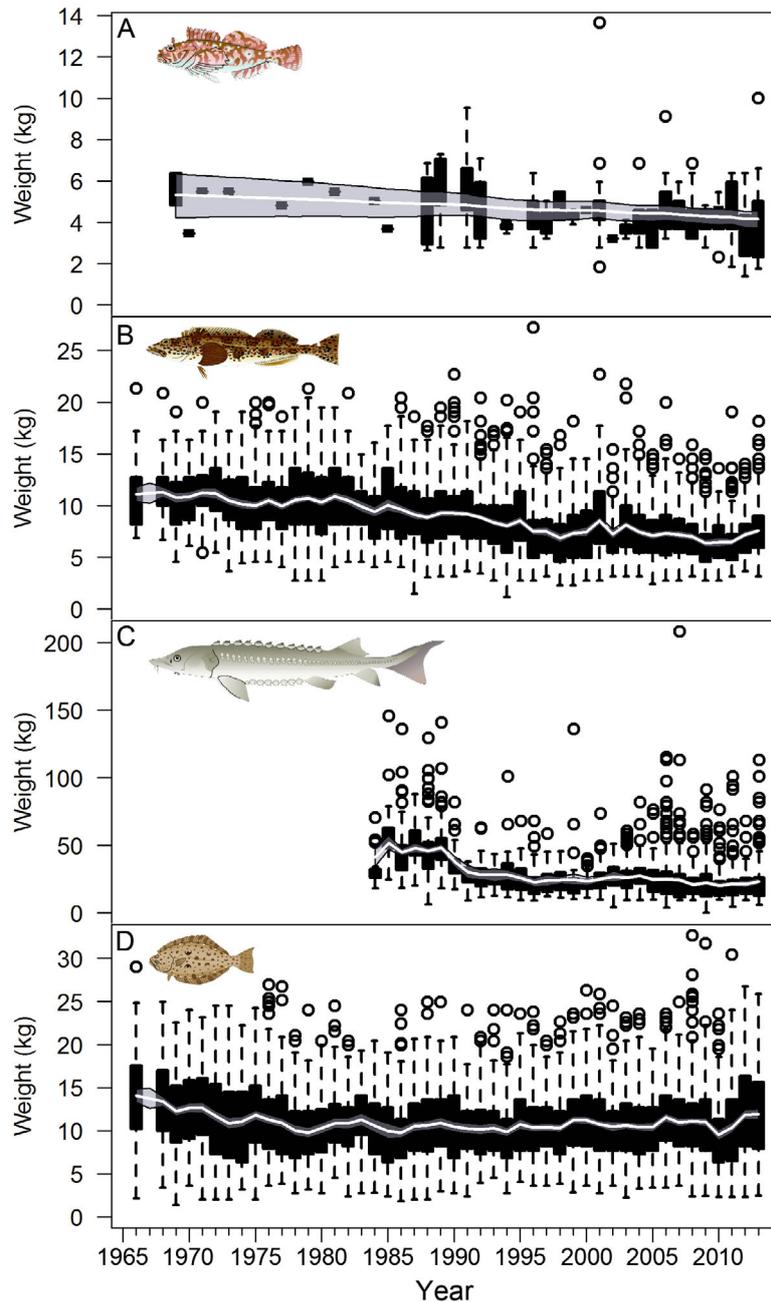


Fig. 3. Time series plots of annual model estimated trophy fish weight (median posterior value, white line) and uncertainty (95% confidence intervals, grey region) overlaid onto boxplots of the raw data for (A) cabezon ( $n = 192$ ), (B) lingcod ( $n = 7884$ ), (C) white sturgeon ( $n = 2877$ ), and (D) California halibut ( $n = 7729$ ). Species binomials are given in Table 1. Boxplot parameters as in Fig. 2

the early 2000s (~50% reduction in trophy size over the time frame). During the last decade, the *Sebastes* complex trophy size appears to have stabilized, and larger outliers are beginning to reappear.

Temporal trends in other demersal nearshore species are shown in Fig. 3A–D for cabezon, lingcod, white sturgeon, and California halibut, respectively.

Records for cabezon (Fig. 3A) showed a slight decline in trophy size over the entire study period. Lingcod (Fig. 3B) trophy size showed a consistent decline in size over the time frame, but increased during the most recent half-decade. White sturgeon (Fig. 3C), which were recorded almost entirely from the San Francisco Bay area, showed a precipitous decrease in

size around 1990–91, but this decline coincided with the implementation of 'slot' size limits for the species. However, even after the slot limit adoption, the species showed a gradual decline in mean trophy size from approx. 28 to 21 kg, although larger outliers have begun to appear more in recent years. California halibut (Fig. 3D) showed a significant decline until 1980, after which time the trophy size stabilized until 2012–13 when trophy sizes increased to levels similar to the late 1960s and early 1970s.

Species more associated with kelp forest communities (Fig. 4A–E) also showed signs of decline in trophy size during the study period. California sheephead (Fig. 4A) declined in the 1970s, and again in the 1990s, but appear to have stabilized during approximately the last decade. Ocean whitefish *Caulolatilus princeps* (Fig. 4B) showed a relatively consistent decline in trophy size, but sample sizes were quite low for the time series. The recreational fishery for giant seabass *Stereolepis gigas* (Fig. 4C) was closed in 1981, so data after that time are limited. While the early portion of the database showed no overall trend in size of giant seabass from 1966 to 1983, there is a clear absence of the largest outliers by the mid-1970s. The few data points in more recent years suggest that relatively large individuals are being caught (and released) again, although these weights are only estimates because the fish are released alive upon capture due to the 1983 closure of the fishery. Kelp bass (Fig. 4D) showed a significant decline in trophy size throughout the study period, and this decline steepened during the most recent 6 yr in the database. Barred sand bass (Fig. 4E) showed a fairly stable trend in trophy size until the late 1990s, but decreased markedly from the 1990s until present.

Demersal elasmobranchs in the database primarily consisted of broadnose sevengill sharks *Notorynchus cepedianus* (Fig. 5A) and leopard sharks *Triakis semifasciatus* (Fig. 5B), both of which are mostly recorded from the San Francisco Bay area. Both species are absent from the database prior to 1984, and leopard sharks did not show a clear trend in size after that time. However, sevengill sharks showed an increase in trophy size beginning in the mid-1990s, and continuing through 2013, which reflects the fact that this is a relatively young recreational fishery.

### Spatial patterns: distance from home port

The relationship between trophy size and distance from port was measured for 10 of the 16 focal species in this study. The following species in order of sample

size were included: lingcod ( $n = 5652$ ), California halibut ( $n = 4831$ ), cowcod ( $n = 1903$ ), vermilion rockfish ( $n = 708$ ), California sheephead ( $n = 573$ ), kelp bass ( $n = 541$ ), barred sand bass ( $n = 353$ ), bocaccio ( $n = 256$ ), yelloweye rockfish ( $n = 153$ ), and cabezon ( $n = 141$ ). Five species (giant seabass, copper rockfish, ocean whitefish, broadnose sevengill shark, and leopard shark) were omitted due to an insufficient number of records containing latitude–longitude coordinates for catch locations, and 1 species (white sturgeon) was omitted because it only inhabits areas relatively close to home ports (bays and estuaries). Table 2 shows a significant interaction between distance and date on trophy fish size ( $p < 0.001$ ). Thus anglers traveled farther over time to catch reportable trophy-sized fish, although the strength of this interaction varied between species (Figs. 6 & 7).

In order to facilitate study and interpretation of the interactive effect of distance and date on trophy catch, we generated binned plots of species-specific trophy sizes as a function of date and distance (Fig. 6 & 7). Rockfishes showed the strongest patterns in trophy size with respect to catch distance through time (Fig. 6). In all 3 distance bins from home port, the *Sebastes* complex exhibited smaller trophy sizes in the period 1990–2013 than in the period 1966–1989. In addition, during the period 1966–1989, the *Sebastes* complex showed smaller trophy sizes within 25 km from home port, and larger trophy sizes at distances >25 km from port ( $p < 0.01$ , Fig. 6E). During the period 1990–2013, trophy sizes remained small out to 50 km from home port, and increased only at distances greater than 50 km from home port. However, these larger sizes from >50 km away are similar to the trophy sizes recorded from <25 km away during the period 1966–1989. In addition, the trophy sizes at the greatest distances decreased over time, and ultimately became similar to trophy sizes reported during the earliest years at the closest distances from port. In other words, anglers now have to travel more than 50 km to catch the same sized rockfishes they used to catch nearer to their home port (cowcod, vermilion rockfish, and bocaccio were the dominant species in this pooled rockfish analysis, and thus significantly influence these results). We also found a similar pattern, although not as strong, for California sheephead, lingcod, cabezon, and California halibut (Fig. 7). Kelp bass showed decreased trophy sizes between the 2 time periods at all 3 distances from port, but there was no clear relationship between trophy size and catch distance over time. Barred sand bass also showed no clear pattern between size and distance from home port, although sample sizes in the farthest distance

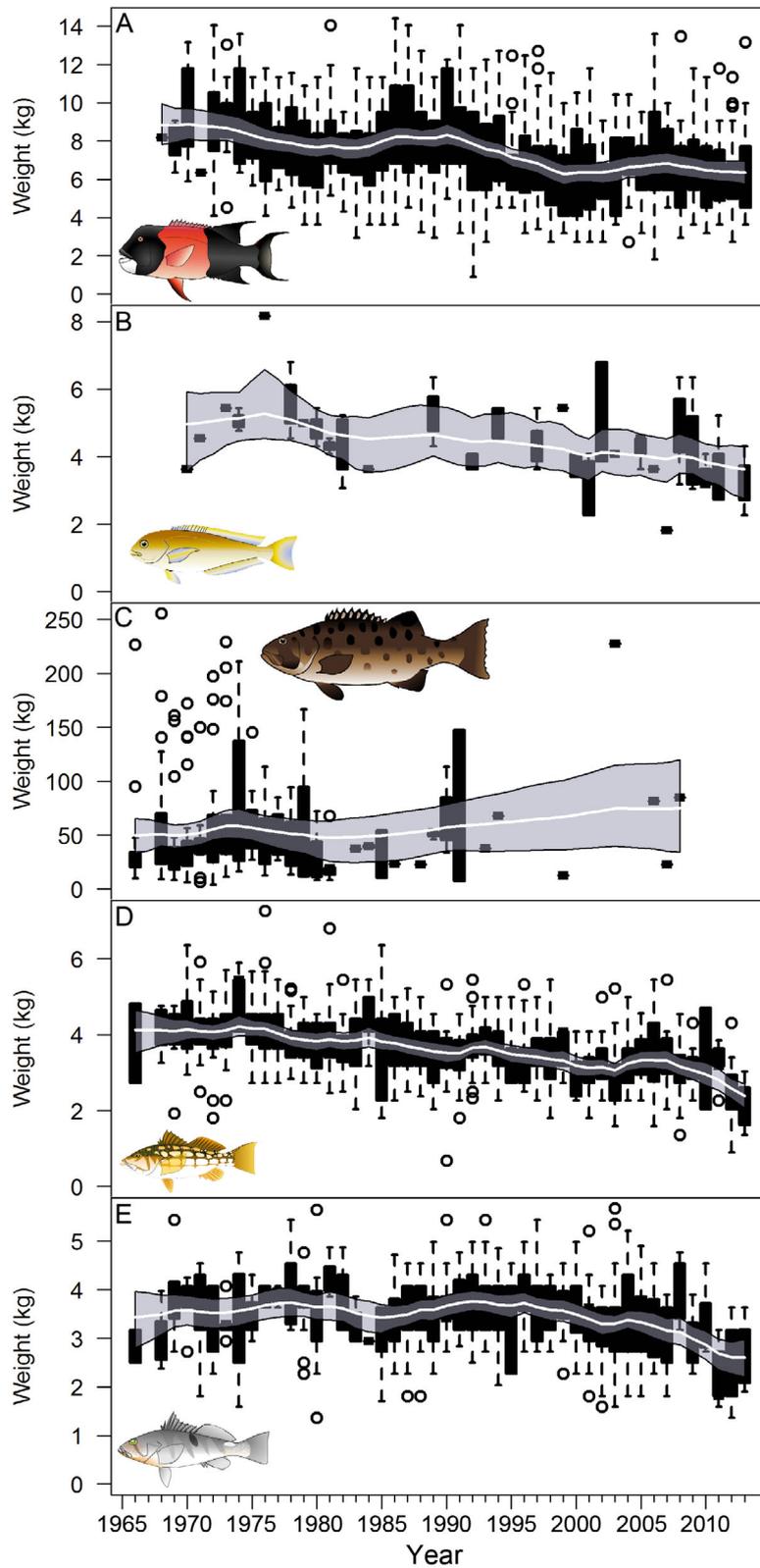


Fig. 4. Time series plots of annual model estimated trophic fish weight (median posterior value, white line) and uncertainty (95% confidence intervals, grey region) overlaid onto boxplots of the raw data for (A) California sheephead (n = 1036), (B) ocean whitefish (n = 70), (C) giant seabass (n = 231), (D) kelp bass (n = 866), and (E) barred sand bass (n = 556). Species binomials are given in Table 1. Boxplot parameters as in Fig. 2

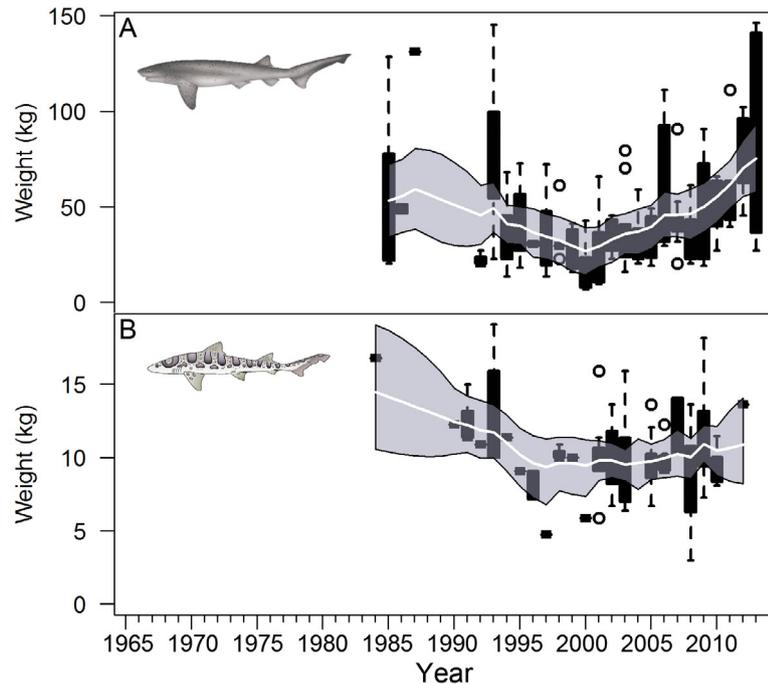


Fig. 5. Time series plots of annual model estimated trophy fish weight (median posterior value, white line) and uncertainty (95% confidence intervals, grey region) overlaid onto boxplots of the raw data for (A) broadnose sevengill shark ( $n = 148$ ) and (B) leopard shark ( $n = 105$ ). Species binomials are given in Table 1. Boxplot parameters as in Fig. 2

bin were very low (<10 individuals) because most are traditionally caught at spawning aggregations that are relatively close to each home port.

#### Northern Channel Islands MPA network effects

Recent changes in trophy fish size over time in the Northern Channel Islands region may be associated with many factors, such as changes in fishing effort, environmental conditions, or regulatory changes. The implementation of the first California state network of MPAs established in 2003 represented a significant regional-scale regulatory change that was intended to benefit the Northern Channel Islands region as a whole (Airamé et al. 2003). Trophy size

data from the 4 Northern Channel Islands were pooled and treated as the MPA network impact region (i.e. the area of the islands outside the MPAs, which was assumed to be within the influence of the island MPA network). These data were compared to trophy size data from the mainland (assumed to be outside the influence of the regional MPA network) for 6 species during the study period (Table 3, the remaining focal species in this study were not recorded in this region with a large enough sample size for spatial analysis). Kelp bass showed overall declines before and after the MPA network at both the islands and mainland regions (Fig. 8A) from 1966–2013. However, the more recent comparison (Fig. 8B) shows that kelp bass declines have continued on the mainland, but stabilized at the islands. California

Table 2. Results of a likelihood ratio test comparing model fits between models with and without a time by distance interaction (see Eq. 6) on trophy weights across species (treated as a random effect). Results indicate that the model with the interaction term results in markedly better fit to the trophy fish size reports. AIC (BIC): Akaike's (Bayesian) Information Criterion

Model	df	AIC	BIC	Log likelihood	Deviance	Chi-squared	p
No distance by time interaction (null): Log(weight) ~ date + distance + (1 + date + distance   species)	10	9651.0	9727.2	-4815.5	9631.0		
Distance by time interaction: Log(weight) ~ date + distance + date:distance + (1 + date + distance   species)	11	9598.6	9682.4	-4788.3	9576.6	54.49	<0.001

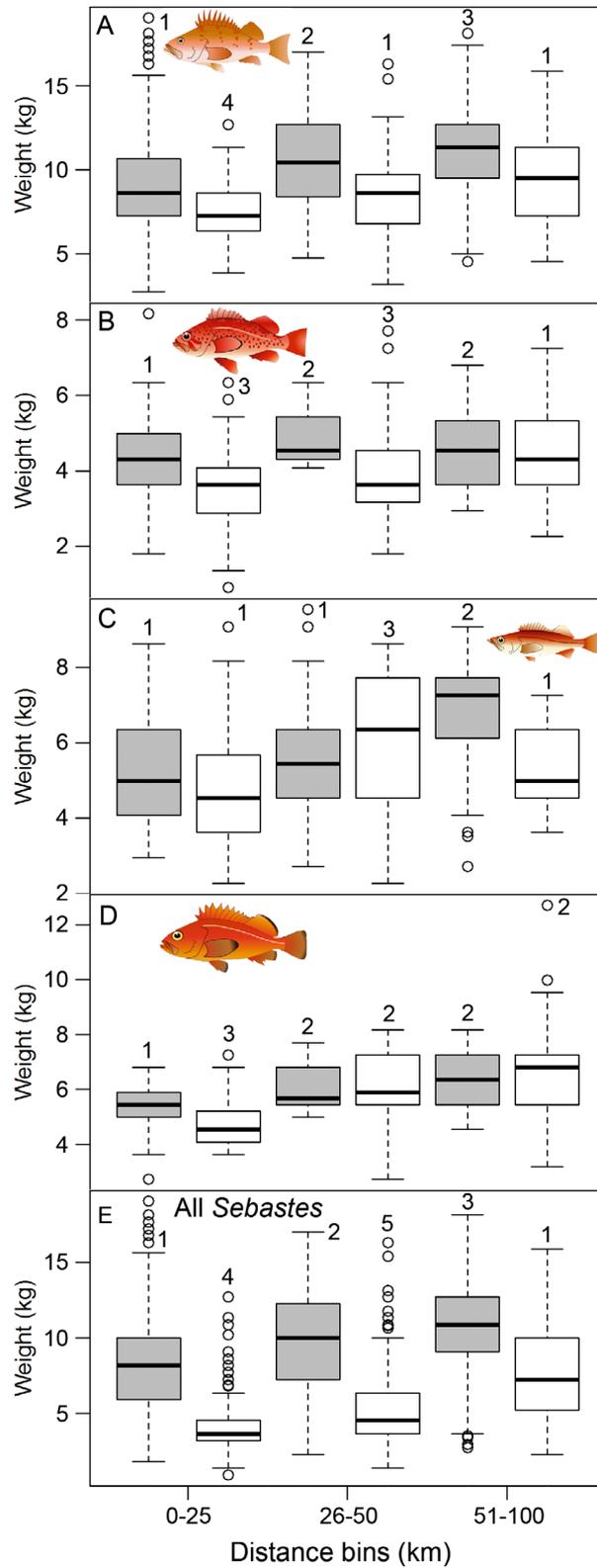


Fig. 6. Median weights of (A) cowcod (n = 1903), (B) vermilion rockfish (n = 708), (C) bocaccio (n = 256), (D) yelloweye rockfish (n = 153), and (E) all *Sebastes* spp. (n = 3104) at 3 distance bins from home port. Gray boxes represent the temporal first half of the database (1966–1989), and white boxes represent the second half (1990–2013). Species binomials are given in Table 1. Boxplot parameters as in Fig. 2; different numbers above boxes denote statistically significant differences ( $\alpha = 0.05$ )

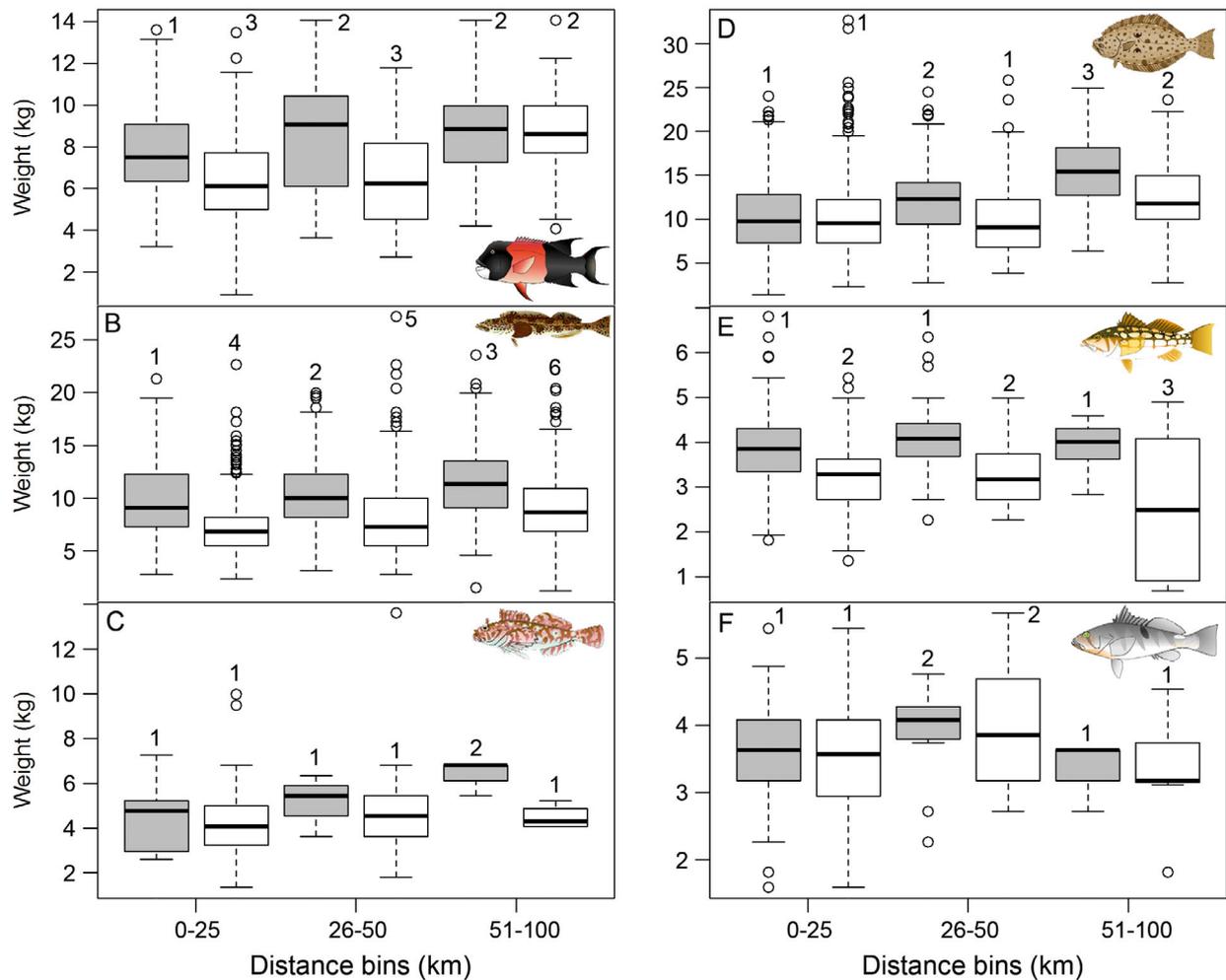


Fig. 7. Median weights of (A) California sheephead (n = 573), (B) lingcod (n = 5652), (C) cabezon (n = 141), (D) California halibut (n = 4831), (E) kelp bass (n = 541), and (F) barred sand bass (n = 353) at 3 distance bins from home port. Gray boxes represent the temporal first half of the database (1966–1989), and white boxes represent the second half (1990–2013). Species binomials are given in Table 1. Boxplot parameters as in Fig. 6

sheephead (Fig. 8C,D) and lingcod (Fig. 8E,F) both showed declines in trophy sizes before and after the MPA network from 1966–2013, but the magnitude of the decline during the more recent years was less at the islands and stabilized on the mainland for lingcod (Fig. 8F). Bocaccio (Fig. 8G,H) showed no significant region and time interactions, likely due to low sample sizes, although the available data suggests possible stabilization of trophy sizes in the more recent temporal comparison (Fig. 8H). Vermilion rockfish decreased in size over time at both the islands and mainland regions from 1966–2013 (Fig. 8I), but the significant interaction between region and time indicates that vermilions showed a greater decrease in the mainland region than at the islands after 2003 (Fig. 8J). California halibut (Fig. 8K,L) showed a stable size trend in both regions before the MPA net-

work, and a significant increase only at the islands during the 10 yr after the network had been implemented relative to the decade prior to the MPA network.

## DISCUSSION

Trophy fishes represent an especially important component of the overall spawning stock biomass because they have greater fecundity with higher-quality eggs (Berkeley et al. 2004, Calduch-Verdiell et al. 2014), maintain genetics for large individual size within the population (Fenberg & Roy 2008), influence community structure and ecosystem function (Friedlander & DeMartini 2002), and affect trophic flow (Sandin et al. 2008). These large size

Table 3. Estimates of the interaction between time period (before vs. after reserve implementation) and reserve status (within network: Channel Islands, vs. outside network: coastal) from a linear mixed effects model (before-after-control-impact [BACI] design). We fit 2 separate BACI models: one using all years leading up to reserve establishment as the 'before' designation (top panel), and one using only the 10 yr prior to reserve establishment (bottom panel). Common names of species are given in

Table 1

Time periods Species	Estimate	SE	<i>t</i>	<i>p</i>
<b>1968–2002, 2003–2013</b>				
<i>Paralabrax clathratus</i>	−0.1855	0.0872	−2.128	0.0348
<i>Semicossyphus pulcher</i>	−0.1783	0.1062	−1.679	0.0944
<i>Ophiodon elongatus</i>	0.0644	0.0341	1.891	0.0588
<i>Sebastes paucispinis</i>	−0.3655	0.2324	−1.573	0.1265
<i>Sebastes miniatus</i>	−0.2111	0.0762	−2.773	0.0062
<i>Paralichthys californicus</i>	−0.0987	0.0542	−1.822	0.0687
<b>1990–2002, 2003–2013</b>				
<i>Paralabrax clathratus</i>	−0.1789	0.0990	−1.808	0.0735
<i>Semicossyphus pulcher</i>	−0.0188	0.1427	−0.132	0.8954
<i>Ophiodon elongatus</i>	0.0947	0.0402	2.359	0.0185
<i>Sebastes paucispinis</i>	−0.0831	0.2974	−0.279	0.7830
<i>Sebastes miniatus</i>	−0.1640	0.0828	−1.979	0.0496
<i>Paralichthys californicus</i>	−0.1669	0.0643	−2.594	0.0097

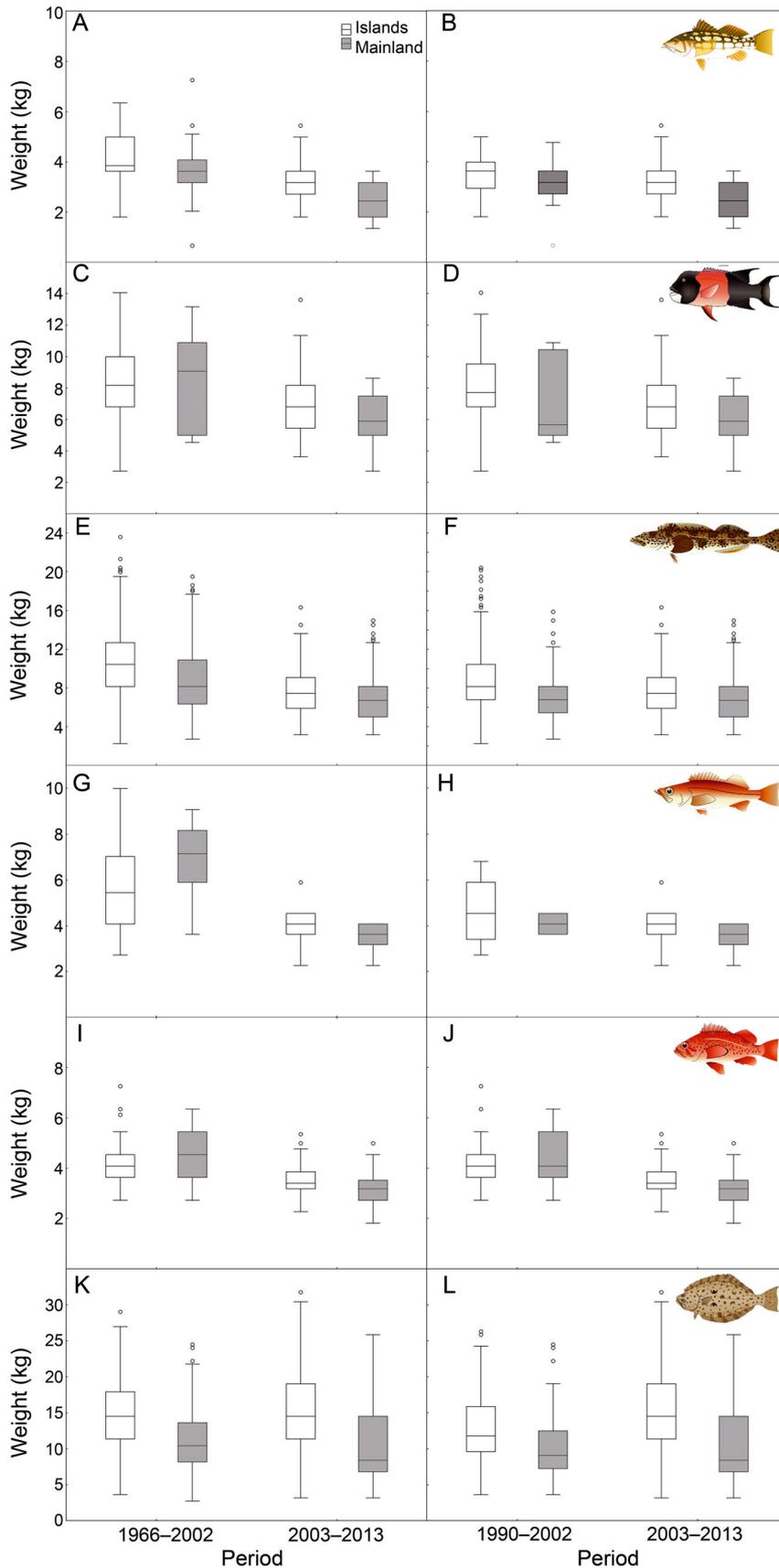
classes are also generally the most highly valued in fisheries. Presence of these large size classes can thus be an indicator of both ecological and fisheries health.

Temporal analyses of trophy sizes among demersal species show a range of trends, but the majority of cases illustrate an overall pattern of decline, followed by a more recent period of stabilization in the majority of cases. Twelve of the 16 demersal species included in this study exhibited long-term declines in trophy size in California from 1966 to 2013. In contrast to the pelagic and coastal pelagic species, such as yellowfin tuna *Thunnus albacares* and Pacific bonito *Sarda chiliensis*, demersal species generally live longer, exhibit slower growth and lower fecundity, mature later, are more localized in terms of movement patterns, and are more consistently accessible to the fishing community. This broad combination of life history characteristics, which collectively translate to a greater likelihood of being negatively impacted by overfishing, may serve as the underlying mechanism influencing the size declines exhibited in the WON database for this species group. Some of the focal species in this study are targeted in both commercial and recreational fisheries (e.g. vermilion rockfish and California halibut), and others are targeted only recreationally (e.g. kelp bass and barred sand bass), but species in both groups exhibited long-term declines in trophy size. California

sheephead (targeted both commercially and recreationally) not only exhibited declines in trophy size in this study, but were also reported to have smaller body sizes, earlier maturation, earlier age of sex changing, and reduced maximum lifespan among populations that were more heavily targeted (Hamilton et al. 2007). While the impacts of fishing are often associated with commercial fisheries, it is clear that California fish populations are impacted by recreational fisheries as well (e.g. Schroeder & Love 2002, Jarvis et al. 2014). Alós et al. (2014) found that recreational fisheries can create a mechanism of selective forcing that results in downsizing of adults through the selectivity of hook-and-line gear, especially when targeting species that exhibit strong spatial population structure. Such evolutionary decreases in body size suggest negative consequences for the reproductive potential of the population (Jørgensen et al. 2007). This may

be occurring among some of the species in our study, given the declines in size that were exhibited. While spatial population structure has been shown to be relatively weak for some of these species, such as kelp bass (Selkoe et al. 2006) and California sheephead (Poortvliet et al. 2013), our results do suggest that recreational fisheries have impacted the size structure of certain species, especially the rockfishes.

The rockfishes show the clearest signs of decline among the species in this study. The hypothesis that fishing pressure drives these declines is bolstered by our spatial analysis demonstrating that, in recent years, anglers are having to travel farther from home port to catch large fish. During the early half of the database (1966–1989), pooled analyses for the genus *Sebastes* showed that rockfishes weighing approx. 8 kg could be caught close to home port. During the more recent half of the database (1990–2013), similar sized fish could only be found >50 km from home port, primarily at offshore banks, near more isolated islands, and in Mexican waters. Anglers have more recently traveled over twice the distance to catch the same-sized rockfish from earlier decades, and the largest outliers are seldom caught at all, at any distance from port (this was true even with cowcod excluded, but the dominant species representing this trend were cowcod, vermilion rockfish, and bocaccio). While this pattern is most pronounced in the genus *Sebastes*, similar patterns can be seen for other dem-



ersal species in the WON database, such as California sheephead and lingcod. Evidence for such serial depletion is limited in California recreational fisheries, although Karpov et al. (1995) found that recreational rockfish landings in California shifted to species inhabiting greater depths over time, while the average weight of shallow-water species also declined. Karpov et al. (2000) also found sequential spatial depletion of red, pink, and black abalone (*Haliotis* spp.) populations in coastal California waters, while Miller et al. (2014) found that fishers have targeted groundfishes at greater depths and distances from port over time.

Despite the overall pattern of decline, there are 2 points that may suggest a more positive future for California demersal species. First, of the 12 species that showed long-term declines during the study period, 9 have more recently transitioned into a state of either stabilization or initial recovery in trophy size. These species may thus be in various states of population rebuilding due to the more progressive fisheries management policies adopted since 2001. These policies included fishing depth restrictions, gear restrictions (reduced number of hooks allowed), seasonal restrictions, and implementation of the cowcod conservation areas. Signs of stocks rebuilding have recently been measured for a number of different groundfish species (Sewell et

Fig. 8. Trophy weights (Western Outdoor News database) from all 4 of the Northern Channel Islands compared to the mainland (Santa Barbara and Ventura coasts) region. Two time periods, 1966–2002 and 1990–2002, are compared to the 2003–2013 period after the marine protected area network was implemented. The species included are (A,B) kelp bass (n = 56), (C,D) California sheephead (n = 211), (E,F) lingcod (n = 1125), (G,H) bocaccio (n = 18), (I,J) vermilion rockfish (n = 95), and (K,L) California halibut (n = 1074). Species binomials are given in Table 1. Box-plot parameters as in Fig. 2

al. 2013), so it is plausible that trophy sizes of some of these species may be recovering as well. Second, an extensive state-wide network of MPAs was recently implemented in a spatially phased process from 2003 to 2012. This network consists of 119 MPAs, 15 special closures, and 5 marine managed areas covering approx. 2200 km<sup>2</sup>, or ~16% of California state waters, across all of the most abundant benthic habitat types (Pope 2014). Because of the life history characteristics stated above, demersal species are the most likely group to benefit from these new MPAs. Some of these species are already exhibiting initial signs of increased densities, abundance, and/or biomass within the Northern Channel Islands MPA network (Hamilton et al. 2010, Karpov et al. 2012, Caselle et al. 2015). The WON trophy data suggest that these increases may have translated to benefits in local recreational fisheries as well. For example, California halibut increased in size in the Northern Channel Islands impact region (outside the island MPA boundaries) since the network was implemented, while they did not increase in size along the adjacent mainland Santa Barbara and Ventura coasts. Kelp bass showed signs of stabilization in the Northern Channel Island impact region (outside the island MPA boundaries) relative to the mainland coast, following declines that occurred in both regions prior to the MPA network, and vermilion rockfish showed greater declines along the mainland than at the islands after the island network was implemented. These results imply that the Northern Channel Islands MPA network may be positively affecting local fisheries yields via spillover. However, spillover was not measured in this study, so a definitive MPA effect cannot be determined. Other potential factors, such as changing environmental conditions, new fisheries regulations, and redistribution (or a regional decrease) of fishing effort could also potentially yield similar results, and thus cannot be ruled out.

The 4 species that did not follow the general pattern of decline are yelloweye rockfish, giant seabass, broadnose sevengill shark, and leopard shark. However, the time series available for yelloweye rockfish and giant seabass are very short, due to population declines and subsequent closures of these fisheries in 2001 and 1983, respectively. In addition, giant seabass were already heavily impacted long before the beginning of the time series in this study (Ragen 1990, Dayton & MacCall 1992). Since the closure for giant seabass, a few larger individuals were reported in catch-and-release records. These records suggest that a recovery in trophy size may be in progress (although post-1983 sizes are only estimates because

the fish were released alive), and recent signs of population recovery for this species have been documented by others (e.g. Pondella & Allen 2008). Broadnose sevengill and leopard sharks may simply be younger fisheries, or catch was not reported prior to the mid-1980s. Sevengills have shown an increase in size over approx. the last 15 yr, likely because anglers have learned more recently how to target and catch this species.

Based on reported trophy sizes over the last half-century, the size of the largest individuals of most targeted species has markedly declined. In some cases, stabilization or increases in the trophy size over the last decade appear to reflect the positive effects of resource management. That is not to say, however, that fisheries management in California is a panacea. Both barred sand bass and kelp bass, for instance, showed declines in trophy sizes over the entire timeframe, with increasing declines during the last 5 yr of data. For barred sand bass, this ongoing decline may reflect the cumulative effects of decades of harvest on known spawning grounds (Jarvis et al. 2014). The decline in kelp bass is more perplexing, although consistent with known trends in catch per unit effort for the species (Jarvis et al. 2014). It may be that declining trends in trophy size are driven by environmental conditions, changes in fishing effort reflective of the fact that southern California anglers can and do shift targeted fisheries, or may simply reflect increasing pressure on the fishery. In general, despite the high value of marine recreational fisheries in southern California, the data and studies necessary to identify mechanisms behind trends in recreational fisheries production are broadly lacking; efforts to leverage the expertise of the fishing community in understanding and assessing resources, as we have done here, will ultimately yield a deeper understanding of the drivers of resource dynamics and the efficacy of resource management.

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