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Recent Trends in the Abundance of Seasonal Gray Whales (*Eschrichtius robustus*) in the Pacific Northwest, 1996-2020

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Recent Trends in the Abundance of Seasonal Gray Whales (*Eschrichtius robustus*) in the Pacific Northwest, 1996-2020

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Abstract

The following report provides an updated estimate of abundance for Pacific Coast Feeding Group (PCFG) gray whales through 2020 using data derived from the collaborative, multi-year photographic survey of gray whales in the eastern North Pacific. The data time series spans 25 years (1996-2020) and fifteen survey regions along the west coast of North America from Southern California to Kodiak, Alaska. The present analysis focuses on data for animals observed between 1 June and 30 November within one of three nested spatial domains: 1) the PCFG range defined by the International Whaling Commission encompassing coastal areas from northern California to northern British Columbia, Canada, including the western Strait of Juan de Fuca; 2) the region defined in the Makah Waiver Request encompassing coastal areas from southern Oregon to southern Vancouver Island, British Columbia, including the western Strait of Juan de Fuca; and 3) the Makah Usual and Accustomed Area encompassing portions of coastal northwestern Washington and the western Strait of Juan de Fuca. The population models are identical to those considered in the last effort to estimate PCFG abundance through 2017 (Calambokidis et al. 2019). As of 2020, the PCFG abundance is estimated to be 212 individuals (SE = 17.9, N_{min} = 198) within the PCFG range. Using the Potential Biological Removal (PBR) formula, with an R_{max} of 6.2% and a recovery factor of 0.5 (Caretta et al. 2013), the PBR for PCFG range would be 3.1. Our abundance estimates indicate that the PCFG has been stable over the last 20 years, declining slightly from an observed peak in abundance in 2015.

Contents

Introduction

The Marine Mammal Laboratory (MML) at the NOAA-NMFS Alaska Fisheries Science Center coordinates and conducts annual surveys for Eastern North Pacific (ENP) gray whales (*Eschrichtius robustus*) from northern California (USA) to British Columbia (Canada) as part of a larger research collaboration to understand ENP population abundance, movements, and stock structure. A small group of ENP whales that demonstrate strong seasonal fidelity to the Pacific Northwest was first identified by Calambokidis et al. (2004) and later recognized by the International Whaling Commission (IWC) as the Pacific Coast Feeding Group (PCFG), which includes individuals observed in two or more years between 1 June and 30 November from 41°N to 52°N latitude. Whereas transient ENP whales passing through to feed in the northern waters of the Chukchi, Beaufort, and Bering seas are rarely observed more than once in the Pacific Northwest, PCFG whales are frequently resighted due to their higher fidelity to the region and increased residency time through the summer and fall. Here, we update the estimates of PCFG abundance through 2020 using gray whale sighting histories since 1996 and the population modeling framework described in Calambokidis et al. (2019).

Methods

Description of Photographic Catalog and Data Processing

The gray whale photographic catalog maintained by Cascadia Research Collective (CRC) provided the baseline data for generating abundance estimates for PCFG gray whales. The CRC catalog is comprised of imagery associated with coastal gray whale sightings from California to Alaska between 1996 and 2020 (Fig. 1) and includes images from individuals identified as members of the PCFG and the broader Eastern North Pacific population. The underlying motivations leading to gray whale encounters varied among observers, from opportunistic sightings reported by citizen scientists to more formal surveys conducted by various research groups. Despite differences in intent, observers followed similar procedures for photographing gray whales. When possible, the left and right sides of the dorsal region proximate to the dorsal hump and the ventral fluke provided the standard for gray whale photographic identification. Photographs from each sighting were shared with CRC for matching and inclusion in the photographic catalog. Markings used to distinguish individual gray whales included variation in skin pigmentation, encrusting invertebrates, the size and spacing of knuckles along the dorsal ridge posterior to the dorsal hump, and unique scarring, which in composite have provided a reliable means of identifying individual gray whales (Darling 1984).

The gray whale catalog represents 15 previously defined survey regions from southern California to Alaska (Table 1). For the purposes of quantifying the abundance of PCFG gray whales, we limited the assessment to nine subregions from northern California (USA) to northern British Columbia (Canada), encompassing a contiguous section of the Pacific outer coast of North America and the western portion of the Strait of Juan de Fuca (SJF; Calambokidis et al. 2019). Specifically, we estimated PCFG gray whale abundance at three nested spatial scales (Fig. 1; Table 1): 1) NCA-NBC is the largest area and includes the coastal survey regions from Northern California (NCA) through Northern Vancouver Island/British Columbia (NBC) which matches the IWC definition of the PCFG range, 2) OR-SVI survey regions extend from southern Oregon (OR) through Southern Vancouver Island (SVI) identified in the Makah waiver request, and 3) MUA, the Makah Usual and Accustomed Area, encompassing portions of coastal northwestern Washington and the western SJF. Inland waters in Washington (other than SJF) and British

Columbia are excluded from the abundance estimates because these areas are used primarily by transient whales during the northbound spring migration.

We temporally truncated the time series to include gray whales photographed and identified within the defined region anytime during the period between 1 June and 30 November following the IWC definition of PCFG membership (hereafter referred to as the sampling period) (Calambokidis et al. 2019). A sighting history was constructed for each unique gray whale photographed using 25 years of data from 1996 to 2020. Multiple sightings of an individual whale within a year were treated as a single detection. However, multiple sightings over the course of a year were used to construct an observed minimum tenure (MT) for each whale. MT was defined as the number of days between the earliest and latest date the whale was photographed with a minimum of one day for any whale observed.

Data Analysis

We followed the population modeling procedures described in Calambokidis et al. (2019) in order to maintain continuity with past efforts. To summarize, we fit open population models within RMark (an R interface for Program MARK; White et al. 1999, Laake 2013) to estimate PCFG abundance and survival using annual sighting history data from the 25-year time series. We considered the same suite of competing models as described in Calambokidis et al. (2019). We used the POPAN parameterization that included a super population size (N), probability of entry (immigration), sighting probability (p), and survival/permanent emigration (φ) following a robust Jolly-Seber (JS) framework (Schwarz et al. 1996). We fitted all combinations of p and φ and used Akaiki Information Criterion (AICc; Burnham and Anderson 2002) to select the most parsimonious model of the 30 fitted models (Table 2). However, multimodal inference was used to compute abundance estimates, unconditional standard errors, and confidence intervals.

The model set included parameterizations that tested for differences between “first-year” and “post-first-year” survival, as defined by the first year an individual was observed, to account for predicted differences in the probability of resighting transient (i.e., non-PCFG) and PCFG animals in consecutive years (Pradel et al. 1997; Table 2). Notably, survival as implemented here is confounded with permanent emigration, particularly within first-year survival estimates. Therefore, we expect survival estimates to be biased low relative to true survival. Survival, and the underlying emigration and transiency patterns, likely vary through time. To account for potential temporal structure in survival, we followed Calambokidis et al. (2019) and implemented two distinct sub-models representing varying degrees of complexity for first-year survival (and therefore transient proportion) by 1) including three period-specific, first-year survival estimates (1996 and 1997, 1998, and 1999 and later); and 2) permitting first-year survival to vary by year. The three periods were selected to reflect the progression in both survey effort and catalog membership with a higher preponderance of newly identified individuals that were also members of the PCFG during the earliest years and more expansive survey coverage after 1998.

Post-first-year survival, and therefore emigration rate, was also expected to change in response to a short-term redistribution of individuals following a stranding event in 1999/2000. As in Calambokidis et al. (2019), we included a group effect in all models that represented two distinct groups and their post-first-year survival: 1) a group incorporating all non-calves newly observed prior to 1999 and all calves independent of year and 2) a group incorporating all non-calves newly observed after 1998. We assumed that all PCFG gray whales were observed in their first year (sighting probability p and probability of entry p_{ent} are fixed to 1 for each cohort year). For estimating non-fixed sighting probabilities (p), we fitted three models that varied by time (year) and/or varied by minimum tenure (MT) in the previous year (Table 2). Finally, we considered models that permit first-year survival to vary as a function of MT with the expectation that whales spending more time in the PCFG range during the sampling period are more likely to be observed in the following year. The effect of MT was either held constant through time or permitted to change across years or time periods.

Abundance Estimation and Mixing Rates

Annual abundance was derived from a modified Jolly-Seber estimator represented by

$$\widehat{N_j} = \sum_{i=1}^{u_j} \widehat{\varphi_{ij}} + \sum_{i=1}^{m_j} 1 / \widehat{p_{ij}} \,,$$

where the abundance of PCFG whales $(\widehat{N})$ in year j is comprised of newly observed individuals (u) who are expected to remain part of the PCFG $(\hat{\varphi})$ and the number of previously observed individuals (m) observed with sighting probability $(\hat{p})$. We assumed that all new PCFG whales were sighted $(p = 1)$, and because we were only interested in estimating the abundance of whales that will remain part of the PCFG (or the portion of newly observed whales that do not permanently emigrate), we included covariates yearly (j) and whale-specific covariates (i) (like minimum tenure). To obtain an abundance estimate for 2020, we assumed that the first-year survival intercept for 2020 was the same as in 2019. For predicting the number of new whales that remained a part of the PCFG (i.e., did not permanently emigrate), a variance-covariance matrix for the abundance estimates was constructed using a Horvitz-Thompson-type variance estimator from Borchers et al. (1998) with an adaptation for the first component to predict the number of new PCFG whales.

We used the methods of Calambokidis et al. (2019) to estimate mixing rates of PCFG and transient whales between December and May. However the data between 2016 and 2020 was selectively processed for PCFG individuals which results in a known bias in the simple aggregate mixing rates during the winter/spring in these later years. Although the off-season image matching is ongoing and expected to be completed for future reporting, here we report the estimates from Calambokidis et al. 2019 and the more recent, selectively processed dataset for comparison.

Results

From 1996 to 2020, 904 unique whales were observed in the PCFG range between June and November, 71.3% (n = 645) of which were observed within the smaller OR-SVI region. The average number of whales identified in any one year was 158, 112, and 39 for the NCA-NBC, OR-SVI, and MUA regions, respectively (Table 3, 4, and 5). Importantly, these numbers do not reflect the true numbers of whales that use each of these areas because 1) not all whales using a subregion are observed that year, 2) not all whales return to the same subregion each year, and 3) not all whales return to the PCFG range each year. The annual average number of newly observed whales (excluding 1996-1998 before the photo-id effort expanded to cover all survey regions) was 33.8, 24.5, and 14.2 for NCA-NBC, OR-SVI, and MUA, respectively. The annual average number of newly observed whales that were "recruited" (observed in a subsequent year, excluding 1996-1998 and 2020) was 13.9 (40.2%), 12.7 (50.5%), and 7.3 (51.4%) for NCA-NBC, OR-SVI, and MUA, respectively.

Mixing Rates Prior to June 1st

From Calambokidis et al. (2019), of 359 whale sightings in NCA-NBC prior to 1 June between 1996 and 2016, 27.3% (n = 98) were of whales that were seen at least once in the PCFG range after 1 June. This percentage declines to 25.1% if restricted to whales observed in two or more years within the PCFG range. For OR-SVI, 26.2% (n = 94) of sightings prior to 1 June were of whales that were seen at least once after 1 June and 23.4% (n = 84) were of whales that were seen in two or more years after 1 June within the smaller region. If we include the partially processed data from 2016-2020, 417 unique whales have been sighted in NCA-NBC prior to 1 June, 27.1% (n = 113) of which were observed in the PCFG range at least once after 1 June. If we restrict the comparison to whales observed in at least 2 years in the PCFG, then the percentage is reduced to 24.5% (n = 102). If we restrict the spatial domain, 25.9% (108) and 22.5% (94) of sightings prior to 1 June were of whales that were seen at least once after 1 June within OR-SVI and MUA, respectively. Of 106 whale sightings from the SJF prior to 1 June, 70% (71) were of whales that were observed in the PCFG after 1 June.

Abundance and Recruitment

Annual PCFG gray whale abundances for NCA-NBC and the smaller regions were derived using model-averaged estimates from the Jolly-Seber open population model sets (Table 6). Estimates for NCA-NBC displayed in Figure 2 are only representative of the time period between 1998 and 2020 due to the reduced effort and survey coverage at the start of the study (1996-1997) leading to known bias in these earlier years. Our estimate of PCFG gray whale abundance for NCA-NBC was 212 individuals in 2020, with a N_{min} of 198 (Fig. 2). We estimated the MMPA's Potential Biological Removal (PBR) for NCA-NBC (PCFG) to be 3.1, with an R_{max} of 6.2% and a recovery factor of 0.5 (Caretta et al. 2013).

New whales that are not identified as calves have appeared annually and many of these new non-calf whales have subsequently returned and been re-sighted (Fig. 3). In NCA-NBC from 1999-2019, an average of 29.2 (range: 8 - 68) new non-calves were observed each year. Of these new non-calf whales, on average 10.4 (range: 0 - 28) whales returned and were observed in subsequent years. It is unknown what proportion of the non-calves used the PCFG range as a calf but were not observed in that year.

Discussion

We provided an updated assessment of abundance for PCFG gray whales, extending the time series used in Calambokidis et al. (2019) through 2020. Our analysis included mark-resight data collected as part of a large-scale collaborative effort to survey PCFG gray whales in coastal waters from northern California to northern Vancouver Island, British Columbia. Importantly, mark-resight models used in estimating abundance are sensitive to survey design, most notably in this case to variation in survey effort within and across years throughout the assumed PCFG range. As in Calambokidis et al. (2019), we do not explicitly account for survey effort due to inconsistencies in how effort was tracked -- if at all -- by contributors to the gray whale photographic catalog. However, given the high resightability of long-lived PCFG gray whales, the impact of excluding effort was likely limited to increased uncertainty in both sighting probabilities and survival/emigration probabilities and, therefore, reduced precision in PCFG abundance estimates. In addition, unaccounted for heterogeneity in behavior (e.g., individual variation in resource utilization, site fidelity, large-scale movements, and response to survey vessels) may also contribute to reduced precision in abundance estimates within a mark-resight context. Yet, as highlighted in previous assessments, the present modeling framework represents the best available for assessing PCFG abundance in light of current data limitations and knowledge gaps.

Our abundance estimates indicated that the PCFG has been stable over the last 20 years, declining from a peak in abundance in 2015. Although mixing rates for PCFG and non-PCFG individuals between December and May were similar to Calambokidis et al (2019), due to a known bias attributable to the selective processing of these data for PCFG whales between 2016 and 2020, we recommend referencing the Calambokidis et al (2019) mixing rate estimates.

Acknowledgments

This analysis would not have been possible without the collaborating organizations and individuals contributing identification photographs. Support for the photographic identification reported here, the comparison of gray whale photographs and preparation of this report came primarily from the National Marine Fisheries Service's West Coast Region with additional support from other collaborators. We thank Chris Yates, Lynne Barre, and Penny Ruvelas at NMFS' West Coast Region for providing consistent funding to MML for the field surveys and photo-identification efforts. Permission to conduct some portions of this research in U.S. waters was provided by the U.S. National Marine Fisheries Service and the Makah Tribe. Portions of the research in British Columbia were conducted collaboratively with Fisheries and Oceans Canada (thanks to John Ford and Graeme Ellis). Volker Deecke assisted in analysis and matching of identifications from South Vancouver Island. William Megill coordinated providing sightings and identifications from CERF, Dawn Goley and Jeff Jacobsen coordinated effort for HSU, Christina Tombach and Dave Duffus coordinated early efforts for UVIC. Leigh Torres and her graduate students at Oregon State University (OSU) provided identification photographs from both central and southern Oregon starting in 2015 and the OSU Whale Telemetry Group provided photographs associated with their tagging efforts. Carrie Newell provided identification photographs from Depoe Bay Oregon. Merrill Gosho, Pat Gearin, Nate Pamplin, and Jonathan Scordino provided photos from Washington. Brian Gisborne's diligence and hard work provided an immense amount of data and photographs from Vancouver Island. A number of people assisted in the field effort and in the printing and matching of photographs at Cascadia Research. Jeff Laake developed the model set and associated code. Erin Falcone, Lisa Schlender, Jennifer Quan, and Amber Klimek helped compile the data from different contributors and conducted photographic matching. Randy Lumper conducted gray whale matching in the early years of this study. Sharon Melin, Nancy Friday, Grace Ferraro, Megan Wallen and James Lee provided many helpful comments, suggestions, and edits.

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Table 1. -- Survey regions and region subsets used for PCFG gray whale abundance estimation. Numbers refer to locations on the map in Figure 1.

		Model Regions		
Survey region	**Region description**	**NCA-NBC**	**OR-SVI**	**MUA**
(1) SCA = Southern California				
(2) CCA = Central California				
(3) NCA = Northern California	Eureka to Oregon border; mostly from Patricks Pt. and Pt. St George	X		
(4) SOR = Southern Oregon		X	X	
(5) OR = Oregon Coast	Primarily central coast near Depoe Bay and Newport, OR	X	X	
(6) GH+ = Gray's Harbor	Waters inside Grays Harbor and coastal waters along the S Washington coast	X	X	
(7) NWA = Northern Washington	Northern outer coast waters with most effort from Capa Alava (Sea Lion Rock) to Cape Flattery	X	X	X
(8) SJF = Strait of Juan de Fuca	U.S. waters east of Cape Flattery extending to Admiralty Inlet (entrance to Puget Sound) with most effort ending at Sekiu Point	X	X	X
(9) NPS = Northern Puget Sound	Inside waters and embayments from Edmonds to the Canadian border			
(10) PS = Puget Sound	Central and southern Puget Sound (S of Edmonds), including Hood Canal, Boundary Bay, and the San Juan Islands			
(11) SVI = Southern Vancouver Island	Canadian waters of the Strait of Juan de Fuca along Vancouver Island from Victoria to Barkley Sound, along West Coast Trail	X	X	
(12) WVI = West Vancouver Island		X		
(13) NBC = Northern British Columbia	British Columbia waters north of Vancouver Island, with principal effort around Cape Caution	X		
(14) SEAK = Southeast Alaska	Waters of southeastern Alaska with the only effort in the vicinity of Sitka			
(15) KAK = Kodiak, Alaska				

Table 2. -- Model specifications for survival (φ) and sighting probability (p) parameters in POPAN models for gray whale photo-identification data. For survival models, β_0 is the baseline intercept for non-transient survival. F_y is 1 if it is year the whale was first observed and 0 otherwise. A subscript for F_y means that it applies only for that cohort except that F_{y99} applies to cohorts 1999 and beyond and F_{yc} represents each of the cohorts from 1996 to 2019. C is 1 if identified as a calf in its first year and 0 otherwise. R is 1 for calves or any whale observed in 1998 or was already in the catalog prior to 1998 and 0 otherwise. β_r is an adjustment to post-first-year survival. MT is minimum tenure value of a whale and β_M is the estimated slope parameter for φ or p. $\beta_{M,96-97}$ applies to 1996-97, $\beta_{M,98}$ to 1998 and $\beta_{M,99}$ applies to 1999-2018. $\beta_{Fy,96-97}$, $\beta_{Fy,98}$ and $\beta_{Fy,99}$ are the first-year survival intercept adjustments for 1996-97, 1998 and cohorts 1999-2018 respectively and $\beta_{Fy,c}$ represents 24 cohort-specific first year survival parameters for 1996-2018. β_{CF} is an adjustment for calf first year survival and β_{CM} is an adjustment for calves to the slope of MT for survival. For the sighting probability models, β_t has 22 levels for t=1998:2017 and β_0 represents the 1997 value. p = 1 for 1996. The best models for the northern California to northern British Columbia region (NCA-NBC) were φ model 9 and p model 2. The best models for the Oregon to southern Vancouver Island region (OR-SVI) were φ model 4 and p model 3. The best models for the MUA were φ model 4 and p model 2.

Model	Parameter Logit Formula	Number of parameters
φ		
1	$\beta_0 + \beta_{Fy} Fy + \beta_r R(1 - Fy)$	3
2	$\beta_0 + \beta_{Fy} Fy + \beta_M MT\, Fy + \beta_r R(1 - Fy)$	4
3	$\beta_0 + \beta_{Fy,96-97} Fy_{96-97} + \beta_{Fy,98} Fy_{98} + \beta_{Fy,99} Fy_{99} + \beta R(1 - Fy)$	5
4	$\beta_0 + \beta_{Fy,96-97} Fy_{96-97} + \beta_{Fy,98} Fy_{98} + \beta_{Fy,99} Fy_{99} + \beta_M MT\, Fy + \beta_r R(1 - Fy)$	6
5	$\beta_0 + (\beta_{Fy,96-97} + \beta_{M,96-97} MT) Fy_{96-97} + (\beta_{Fy,98} + \beta_{M,98} MT) Fy_{98} + (\beta_{Fy,99} + \beta_{M,99} MT) Fy_{99} + \beta_r R(1 - Fy)$	8
6	$\beta_0 + \beta_{Fy,c} Fy_c + \beta_M MT\, Fy + \beta_r R(1 - Fy)$	22
7	$\beta_0 + \beta_{Fy,c} Fy_c + \beta_M MT\, Fy + \beta_{CF} C\, F_y + \beta_r R(1 - Fy)$	23
8	$\beta_0 + \beta_{Fy,c} Fy_c + \beta_M MT\, Fy + \beta_{CF} C\, F_y + \beta_{CM} C\, MT + \beta_r R(1 - Fy)$	24
9	$\beta_0 + (\beta_{Fy,96-97} + \beta_{M,96-97} MT) Fy_{96-97} + (\beta_{Fy,98} + \beta_{M,98} MT) Fy_{98} + (\beta_{Fy,99} + \beta_{M,99} MT) Fy_{99} + \beta_{CF} C\, F_y + \beta_r R(1 - Fy)$	9
10	$\beta_0 + (\beta_{Fy,96-97} + \beta_{M,96-97} MT) Fy_{96-97} + (\beta_{Fy,98} + \beta_{M,98} MT) Fy_{98} + (\beta_{Fy,99} + \beta_{M,99} MT) Fy_{99} + \beta_{CF} C\, F_y + \beta_{CM} C\, MT + \beta_r R(1 - Fy)$	10
p		
1	$\beta_0 + \beta_t$	19
2	$\beta_0 + \beta_t + \beta_M MT$	20
3	$\beta_0 + \beta_M MT$	2

Table 3. -- Classification of whales seen within the PCFG (Northern California to Northern British Columbia) from 1 June to 30 November from 1996 to 2020.

Year	Total Seen[a]	Newly Seen[b]	Newly Seen and Seen Again[c]
1996	45	45	41
1997	69	45	36
1998	132	71	48
1999	151	68	12
2000	140	54	28
2001	172	61	26
2002	203	52	29
2003	157	20	15
2004	178	29	13
2005	134	17	10
2006	126	8	1
2007	120	20	9
2008	174	50	18
2009	152	22	7
2010	144	15	12
2011	163	19	5
2012	208	53	21
2013	232	58	25
2014	201	38	16
2015	211	42	16
2016	186	31	13
2017	152	14	2
2018	146	24	5
2019	185	32	9
2020	163	16	n/e
Total	3,944	904	417
Average[d]	157.8	33.8	13.9

[a] "Total Seen" is the number of unique whales seen/identified in each year.
[b] "Newly Seen" is the number of whales seen that year that had not been seen prior to that year (but within the 1996 to 2020 period).
[c] "Newly Seen and Seen Again" is the number of whales that were seen in at least one more year within the PCFG range during June 1 to November 30 subsequent to the first year they were seen.
[d] Averages for Newly Seen exclude 1996 to 1998 because photo-identification effort expanded to cover all survey areas in 1999. Averages for Newly Seen and Seen Again exclude 1996 to 1998 and 2020 for the same reason as above (as well as it not being possible to determine if whales seen in 2020 were seen in a subsequent year).

Table 4. -- Classification of whales seen within the OR-SVI (Oregon to Southern Vancouver Island) survey region from 1 June to 30 November from 1996 to 2020.

Year	Total Seen[a]	Newly Seen[b]	Newly Seen and Seen Again[c]
1996	30	30	27
1997	36	20	13
1998	86	55	37
1999	71	23	10
2000	70	27	15
2001	128	56	22
2002	103	38	27
2003	110	26	20
2004	117	30	16
2005	107	17	10
2006	96	10	3
2007	114	22	10
2008	123	22	10
2009	118	17	6
2010	93	8	8
2011	89	9	7
2012	127	28	18
2013	147	37	21
2014	152	36	17
2015	161	32	14
2016	176	36	15
2017	130	14	3
2018	128	18	5
2019	150	23	10
2020	141	11	n/e
Total	2,803	645	344
Average[d]	112.1	24.5	12.7

[a] "Total Seen" is the number of unique whales seen/identified in each year.
[b] "Newly Seen" is the number of whales seen that year that had not been seen prior to that year (but within the 1996 to 2020 period).
[c] "Newly Seen and Seen Again" is the number of whales that were seen in at least one more year within the PCFG range during June 1 to November 30 subsequent to the first year they were seen.
[d] Averages for Newly Seen exclude 1996 to 1998 because photo-identification effort expanded to cover all survey areas in 1999. Averages for Newly Seen and Seen Again exclude 1996 to 1998 and 2020 for the same reason as above (as well as it not being possible to determine if whales seen in 2020 were seen in a subsequent year).

Table 5. -- Classification of whales seen within the MUA (NW Washington and western SJF) survey region from 1 June to 30 November from 1996 to 2020.

Year	Total Seen[a]	Newly Seen[b]	Newly Seen and Seen Again[c]
1996	19	19	18
1997	27	15	11
1998	37	23	9
1999	11	1	0
2000	14	11	8
2001	32	19	7
2002	8	1	1
2003	22	11	6
2004	25	13	10
2005	33	9	6
2006	58	23	18
2007	20	2	2
2008	75	29	16
2009	57	13	4
2010	26	4	3
2011	39	11	6
2012	67	22	9
2013	66	22	8
2014	63	24	9
2015	47	16	6
2016	34	10	2
2017	53	18	3
2018	17	5	2
2019	55	17	11
2020	64	18	n/e
Total	969	356	175
Average[d]	38.8	14.2	7.3

[a] "Total Seen" is the number of unique whales seen/identified in each year.
[b] "Newly Seen" is the number of whales seen that year that had not been seen prior to that year (but within the 1996 to 2020 period).
[c] "Newly Seen and Seen Again" is the number of whales that were seen in at least one more year within the PCFG range during June 1 to November 30 subsequent to the first year they were seen.
[d] Averages for Newly Seen exclude 1996 to 1998 because photo-identification effort expanded to cover all survey areas in 1999. Averages for Newly Seen and Seen Again exclude 1996 to 1998 and 2020 for the same reason as above (as well as it not being possible to determine if whales seen in 2020 were seen in a subsequent year).

Table 6. -- Model-averaged estimates of PCFG gray whale abundance (N), standard errors (se), and minimum population estimate (N_{min}) using data from 1996 - 2020 from three spatial subsets: 1) northern California to northern British Columbia (NCA-NBC), 2) Oregon to southern Vancouver Island (OR-SVI) , and 3) the Makah Usual and Accustomed Area (MUA). The estimates were derived from independent model sets constrained by a nested spatial structure.

	NCA-NBC			OR-SVI			MUA		
Year	**N**	**SE(N)**	**N_{min}**	**N**	**SE(N)**	**N_{min}**	**N**	**SE(N)**	**N_{min}**
1996	39	2.8	37	25	2.3	23	17.7	1.4	16.6
1997	81	10.0	73	46	5.5	41	32.4	4.8	28.6
1998	133	13.5	122	94	8.3	87	43.5	10.6	35.5
1999	145	14.3	133	82	6.5	76	42.8	17.0	31.0
2000	147	13.7	136	86	7.6	79	36.0	23.2	21.9
2001	182	13.4	171	156	10.9	147	54.4	14.4	43.7
2002	210	23.5	191	128	9.7	120	46.1	23.2	30.9
2003	209	16.5	196	169	12.2	159	55.1	18.3	42.0
2004	224	19.4	208	159	10.8	150	58.2	18.4	44.9
2005	208	29.3	184	170	12.5	160	64.2	13.4	54.0
2006	195	20.4	178	152	11.4	143	74.0	9.8	66.2
2007	185	28.5	163	173	12.3	162	79.7	23.6	62.4
2008	217	19.4	202	199	14.1	188	90.8	9.4	83.2
2009	208	21.3	191	165	10.8	156	94.6	13.9	83.6
2010	201	18.8	186	144	10.9	135	98.7	26.4	79.1
2011	213	16.8	200	140	10.7	131	94.5	19.6	79.5
2012	229	16.3	215	181	12.0	171	105.7	14.5	94.2
2013	249	17.5	235	194	11.4	185	108.8	15.7	96.4
2014	245	18.7	230	210	12.5	199	115.8	18.9	101.0
2015	257	17.9	242	225	12.8	215	131.5	28.4	109.9
2016	244	24.5	224	240	13.5	229	131.5	34.6	105.8
2017	224	22.1	206	197	12.6	187	121.4	23.3	103.4
2018	211	24.5	191	201	13.3	190	104.4	40.1	76.4
2019	228	24.0	209	231	14.4	219	116.6	21.0	100.3
2020	212	17.9	198	199	11.2	190	119.4	19.2	104.4

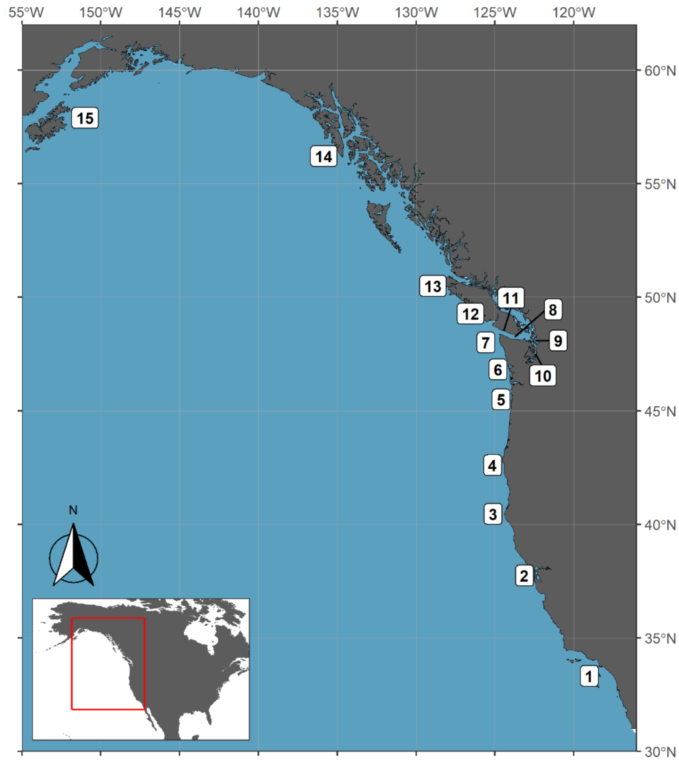

Figure 1. -- Locations for photo-identifications of Eastern North Pacific gray whales. Numbers refer to the regions described in Table 1.

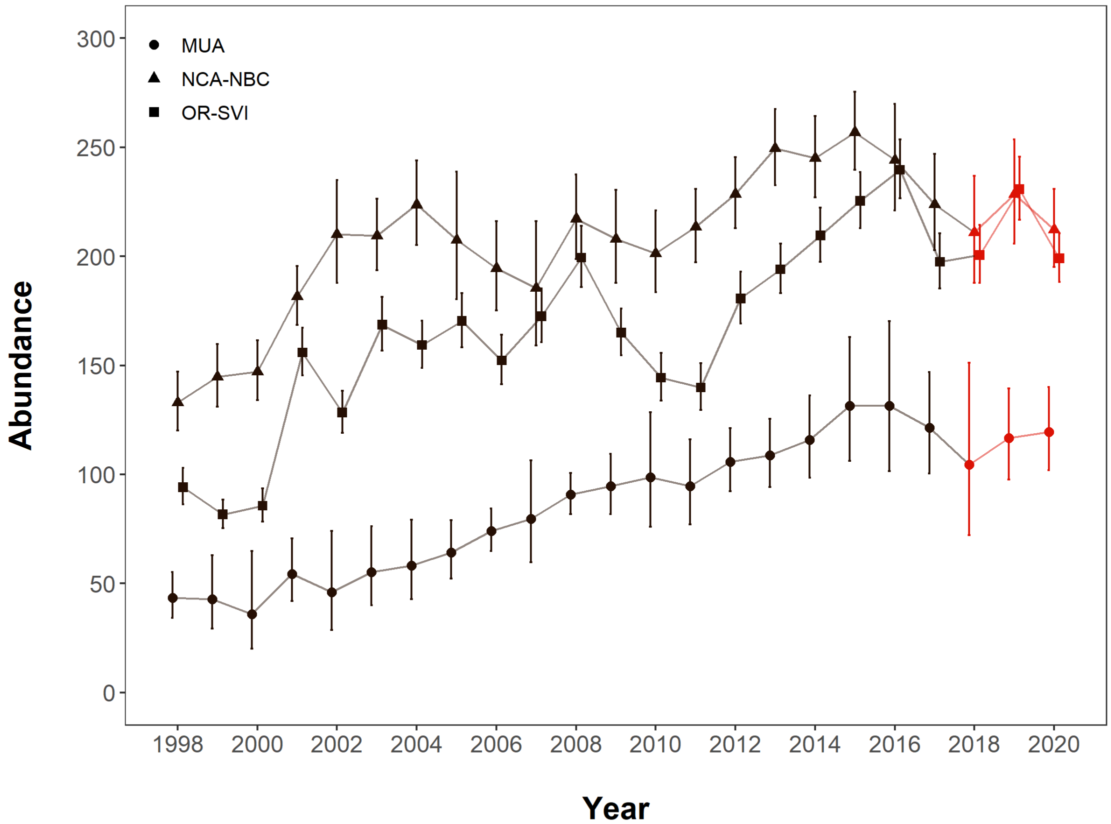

Figure 2. -- Annual PCFG gray whale abundance estimates for 1998 - 2020 in NCA-NBC, OR-SVI, and MUA using the POPAN parametrization. Red values reflect updated estimates using data from 2018 through 2020 from this report.

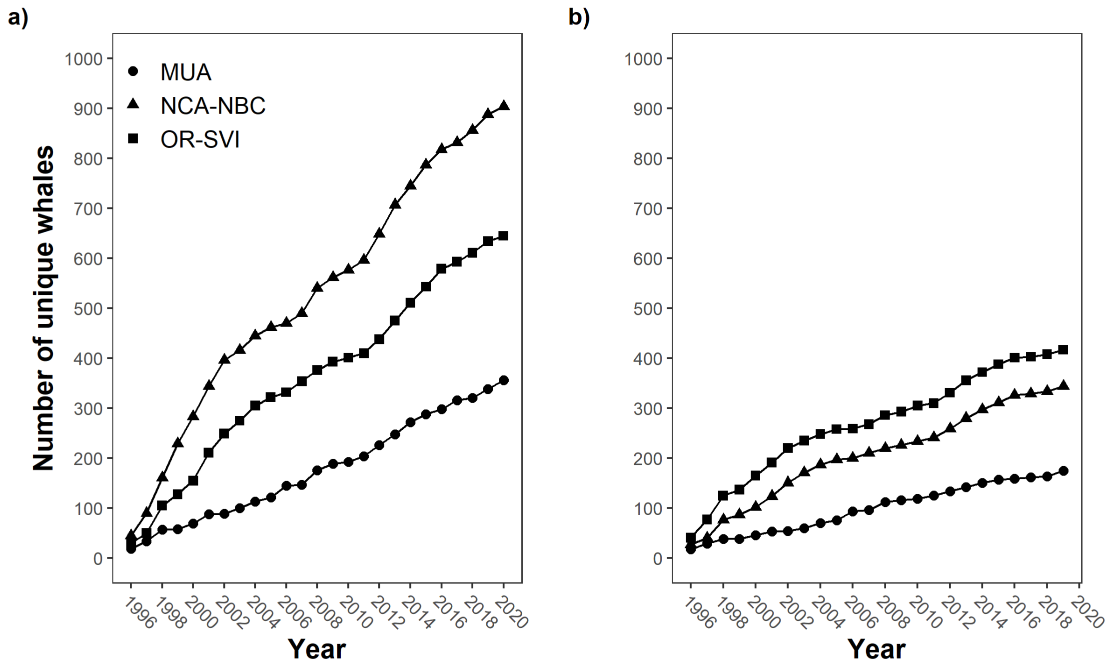

Figure 3. -- Discovery curves for unique gray whales observed between 1 June and 30 November in at least one year (a) or more than one year (b) in NCA-NBC, OR-SVI, and MUA for 1996 - 2020.

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