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Community-level effects of spatial management in the California drift gillnet Fishery

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ABSTRACT

Fisheries management interventions that protect certain species by redistributing fishing effort may generate unintended consequences for other species. In the California drift gillnet fishery for swordfish and sharks, a large spatial closure was implemented in 2001 to protect endangered leatherback turtles, which limited fishing effort to the Southern California Bight. Leatherback bycatch has since decreased, but the effects on other species have not been comprehensively examined. Here, we explore the effects of this closure on the community catch composition in the fishery and find that other protected species may have benefited, while catch per unit effort of major target species increased or was not significantly affected over the long term. However, a time-series analysis reveals that changes in catch trends across twenty species began at least five years before the closure was implemented, suggesting that previous regulatory measures or other drivers may also contribute to these trends. These results highlight the importance of comprehensive approaches that include the historical context when evaluating management outcomes.

1. Introduction

Fisheries management interventions designed to protect a single species may generate unintended consequences for other species. This has been a particular concern for fisheries that incur bycatch, or incidental catch, of protected species or overfished stocks, where legal mandates or ecological concerns often lead to single-species interventions. Policies such as spatial closures or gear bans designed to reduce bycatch of individual species have created increased bycatch of other threatened or commercially valuable species in the U.S. Eastern Pacific tuna fishery (Hall, 1998), international North Pacific pelagic longline fishery (Lewison et al, 2003), U.S. Atlantic longline fishery (Baum et al., 2003), and Alaska bottom-trawl fishery (Abbott and Haynie, 2012) as fishermen shifted their spatial distribution or switched fishing gear, posing increased risks to sea turtles, seabirds, sharks, and Pacific halibut (*Hippoglossus stenolepis*), respectively. The prevalence of these unintended consequences demonstrates the importance of evaluating bycatch management interventions broadly, not just based on effects on specific target or bycatch species. Such comprehensive evaluation is crucial for adapting existing management plans as well as planning future interventions to be effective at the ecosystem level.

Bycatch has been a major concern in the California drift gillnet fishery for swordfish (*Xiphias gladius*) and sharks (shortfin mako, *Isurus oxyrinchus*; and common thresher, *Alopias vulpinus*). Gillnets, one-mile long, large-mesh nets that soak overnight, are typically unselective, resulting in a large number of historical interactions with various species of finfish, invertebrates, sharks, marine mammals, and sea turtles (NMFS, 2018) (Table 1). A series of gear modifications and time/area closures, most designed to reduce bycatch of individual species or species groups, have been implemented since the fishery's inception in the late 1970s (Table 2). Of these, the largest and most prominent is the implementation of the 2001 Pacific Leatherback Conservation Area (Fig. 1), which prohibits gillnet fishing from August 15th – November 15th from Point Conception to central Oregon (an area over 550,000 km^2) to protect endangered leatherback sea turtles (*Dermochelys coriacea*) while they forage in the California Current.

The direct effects and appropriate scale of the Pacific Leatherback Conservation Area (hereafter referred to as "the closure" or "the leatherback closure") remain a topic of study and controversy among conservationists, fishermen, and scientists. Many reports note that

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Table 1
Drift gillnet catch species referenced in this manuscript. Target species (defined as over 75% retained) icons are blue, while bycatch species icons are red. The percentage of total catch is calculated as number of individuals recorded in the observer data over total individuals of all species recorded. Analyses refer to the methods used in this study.

Icon	Species	Common name	Number caught	% total catch	Analyses
	*Mola mola*	Common Mola	55235	33.29	Both
	*Prionace glauca*	Blue Shark	22340	13.46	Both
	*Xiphias gladius*	Broadbill Swordfish	18502	11.15	Both
	*Thunnus alalunga*	Albacore Tuna	17382	10.48	Both
	*Katsuwonus pelamis*	Skipjack Tuna	9720	5.86	DFA
	*Isurus oxyrinchus*	Shortfin Mako Shark	8161	4.92	Both
	*Alopias vulpinus*	Common Thresher Shark	6632	4.00	Both
	*Scomber japonicus*	Pacific Mackerel	6480	3.91	DFA
	*Lampris guttatus*	Opah	5655	3.41	Both
	*Thunnus orientalis*	Bluefin Tuna	4520	2.72	Both
	*Auxis rochei*	Bullet Mackerel	3332	2.01	GLM
	*Sarda chiliensis*	Pacific Bonito	1128	0.68	GLM
	*Delphinus delphis*	Short-Beaked Common Dolphin	385	2.32×10^{-3}	Both
	*Zalophus californianus*	California Sea Lion	216	1.31×10^{-3}	Both
	*Mirounga angustirostris*	Northern Elephant Seal	115	6.93×10^{-4}	Both
	*Lissodelphis borealis*	Northern Right Whale Dolphin	73	4.40×10^{-4}	Both
	*Fulmarus glacialis*	Northern Fulmar	36	2.17×10^{-4}	Both
	*Lagenorhynchus obliquidens*	Pacific White-sided Dolphin	36	2.17×10^{-4}	DFA
	*Grampus griseus*	Risso's Dolphin	35	2.11×10^{-4}	Both
	*Dermochelys coriacea*	Leatherback Turtle	25	1.51×10^{-4}	Both
	*Delphinus capensis*	Long-Beaked Common Dolphin	23	1.39×10^{-4}	Both
	*Phocoenoides dalli*	Dall's Porpoise	23	1.39×10^{-4}	Both
	*Caretta caretta*	Loggerhead Turtle	16	9.64×10^{-5}	GLM

observed leatherback bycatch fell from a mean of two interactions per year to zero following the implementation of the closure (e.g. Carretta et al., 2017; Marsh and Stiles, 2011; Moore et al., 2009); population declines or reduced effort in the fishery may also contribute to this trend (Curtis et al., 2015). The closure has also been implicated in reducing the fishery's economic viability; swordfish fishermen cite the closure as a key factor driving attrition in the fishery, which peaked at over 200 permitted vessels in the mid-1980s and today has fewer than twenty (Benson et al., 2008; Gjertsen et al., 2014; PFMC, 2017). Other external factors such as fuel prices, swordfish market value, or dynamics in other fisheries may also play a role in the decline (Stohs, 2011).

Given the scale of the closure, there has been considerable interest in its potential effects. Studies indicate that a major effect of the closure has been a shift in the fishery's spatial footprint, essentially limiting effort to the Southern California Bight (Benson et al., 2008; Carretta et al., 2017; NMFS, 2013). The overall effects of the closure are considered so significant that studies of patterns of fishing effort or catch in the fishery tend to use it as a defining feature, dividing analysis of historical trends into pre- and post-2001 units (Carretta et al., 2017; Eguchi et al., 2017; Martin et al., 2015; NMFS, 2013; Soykan et al., 2014; Urbisci et al., 2016). While the closure's potential unintended consequences in terms of international transfer effects on sea turtle bycatch have been considered (Helvey et al., 2017), the effects of this closure on species in the California Current ecosystem beyond leatherbacks or a few key catch and bycatch species (Urbisci et al., 2016), and the effects of the corresponding geographic shift in effort, have not been explicitly evaluated.

The National Marine Fisheries Service (NMFS) regulates the drift gillnet fishery under the Magnuson-Stevens Act and has collected detailed onboard observer data for approximately 20% of fishing sets in the drift gillnet fishery since 1990, allowing for long-term analysis of the suite of discarded bycatch species in addition to landings. We sought to examine the effects of the southward concentration of fishing effort following the closure on community-level catch and bycatch in the fishery, to promote a more comprehensive understanding of the potential effects of this management intervention on the California Current marine ecosystem. We explored changes in catch per unit effort (CPUE) for the suite of species catalogued in the observer data over short (~5 year) and long (~20 year) time periods bounding the 2001 closure implementation. Our long-term examination led us to question assumptions about the importance of the leatherback closure in driving change in this fishery.

Table 2
Regulatory timeline and the number of active drift gillnet vessels over the fishery's history. Regulatory events are compiled from Berube et al. (2015) and Teo et al. (2016). Active vessels from 1980 to 1989 from PFMC (2008) and 1990–2017 from PFMC (2017).

Year	Regulatory Events	# Vessels
1977	Initial development of the fishery	
1978		
1979	-Fish and Game Commission authorizes sale of swordfish - Fisheries Management Plan developed for billfish and sharks	
1980	- Gillnets outlawed in the water from 2 hours before sunset to 2 hours after sunrise June 1–Nov 14 south of Channel Islands. - Radar reflector pole at end of net required - Non-transferable, limited entry permit system established	100
1981	Swordfish overtakes shark as primary target species	118
1982	- Drift gillnet fishing prohibited Feb 1–April 30 - Minimum mesh size changed to 14" - Waters around Channel Islands (6 nm or 10 nm) closed to drift gillnets May 1–July 31 - Swordfish/marlin quotas replaced by limiting swordfish landings to equal thresher and mako May 1–Sept 15 - New entrants (150 permits maximum) allowed in drift gillnet fishery	166
1983	Experimental permits and development of drift gillnet fishery for swordfish and shark in Oregon and Washington	193
1984	- Limited entry permit system enacted − 35 additional experimental permits granted for fishing north of Point Arguello	214
1985	-Waters 25 nm from coast closed to drift gillnets Dec 15–Jan 31 to protect gray whales -Equal shark-swordfish rule eliminated	228
1986	-Waters 75 nm from coast closed to drift gillnets June 1–Aug 14 to protect breeding thresher sharks -Drift gillnets prohibited within 12 nm from shore north of Point Arguello -Drift gillnets prohibited between Point Reyes and the Farallon Islands	204
1987		185
1988	Additional marine mammal protections enacted: vessels must display Marine Mammal Protection Act permit, report marine mammal kills, permit federal observers	154
1989	-WA and OR drift gillnet fishery closed -Thresher shark closure (75 nm) shifted to May 1–July 14	144
1990	Mandatory federal observer program begins	141
1991		121
1992	Thresher shark closure (75 nm) extended to May 1–August 14	120
1993		124
1994	-"Sunset clause" prohibits new drift gillnet entrants except by permit transfer -All gillnets and trammel nets prohibited in California state waters (3 nm from coast) and within 1 nm of Channel Islands	129
1995		118
1996	Take Reduction Plan requires net-buoy extenders of 36'	112
1997	Pingers mandated to reduce cetacean bycatch	109
1998	Loggerhead turtle mortality triggers Endangered Species Act Section 7 re-initiation	99
1999	Observed interactions with fin whale, green turtle, olive ridley turtle trigger Endangered Species Act Section 7 re-initiation	86
2000		72
2001	Pacific Leatherback Conservation Area prohibits drift gillnets between Point Conception and 45 N from August 15–November 15	61
2002		52
2003	Loggerhead Conservation Area prohibits drift gillnets south of Point Conception and east of 120 W June 1–August 31 during El Niño	44
2004	Pacific Fishery Management Council approves Fishery Management Plan for West Coast Fisheries Highly Migratory Species	36
2005		38
2006		39
2007		40
2008		30
2009		35
2010	Interactions with sperm whales observed	26
2011		22
2012		17
2013		18
2014	-State bill AB 2019 to ban drift gillnets fails -Pacific Fisheries Management Council rejects proposal to modify Pacific Leatherback Conservation Area	21
2015	Marine Mammal Protection Act import rule enforced	19
2016	State bill SB 1114 to phase out drift gillnets fails	25
2017	Federalization of drift gillnet fishery permits	17
2018	Driftnet Modernization and Bycatch Reduction Act (S. 2773 and H.R. 5638) to phase out drift gillnets introduced in U.S. Congress	

2. Methods

2.1. Community-level CPUE comparisons

We analyzed NMFS Southwest Region Fisheries Observer Program data for the period 1990–2015 (1502 fishing trips, 8722 net sets), during which the mean annual percentage onboard observer coverage was 18%. As the swordfish fishing season runs August to January, we refer to each fishing season by its first year (e.g. 1990–1991 fishing season is 1990) for brevity. We used a generalized linear model with a binary variable representing the implementation of the closure to test its effect on the CPUE of each of the 127 species recorded in the observer data, and present the subset of results for species with the largest changes in CPUE. All species for which results are presented in this paper are described in Table 1. Observers separate species into two categories: "protected species" (marine mammals, sea turtles, and seabirds), and "fish and sharks" (including invertebrates or anything else not in the previous category, both target species and bycatch), so we maintained these categories for analysis. Tunicates and unidentified invertebrates were removed from analysis because inconsistent reporting led to large outliers. We used a Poisson distribution with a natural log link for those models because protected species are caught much less frequently than fish and shark species. Although more complex statistics are needed to address rare bycatch events explicitly (e.g.

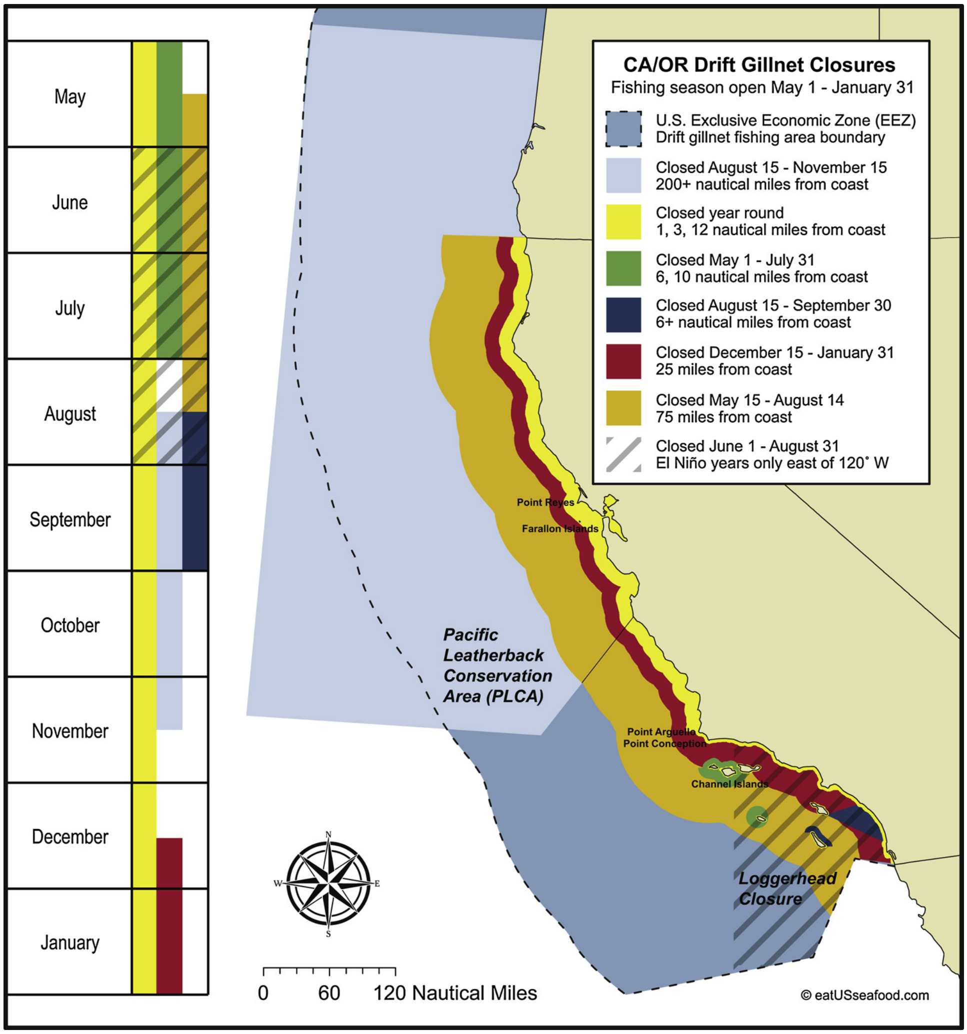

Fig. 1. The spatial and temporal extent of all time and area closures implemented in the fishery, with the Pacific Leatherback Conservation Area in light blue. Figure by Jonathan Gonzalez, eatUSseafood.com (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Carretta et al., 2017), these models are appropriate for assessing overall trends.

We defined CPUE as the number of individuals caught per fishing set (Hahlbeck et al., 2017; NMFS, 2001; Urbisci et al., 2016). We explored the effects of net length and mesh size but these did not change the overall findings. We performed the generalized linear models over the full length of the observer data (1990–2015) and the five fishing seasons preceding and following the implementation of the closure (1996–2005; 689 trips, 4011 net sets, mean 20.05% observer coverage) for two geographic regions: all sets recorded in the dataset as well as the subset occurring within the Southern California Bight, defined as fishing sets between the California-Mexico border (31° latitude) and Point Conception (34.45° latitude) (1077 trips, 5507 net sets). We used a Bonferroni correction to determine the statistical significance of effects.

2.2. Common trends

To characterize community-level trends in CPUE, we used dynamic factor analysis (DFA), a method for estimating common trends in multiple time series (Andrews et al., 2015; Samhouri et al., 2017; Zuur et al., 2003). DFA produces a model revealing shared trends among time series and covariates and factor loadings describing the relationship between the individual input time series and the common trends. We performed DFA on annual mean CPUE time series of the 10 most commonly caught fish and sharks and the 10 most commonly caught protected species (Supplemental Fig. 1), although for protected species, "commonly" caught is a relative term; catch of many of these species is considered a rare occurrence. These included target or secondary target species (defined as ≥75% retained: swordfish, shortfin mako shark, common thresher shark, bluefin tuna, albacore tuna, and opah) and bycatch species (common mola, blue shark, skipjack tuna, Pacific mackerel and all protected species).

DFA was performed over the full range of the observer data (1990–2015) with the MARSS package (version 3.9) in R (version 3.4.2) (Holmes et al., 2013). We tested models with up to four common trends and four variance-covariance matrix structures (diagonal and equal, diagonal and unequal, equal variance-covariance, and unconstrained), and evaluated model performance with corrected Akaike's Information Criterion. We used a cutoff of 0.05 to consider factor loadings for interpretation (Holmes et al., 2013), and 0.20 to define association with the common trend(s) (Zuur et al., 2003).

The model with the best-performing number of trends and matrix structure was fit with each of six possible covariates: a binary variable representing the implementation of the closure, a binary variable representing the implementation of pingers (high-pitched noise emitting devices to discourage cetacean bycatch), sea surface temperature (Scripps Pier, http://www.sccoos.org/data/autoss/timeline/?main=single&station=scripps_pier), the interaction between the closure and sea surface temperature, the Oceanic Niño Index (ONI, http://origin.

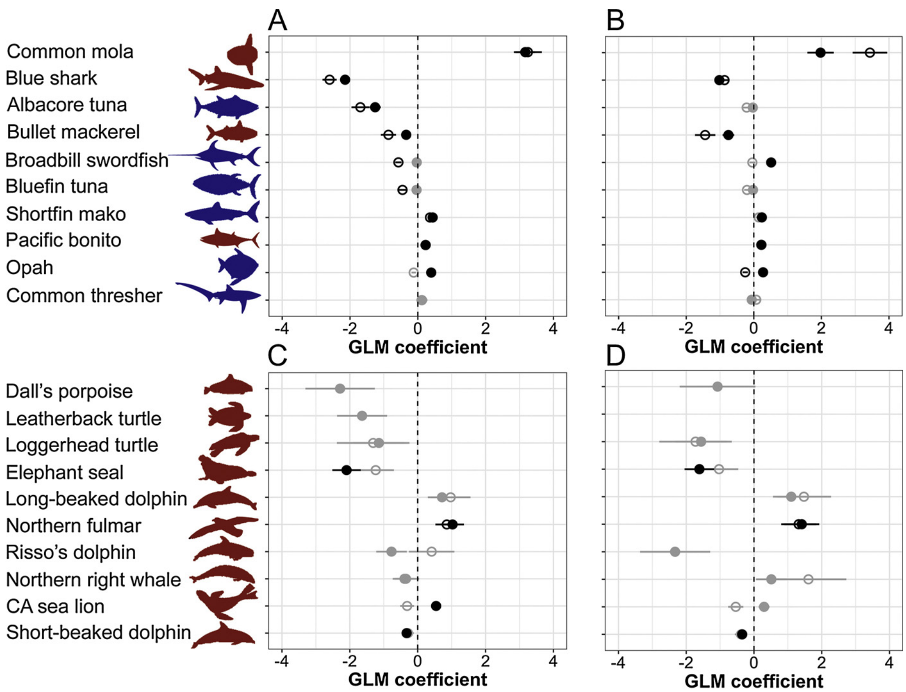

Fig. 2. Generalized linear model coefficients for the effect of the leatherback closure on catch per unit effort for the full time period (closed circles) and five-year period (open circles). Coefficients are shown for models using all fishing sets (A and C), and just sets occurring within the Southern California Bight (B and D). The species with the ten largest absolute changes over the five-year period among fish and sharks (A and B) and protected species (C and D) are shown. Gray circles represent insignificant changes in CPUE (Bonferroni-corrected $p > 0.05$). Dall's porpoises, leatherback turtles, and Risso's dolphins had zero catch during one or both of the five-year periods, so values are not shown.

cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php), and the inflation-adjusted landed price of swordfish for each year (PFMC, 2017). Annual swordfish price was calculated by dividing inflation-adjusted annual swordfish revenue by annual swordfish landings, with a 1.45:1 ratio of round weight to landed weight.

3. Results

3.1. Community-level CPUE comparisons

The two species with the largest effects on CPUE were both bycatch species: common mola CPUE was positively correlated with the implementation of the closure over both periods, while blue shark CPUE was negatively correlated. Among major target species, swordfish CPUE saw a significant negative effect over the short term but did not significantly change over the long term and shortfin mako shark CPUE increased over both periods, whereas albacore tuna CPUE decreased over both periods. The fish and shark species with the ten largest absolute generalized linear model coefficients (over the five-year period) are shown in Fig. 2**A**. For most protected species, the implementation of the closure did not significantly affect CPUE over either period (ten largest absolute coefficients in Fig. 2C). Coefficients represent the strength of the relationship between CPUE and the implementation of the closure, multiplying CPUE values in the case of fish and sharks (e.g. common mola CPUE increased by approximately 3 times following the implementation of the closure), and log CPUE values for protected species fit with the Poisson distribution (e.g. elephant seal CPUE decreased by approximately e^{-2}, or ˜0.135, times). Elephant seals and short-beaked common dolphins saw a significant negative effect over the long term, while California sea lions saw a significant positive affect over the long term. Northern fulmar CPUE was significantly positively correlated with the implementation of the closure over both time periods, but were only caught in 2000, 2002, 2003, and 2005.

Generalized linear model results for the Southern California Bight were similar to patterns seen for the entire region among both protected and fish/shark species, although in most cases the effect amplitude was dampened (Figs. 2**B** and **2D**). Notable differences include swordfish, which saw a significant positive effect on long-term CPUE in the Bight as opposed to an insignificant effect across all sets, and albacore tuna, for which CPUE did not significantly change in the Bight over either period, whereas its CPUE significantly decreased in both periods across all sets. Generalized linear model coefficients and p-values are displayed in Supplemental Table 1.

3.2. Common trends

The best DFA model had one common trend with a diagonal and equal matrix, and none of the covariates improved the fit of the model (Table 3). The trend is generally decreasing, with the steepest slope approximately between 1996 and 2012 followed by a slight upward trend (Fig. 3A). The majority (55%) of analyzed species had positive factor loadings for this trend, indicating a positive correlation with the trend, i.e. decreasing CPUE (Fig. 3B). Shortfin mako shark, common mola, bluefin tuna, opah, long-beaked common dolphin, and California sea lion had negative factor loadings, indicating increasing CPUE over time. Elephant seals and blue sharks, both positively correlated, show the strongest correlation with the trend; they are the only species above the "arbitrary" cutoff of 0.2 from Zuur et al. (2003) to define association with the trend, while opah (negatively correlated) and Dall's porpoise (positively correlated) would be considered marginally less associated. Factor loadings for all 20 included species are available in Supplemental Table 1.

Although factor loadings were generally low, their directionality and magnitude are largely consistent with the CPUE comparisons. CPUE patterns for long-beaked common dolphins appear to correlate more strongly with this common trend than with the binary implementation of the closure. For bluefin tuna, higher landings in recent years are likely driving the loading on the common trend, while low landings through the 2000s relative to the mid 1990s may explain the significant generalized linear model coefficient over the shorter time period.

4. Discussion

Fisheries are complex systems, and attributing drivers of change is difficult. In this fishery, the outcomes of one regulatory intervention for a diverse set of species are difficult to disentangle from the interacting effects of other social and ecological drivers across many scales. Over

Table 3
Model selection criteria from the top 15 dynamic factor analysis models with 1–4 common trends and 0–2 covariates. R = variance-covariance matrix structures, m = number of trends, logLik = log likelihood, AICc = corrected Akaike information criterion, ΔAICc = difference in model AICc from best model AICc.

R	m	Covariates	logLik	AICc	ΔAICc	Akaike weight	Cumulative Akaike weight
Diagonal and equal	1	None	−687.14	1418.14	0.00	0.66	0.66
Equal variance-covariance	1	None	−686.80	1419.63	1.49	0.31	0.98
Diagonal and equal	1	ENSO	−667.81	1424.83	6.70	0.02	1.00
Diagonal and equal	2	None	−674.59	1436.04	17.90	0.00	1.00
Equal variance-covariance	2	None	−674.02	1437.25	19.11	0.00	1.00
Diagonal and unequal	1	None	−679.24	1445.32	27.18	0.00	1.00
Diagonal and unequal	2	None	−657.12	1447.63	29.49	0.00	1.00
Diagonal and equal	3	None	−662.26	1455.36	37.22	0.00	1.00
Diagonal and equal	1	Pingers	−683.57	1456.35	38.22	0.00	1.00
Equal variance-covariance	3	None	−661.94	1457.27	39.13	0.00	1.00
Diagonal and equal	1	Price	−685.19	1459.59	41.45	0.00	1.00
Diagonal and equal	1	PLCA	−685.52	1460.25	42.11	0.00	1.00
Diagonal and equal	1	SST	−685.65	1460.50	42.36	0.00	1.00
Diagonal and unequal	3	None	−642.59	1466.35	48.21	0.00	1.00
Diagonal and equal	1	SST & PLCA	−668.24	1474.99	56.85	0.00	1.00

the study period, the drift gillnet fishery experienced a suite of regulatory changes, an altered spatial footprint, declining participation, and extreme environmental variability in the form of El Niño and La Niña events. Beyond the scope of this study were subtler and perhaps more important changes including broader market and economic drivers, dynamics of other fisheries, population fluctuations and shifting spatial distributions of species, and potential changes in overall fisher behavior and skill as a result of attrition. Furthermore, for many of the protected species studied, which may be of greater management concern, catch events are quite rare, reducing our power to attribute changes in catch to particular drivers. Our analyses here might be considered a first step toward a more comprehensive approach to evaluating management outcomes in this fishery.

Proponents of the Pacific Leatherback Conservation Area may be encouraged that it does not appear to have generated substantial unintended consequences for other protected species. Protected elephant seals and short-beaked common dolphins, particularly, appear to have benefited from the closure when we model its effect on their CPUE. Meanwhile, with the exception of albacore tuna, CPUE of target species was positively correlated with the implementation of the closure or did not significantly change over the long term, results consistent with past studies (Urbisci et al., 2016). Although the fishery's effort was limited to the Southern California Bight as a result of the closure, this does not appear to have driven changes in CPUE trends among the most commonly-caught species, as patterns in CPUE change were similar in the Southern California Bight and in the overall fishery.

When we analyze aggregated time series over the longer term, however, our results suggest that using the 2001 closure as the dividing point for study may be misleading. Our DFA suggests that the leatherback closure did not exacerbate previously changing trends in CPUE for the species analyzed. That the slope of the common trend did not change around 2001, when the closure was implemented, may indicate that the closure served to continue processes already in place. This result is surprising given the emphasis on the leatherback closure in analyses and discussion of the fishery, but may point to the success of previous management measures. Although association with this trend was low among most species, the lack of any trend that had a clear response aligned with the closure, nor clear demarcations in the CPUE time series, suggest that the closure had a limited impact on trends in CPUE over the fishery's history. Future studies of lagged or cumulative effects of mounting regulations rather than of one intervention in particular may be useful for characterizing drivers of change in this fishery.

Lack of clear adherence to a common trend may also indicate that other factors, such as population dynamics and shifting species distributions may contribute to changes in CPUE as well. For example, in the case of the California sea lion, a decrease over the short period but an increase over the long period could be indicative of the population growth documented in the species over the last few decades (Laake et al., 2018). For Northern fulmar, a relatively high total catch among protected species was concentrated in a few years in the early-mid 2000s, perhaps due to a shift in distribution or fishing behavior. This gives the appearance of increased CPUE correlated with the closure that was likely unrelated without further corroboration. Any change in species abundance or distribution would affect our analyses, but

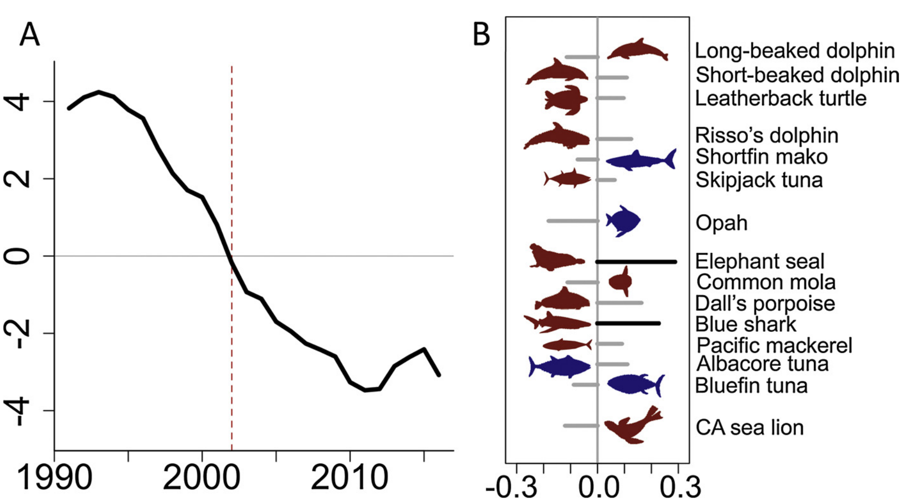

Fig. 3. Dynamic Factor Analysis common trend (A) and factor loadings (B) for the best fit model. Factor loadings in gray are above the 0.05 cutoff used in Holmes et al., 2013, while black factor loadings are above the 0.20 cutoff used in Zuur et al., 2003. Dotted red line denotes the 2001 implementation of the leatherback closure (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

because many of the species in this database are neither commercially landed nor explicitly protected—common mola, the species with the largest modeled effects on CPUE, falls in this category—there is little fisheries-independent (or even fisheries-dependent) data on their populations. Thus, we were unable to account for population dynamics in our study.

Oceanographic and environmental variability may also mediate the catch of certain species. Although the El Niño index did not improve the DFA model, it has been documented that the strong 1997 El Niño and 1999 La Niña resulted in unusual or novel species interactions (Table 2) (NMFS, 2001) and may have affected the abundance of other species as well. Because these anomalous years occurred in the five years preceding the closure, they likely influenced our generalized linear models, but were not included in those analyses. Other environmental features such as substrate and frontal features associated with upwelling have been shown to influence interactions with common mola and bluefin tuna (Hahlbeck et al., 2017) and may have effects on other species as well. More specific evaluations of how the fishery's limited spatial footprint interacts with highly anomalous conditions may shed light on whether certain species are more likely to be caught as a result of the leatherback closure and contribute to emerging management strategies that explicitly consider the effects of changing oceanographic conditions on multiple species' habitat use (Hazen et al., 2018).

In addition to advancing more holistic studies of the effects of management on CPUE trends, parallel or integrated work is needed to understand how this closure, and other aforementioned factors, affect this fishery's human dimensions. As with catch trends, the decline in fishing effort and fishery participation started long before the leatherback closure was implemented, but the southward delimitation of the fishery and loss of participation in ports north of the closure undoubtedly affected the economy, culture, and resilience of those communities. In particular, studies in ports north of the Southern California Bight that no longer participate in the drift gillnet fishery may elucidate how the suite of regulations and environmental changes in this fishery have influenced the economic and environmental sustainability of California's fishing system as a whole.

5. Conclusion

This study is an encouraging look at the broader success of a fisheries management intervention from a community-composition perspective. The 2001 leatherback closure has largely been successful in its aims of reducing leatherback turtle bycatch (Eguchi et al., 2017) and does not appear to have created major unintended consequences for other species caught in the fishery. Its effects, however, are likely intertwined with those of previous management measures. The focus on the leatherback closure as a driver of bycatch and socioeconomic trends may mask the impact of previous regulatory, environmental, economic, or other drivers, and combinations thereof. This analysis reveals some pitfalls of narrow or short-term evaluation of management interventions, and points to the importance of explicit evaluation of management effects with attention to other factors in the fishery, including the historical context of regulations. It also highlights the need for continuous monitoring and evaluation of large-scale management interventions, both for possible unintended consequences and for their efficacy in a dynamic and changing environment.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2019.02.010.

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