A tale of two species: disaggregating mixed historical catches of two most common skates in the Northeast Pacific Ocean.

Vladlena Gertseva[1]*, Sean E. Matson[2], Ian G. Taylor[1]

[1]Fishery Resource Analysis and Monitoring Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, WA 98112, USA.

[2]Sustainable Fisheries Division, West Coast Region, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, WA 98115, USA.

*Corresponding author: Vladlena Gertseva. E-mail: Vladlena.Gertseva@noaa.gov. Phone: (+1) 206-860-3457.

Abstract

Historical catch data represent a key source of information for fisheries stock assessment models. Historically, commercial fishery catch statistics were estimated from the portion of catch landed in ports. However, many species with relatively low economic value have not been recorded on a species basis but instead as a part of an aggregate category. Reconstructing component species catch from an aggregate category is a common challenge for fisheries stock assessment efforts around the world. Skates are one group of species with low economic value for which landed catch has not been commonly reported by species. In this paper, we present a novel approach to disaggregate the historical catch of the two most abundant skate species on the West Coast of the United States, longnose skate (*Caliraja rhina*) and big skate (*Beringraja binoculata*), landed within the aggregated skate category, in ports of Washington State. We used a combination of fishery-dependent and fishery-independent data sources to account for changes in the spatial extent of the fishery over time, and differences in the depth distribution of these two skate species. While developed to disentangle aggregate catch of longnose and big skates, the approach is not limited to skates on the West Coast of the United States, but can be adapted for any species which landings have been reported within an aggregated category elsewhere.

Keywords: historical catch estimates; fisheries stock assessment; longnose skate; big skate; Northeast Pacific Ocean.

Introduction

Historical catch data are a key source of information for fisheries stock assessment models (Hilborn and Walters 2003, Branch et al. 2011, King 2013). Inaccurate catch histories can lead to assessment model misspecification, errors in estimation of key model parameters and, in turn, inaccurate estimation of stock size and the scale of expected recruitments (Gertseva and Matson 2021). Such errors can degrade the quality of assessment results that are necessary for the conservation and management of fish stocks. Catch information from commercially harvested species is also used to track global trends in fishing and aid to sustainable management and conservation of marine resources (Hilborn et al. 2003, Branch 2008, Branch et al. 2011, King et al. 2017).

Total catch of a fish stock consists of two components: the portion of catch that was retained and subsequently landed in ports, and the portion of the catch that was discarded at sea (Hilborn and Walters 2003, Haddon 2011). Historically, commercial fishery catch statistics have primarily consisted of the fraction landed in port, which originates from landing receipts filled out by fish dealers or dockside catch monitors. However, for many species with relatively low economic value that are caught incidentally with other commercially important species, even landed catch information has been limited, because their catch has not been recorded for individual species, but instead as a part of an aggregate category (Dulvy and Reynolds 2002). It has been shown that seemingly stable aggregated catch statistics among several species can mask the decline in one or more species within the aggregate group, due to increases (sometimes compensatory) in others (Dulvy et al. 2000).

Skates (family *Rajidae*) are the most widely distributed group of batoid fish with approximately 200 species described (Last et al. 2016). They are benthic inhabitants that are found in all coastal waters but are most common in cold temperatures (Ebert and Compagno 2007). Skates, like other elasmobranch species, also represent one of the most vulnerable group of fishes because their low fecundity, slow growth and late maturation make them highly susceptibility to overfishing (Dulvy and Reynolds 2002, Dulvy et al. 2014, Matson and Gertseva 2020). Skates are one group of species with low economic value for which landed catch (landings) has not been commonly reported by species (Dulvy et al. 2000, Gertseva et al. 2019, Taylor et al. 2019, Gertseva and Matson 2021). Lack of species-specific catch statistics has presented a challenge for the accurate assessment of the status and sustainable management of skate stocks. Therefore, progress in estimating species-specific composition of aggregate skate landings is necessary to ensure long-term sustainability of these vulnerable species.

Multiple approaches have been used to estimate individual species' proportions to the catch of an aggregated category. Many of these are based on calculating an individual species proportions from a time period (usually recent) in which these are known, and applying those proportions to the period with no information on species-specific catch (Gertseva 2009). This approach assumes that proportions of different species within the group stay relatively stable throughout time, and the recent period is representative of the earlier period with undocumented species composition. However, this assumption may not be true if the recent period, with known species-specific data, is different from the earlier period with aggregate data only. For example, the spatial distribution of the fishery may change over time due to changes in the target stock spatial distribution, bycatch avoidance behaviors, or management measures, such as spatial closures (Miller et al. 2014). When species that comprise an aggregate category differ in their preferred habitats and distributions, spatial changes in fishing effort result in changes in relative contribution of individual species to an aggregate.

Longnose skate (*Caliraja rhina*) and big skate (*Beringraja binoculata*) are the most abundant skate species on the West Coast of the United States in terms of biomass and abundance as they represent over 90% of skate catches in the area (Gertseva 2009, Gertseva et al. 2019, Taylor et al. 2019). Both species are broadly distributed in the Northeast Pacific Ocean, from Alaska to beyond southern Baja California (Love et al. 2021, Snytko 1987, Eschmeyer and Herald 1983, Mecklenburg et al. 2002), but their depth distributions differ. Longnose skate is most common at depths between 150 and 400m (Tolimieri and Levin 2006, Bizzarro 2015), while big skate is mostly found on the continental shelf, shallower than 200m (Bizzarro et al. 2014, Farrugia et al. 2016). Both of these species are caught along with other, more-valuable target species, including sablefish (*Anoplopoma fimbria*) and petrale sole (*Eopsetta jordani*), in the groundfish demersal trawl fishery of the West Coast of the U.S., and the retention of both species increased since mid-1990s (Gertseva et al. 2019, Taylor et al. 2019). Also, on the U.S. West Coast, fishery management efforts were actively developing over the last four decades, and since the early 2000s, these measures included implementation of multiple spatial conservation areas, closed to fishing to help recover some of the depleted groundfish stocks. Given the differences in depth distribution between these two species and changes in depth of fishing, not accounting for depth specific species compositions creates a potential for a masked decline in individual species within the aggregate group. Therefore, a spatially explicit approach for separating skate species-specific historical landings is necessary.

Here, we present a novel approach to estimate the historical species-specific catch of longnose and big skate landed in Washington State using historical aggregate catch data from the groundfish demersal trawl fishery while accounting for changes in the spatial extent of the fishery and depth differences of the two skate species. We used a combination of fishery-dependent and fishery-independent data sources to estimate the contribution of individual species to aggregate landings, and validated our results using the data from the most recent period for which fishery landings are available by individual species.

This study was initiated to resolve a critical need for recent longnose skate and big skate stock assessments (Gertseva et al. 2019, Taylor et al. 2019), and focused on the waters off Washington State because that area was lacking species-specific estimates of skate historical landings, unlike other areas along the US West Coast. Since then, we refined our approach and improved the estimates, which are now ready to be used in the next stock assessments for these two species. Our approach, evaluated using one specific area, can potentially be expanded to other parts of the coast. Also, even though we focused on longnose and big skates on the West Coast of the United States, the approach we describe is flexible, and can easily be adapted for other species elsewhere in the world, for which landings have been reported within an aggregated category.

Methods

Data sources

The groundfish fishery existed on the West Coast since late-1800s (Miller et al. 2014), but the bottom trawl fishery advanced in the 1930s with the invention of balloon trawl nets (Love et al. 2002), and quickly expanded along the U.S. West Coast, and to deeper waters by the late-1940s (Harry and Morgan 1961, Alverson et al. 1964, Love 2002).

The commercial landings made by the groundfish demersal trawl fishery of the West Coast of the U.S from 1981 forward are reported in the Pacific Fisheries Information Network (PacFIN), which is a collaboration between Pacific States Marine Fisheries Commission, National Marine Fisheries Service (NMFS), and West Coast state fishery management agencies. Prior to 1980s landings of skates were minimal (most were discarded), and we limit our reconstruction here to years from 1981 forward.

PacFIN manages information on landed catch from landings receipts (also called fish tickets) and dockside samplers along the U.S. West Coast and reports landed catch by year, gear type, port of landing and many other categories. Until 2010, all skate landings were reported together in the 'Unspecified Skate' category (Fig. 1). However, since 2010, coastwide landings of longnose skate have been reported separately from other skates, and in 2015 big skate was also separated into a single species category (Fig.2).

Fish tickets rarely include information on depth of fishing. However, PacFIN also hosts logbooks, which are recorded by vessel captains and contain information on the spatial distribution of individual hauls within commercial trawl fishing trips. Logbook records include landed catch for aggregated skates, geographic location of catch, and depth of fishing. This source of data is more detailed than the fish tickets recorded by the dockside samplers and processors. However, since logbook records have not been mandatory, this source (unlike fish tickets) represent only a portion of the total landed catch. Logbook data for Washington State skate landings in PacFIN goes back to 1987. Until 2016, all skates were reported in logbook as one category of unspecified skate (even though longnose skate catch was reported separately on fish tickets since 2010). From 2017 onward, logbook data include multiple skate categories (Fig.

2). Logbook records illustrate that depth of skate catch landed in Washington ports indeed varied among years (Fig. 3).

To estimate the contribution of different skate species to aggregate skate fishery catches by depth, we used fishery-independent data from the NMFS West Coast Groundfish Bottom Trawl Survey (WCGBTS). This survey has been conducted annually since 2003, covering depths between 55 and 1280 m along the U.S. West Coast between the U.S.-Canada and U.S.-Mexico borders (Keller et al. 2017). The survey data contain haul-level skate catch by species, geographic location, and fishing depth. We filtered the survey data to only include catches in coastal waters off Washington State. We then divided skate catch into a series of depth bins, and estimated proportions of longnose skate and big skate within each depth bin. The data were divided into 25 fm (46 m) bins for depths up to 150 fm (274 m), and into 50 fm (91 m) bins for depths of 150 fm and deeper. The finer bins were used for depths where the vast majority of big and longnose skate co-occur, to better account for changes in percent contribution of these species by depth within the aggregate. We used depth bins in fathoms (rather than meters), to align with and better account for impacts of spatial management measures (such as spatial closures) on relative species contribution to an aggregate; such spatial measures are commonly applied for selected depths defined in fathoms.

We explored multiple binning options, and investigated the potential for including latitudinal as well as seasonal components, in addition to depth. However, preliminary data evaluation indicated that species proportions did not trend with latitude, when stratifying by one degree latitude. The same was true among temporal strata, when dividing the survey as granularly as the data would support, in this case, dividing the survey into two time periods (one for spring/early summer, and two summer/early fall). Therefore, we only focused on depth-specific bins, as data indicated clear differences in big skate and longnose skate distributions by depth (Fig. 4).

From WCGBTS data, it is evident that big skate occupy shallower depths (100 fm and less), while longnose skate predominantly occurs in deeper waters (Fig. 4), which is consistent to what is reported in literature (Tolimieri and Levin 2006, Bizzarro et al. 2014, Bizzarro 2015, Farrugia et al. 2016). There is some degree of interannual variability in proportional species contribution to the aggregate category (Fig. 5), potentially due to environmental variability, behavior and movements (and resultant distribution) of species at the time of sampling each year or other year-specific factors, as well as sampling variability associated with the random stratified survey design (Keller et al. 2017).

Method overview

The main goal of the study was to estimate historical catch of longnose and big skates retained within the groundfish bottom trawl fishery and landed in Washington State ports in the aggregate skate category for use in stock assessments of both species. Our method included three main steps: 1) estimating proportions of longnose skate and big skate in combined skate catches by depth and year within the WCGBTS catches, 2) estimating longnose skate and big skate catch by depth and year in logbook catch data by applying survey proportions of longnose skate and big skate to logbook reported catches by year, and 3) expanding longnose skate and big skate catches from logbook data to the total species-specific landings by year (reported in fish tickets), to account for unsubmitted logbooks. The reconstruction covered the period between 1981 with the start of PacFIN data and goes through 2009 for longnose skate and through 2014 for big skate, when these were removed from the aggregate category.

The approach to estimating individual skate proportions by depth within the WCGBTS catches (step one) was described above. The second and third steps are more complex and include multi-stage algorithms. To estimate species-specific skate catch from fishery logbook data, haul-specific catch of aggregated skates from logbooks was assigned to the appropriate depth bin. We then applied depth-specific proportions of longnose skate and big skate (as estimated from WCGBTS data) to each haul of total skate catch from logbooks, to obtain the species-specific catch of each skate by depth of each haul. Equation (1) below describes what was done in step 2 of the algorithm:

$$(LBL)_{s,y} = \sum_{d=1}^{d=n} \left[(LBL)_{y,d} \cdot \frac{(SC)_{s,y,d}}{(SC)_{y,d}} \right]$$

Equation (1)

Where *LBL* is the amount of logbook landings of skates, *SC* is survey skate catch by species, *s*, year, *y,* and depth bin, *d*, with *d* ranging from one to *n*.

When survey data were available (Fig. 2), survey proportions of big and longnose skates within total skate catch $\left(\frac{(SC)_{s,y,d}}{(SC)_{y,d}}\right)$ were applied to catch reported in logbooks (*LBL*) by depth (*d*) and year (*y*) to account for interannual variability in depth-specific proportions of individual species. Prior to 2003 (before the survey began to operate), average proportions of longnose and big skates at depth between 2003 and 2007, were applied to depth-specific commercial logbook data. We summed the depth-specific estimates of longnose and big skates catch in trips with logbooks records into year-specific catch time series of each of these skate species ($(LBL)_{s,y}$).

As the third step in estimating species-specific skate landings, we expanded catch of longnose and big skates reported in commercial logbooks to the level of total skate landings reported via fish tickets. For this, we calculated the proportions of longnose and big skates in aggregate skate catch from logbooks each year $\left(\frac{(LBL)_{s,y}}{(LBL)_y}\right)$, and applied these year-specific proportions to total Washington skate landings by year $\left((L)_y\right)$ (Equation 2 below).

$$(L)_{s,y} = (L)_y \cdot \frac{(LBL)_{s,y}}{(LBL)_y} \qquad \text{Equation (2)}$$

Where *L* is fish ticket landings, *LBL* is amount of logbook landings of skates, *s* in the subscript stands for species and *y* for year.

For the period with logbook data available (1987 forward, Fig. 2), proportions of big and longnose skates were applied by year $\left(\frac{(LBL)_{s,y}}{(LBL)_y}\right)$, again to account for interannual variability in the contribution of individual species within the aggregate group. To disaggregate catch data between 1981 and 1987 (when logbook data were not available), we applied the average proportions of big and longnose skate calculated using the earliest five years of logbook data (1987-1991) and applied those to the total skate landings in Washington from 1981 - 1987..

Method validation and uncertainty

To validate our method and the results, we compared our estimated landings for longnose skate versus species-specific landings recorded in PacFIN, calculated based on port sampling, over the period between 2010 and 2016. Landings of longnose have been reported in PacFIN separately from other skate species since 2010 (Fig. 2). However, they continued to be reported within the aggregate skate category in logbooks until 2016. Therefore, for the period between 2010 and 2016, we had longnose skate landings from PacFIN, but also had logbook data on aggregate skates to make predictions using our approach. Big skate has been reported in PacFIN separately from other skates since 2015, and we did not have enough overlap to compare the landings between two sources (Fig. 2); therefore, our validation efforts focused on longnose skate alone. The relationship between our estimated landings amounts, produced using the described approach (independent variable), versus longnose skate landings records from logbooks in PacFIN (dependent variable) was fitted by linear regression, and goodness of fit was calculated as R^2.

To account for uncertainty in using average proportion at depth, we estimated high and low catch streams, by applying increased (plus two standard deviations) and decreased (minus two standard deviations) proportions of longnose and big skates within each depth bin, calculated from WCGBTS data.

Results and Discussion

Disaggregated time series of species-specific longnose and big skate landings in Washington show that longnose skate dominated historical skate catch, and amount of longnose skate landings on average was three times larger than that of big skate (Fig. 6). Year-specific estimates of landings (Fig. 6) account for the changes in depth of catch (Fig. 3) and therefore, allow for more accurate estimation of species-specific contribution to the overall skate catch. For instance, we see a shift to deeper areas in the distribution of annual, aggregate skate fishery catch in recent years (Fig. 3), concomitant with fishery effort shifts reported Somers et al. (2023). This trend is likely to continue due to avoidance of some nearshore species off the West Coast. This shift translates into the decreased catch of big skate, since this species occurs primarily in shallower depths, and larger contribution of longnose skate, which dominates the deeper areas

Given a more limited, and shallower depth distribution of big skate, compared to widely distributed longnose skate (Fig. 4), uncertainty around big skate catch results in larger intervals around estimates for both species (since composition proportions are interdependent), emphasizing the importance of accounting for depth. Additionally, one would especially expect to see increased uncertainty around estimates in this method during periods when depth distributions of fishery effort shifts, which we see in Fig. 6.

Depth distribution of fishing effort can change in relation to both target seeking and bycatch avoidance behavior by the fleet, as well as management-related spatial closures, although the exact dynamics can be difficult to determine. On the U.S. West Coast, varied and sometimes intense fishery management measures have been implemented for groundfish species, which depending on the species and fishery sector, may include trip limits, quotas, mesh size requirements; depth, area, season, and gear restrictions; and other measures (Matson et al. 2017). Since the early 2000s, multiple management measures have been implemented to recover some depleted groundfish stocks. For instance, yelloweye rockfish (*Sebastes ruberrimus*) has been managed under a rebuilding plan since 2002, and bycatch of this species has been constraining to shelf fishery effort since. Only recently, allowable catch of yelloweye rockfish catch limits started to increase, which is leading to recovering some level of fishing efforts to depths on the shelf in some areas of the coast. Such management measures, whether directed to impact catch of targeted or bycatch stocks, can influence spatial and temporal effort distributions (including depth of fishing), and have immediate or downstream effects within a mixed stock groundfish fishery, including on species composition. Not accounting for fishing depth dynamics over time can lead to unanticipated correlated errors among species within the aggregate catch (Karnowski et al. 2014, Gertseva 2009). The method described in the paper can account for changes in depth of fishing, caused from the shift in spatial coverage of the fishery.

Comparison of our estimated landings of longnose skate and big skate, versus actual landings informed by species-composition estimates from dockside sampling (reported in PacFIN) allowed us to validate the method. For big skate, the two data sources had only a two-year overlap (2015 and 2016), but for longnose skate both sources were available for the period between 2010 and 2016 (Fig. 2), which enabled direct comparison and validation of the proposed method. Linear regression between our estimated longnose skate landings versus actual landings reported in PacFIN for that period demonstrated excellent overall fit ($R^2 = 0.795$, p=0.0007, RMSE=12.089, Figure 7), indicating that our approach yields realistic and reasonably accurate results overall. Discrepancies can be explained by uncertainty associated with our estimates, but also potentially by limited dockside sampling of landed aggregate skate landings in some spatial strata informing records of actual landed catch, which can cause some degree of uncertainty in PacFIN records.

The uncertainty intervals in estimated landings (Fig. 6) encompass variation related to characteristics of data used to estimate the species-specific contributions to an aggregate total. However, multiple factors can contribute to species compositions of an aggregate that were not accounted for here. For instance, there can be potential limitations in using data from the survey conducted during only a portion of the year (from late spring to early fall) to inform fishery catches that occur year around. We also assume here that species compositions in survey total catch are representative of the fishery landings; while landings are only a part of fishery total catch. Since both skate species have not been targeted, and discards primarily occur because of lack of market (Rogers 1994), it was assumed that there is no preference in retaining one skate species over the other, and both species had the same discard probability; and thus survey catch composition can be used to inform species composition of landings.

In the recent observer data, there has been evidence for discarding of smaller individuals while retaining larger ones. However, we do not have reliable information as to the criteria for relative species retention preference of one species over the other, over a variety of situations with both single and mixed species compositions. In some cases, fishers are said to prefer skates that are not too small because of not large enough marketable (wings) body portion. In others, not too large, due to difficulty handling them. Also, the applicability of the recent data in this aspect to other historical periods is not known, since discard amounts and retention trends also have been known to change over time with other species.

Another source of uncertainty in our estimates is related to reliability and representativeness of logbook data, given that only part of trips were accompanied by logbook records. It is reasonable to assume that available logbook data realistically represent general fishing practices over the years. However, the relative amount of logbook reported catch versus total PacFIN landings dropped since 2011, which could have affected accuracy of our estimates during years used for method validation and partially explain discrepancies between our estimates and actual landings reported in PacFIN. The reason for decrease in logbook reported catch is not clear, but it coincided with implementation of an Individual Fishing Quota (IFQ) system on the West Coast of the United States (Matson et al. 2017).

Uncertainty calculated around estimated historical landings can be directly used in fisheries stock assessment process as well, to help evaluate the influence of potential alternatives of high and low scenarios in longnose and big skate landings on model results through sensitivity analysis. Sensitivity analysis is an excellent way to reveal and explicate to what degree the assessment model output is affected by varying amounts of deviation from assumed fishery landings time series. Cope and Gertseva (2020) provide a detailed overview of using sensitivity analysis to evaluate structural and data uncertainty in stock assessments and to identify aspects of the model that deserve further attention when quantifying uncertainty in model outputs and management quantities.

Although focused on skates landed in Washington State, on the West Coast of the United States, the method presented here is not limited to a particular species or geographic location, but can be easily adapted and used for other species landed within aggregate categories around the world. In our study, we only divided data into depth-specific bins, since we considered a relatively limited latitudinal range of waters off Washington State, and the data did not show trends in relative species occurrences by latitude. However, our approach could be easily applied to a more complex spatial grid, based for instance on depth and latitude; the choice of grid would depend on habitat preference of the contributing species to the aggregate category, and distribution of fishing efforts. Also, seasonal bins could be applied for migrating species when relative contribution of species within an aggregate varies within the year.

It is noteworthy that landings represent a fraction of the total fishery catches; there is also discarded catch that contributes to total removals of a stock. Limited information on historical discard indicate that prior to mid-1990s, the vast majority of skate catch was discarded at sea due to lack of market (Rogers 1994), and only small amount of total skate catch was landed along the West Coast and in Washington State ports. Discarded catch of skate in the mid-1980s, for instance, accounted for more than 90% of total skate removals (Rogers 1994). However, in the mid-1990s, a limited market for skate products appeared on the U.S. West Coast and retention of skates in the bottom trawl fishery increased, while discards decreased to about 50% of the total removals (Martin and Zorzi 1993, Bonfil 1994, Gertseva et al 2019, Gertseva and Matson 2021). Currently, West Coast skates are marketed in limited amounts when they are sold fresh or fresh-frozen, as well as dried or salted and dehydrated (Love et al. 2002). Gertseva and Matson (2021) recently developed a method to predict total removals of bycatch species based on the catch of a co-occurring targeted species; the method has already been applied in multiple stock assessments of elasmobranch stocks (Gertseva et al. 2019, Taylor et al. 2019, Gertseva et al. 2021). In stock assessment models however, landings and discards are commonly treated separately to account for differences in length composition between retained and discarded fish and more accurately estimate fishery selectivity curves. Therefore, landings represent an essential data source for stock assessment and management of both targeted and non-targeted species, despite what portion of the catch is discarded, and progress in reconstructing historical landings is necessary.

Acquisition or estimation of accurate catch time series is of utmost importance in obtaining valid and reliable stock assessment results, a critical endeavor for ensuring sustainability and conservation the world over, and disentangling aggregate species categories presents a common problem for stock assessment. The approach described here represents progress in this area, as here we developed a method enabling improvement in reconstruction of species-specific landings within an aggregate category, accounting for fishing depth dynamics over time. The approach presented here was already used to resolve a critical need for species-specific estimates of skate historical landings in the most recent longnose skate and big skate stock assessments (Gertseva et al. 2019, Taylor et al. 2019). Currently evaluated using a limited area, our approach can be expanded to other parts of the coast in future assessments of these two skate species.

It is important to continue efforts to improve our understanding of historical fishery removals. In the future, approaches based on using statistical methods, such as Dirichlet regression (Maier 2014) and multinomial logistic regression (Hilbe 2009) could be attempted for these two species, in order to produce model-based predictions of species composition, using depth as a predictor, similar as Moran et al. (2021) used latitude to predict Chinook stock composition.

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References

Alverson, D.L., Pruter, A.T., Ronholt, L.L. 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. Institute of Fisheries, University of British Columbia.

Branch, T. A. 2008. Not all fisheries will be collapsed in 2048. Marine Policy, 32:38–39.

Branch, T.A., Jensen, O.P., Ricard, D., Ye, Y., Hilborn, R.A.Y., 2011. Contrasting global trends in marine fishery status obtained from catches and from stock assessments. Conservation Biology, 25(4): 777-786.

Bizzarro, J.J., Broms, K.M., Logsdon, M., Yoklavich, M.M., Kuhnz, L., Summers, A.P. 2014. Spatial segregation in eastern North Pacific skate assemblages. PLOS ONE, 9: e109907.

Bizzarro, J.J. 2015. Comparative resource utilization of eastern North Pacific skates (Rajiformes: Rajidae) with applications for ecosystem–based fisheries management. Ph.D. Dissertation. University of Washington, School of Aquatic & Fishery Sciences. Seattle, WA.

Bonfil, R. 1994. Overview of world elasmobranch fisheries. FAO Fisheries Technical Paper No 341.

Cope, J. and Gertseva, V., 2020. A new way to visualize and report structural and data uncertainty in stock assessments. Canadian Journal of Fisheries and Aquatic Sciences, 77(8): 1275-1280.

Dulvy, N.K., Metcalfe, J.D., Glanville, J., Pawson, M.G. and Reynolds, J.D., 2000. Fishery stability, local extinctions, and shifts in community structure in skates. Conservation Biology, 14(1): 283-293.

Dulvy, N.K., Reynolds, J.D., 2002. Predicting extinction vulnerability in skates. Conservation Biology, 16(2): 440-450.

Ebert, D.A., and Compagno, L.J. 2007. Biodiversity and systematics of skates (chondrichthyes: *Rajiformes: Rajoidei*). In Biology of skates. Springer. pp. 5-18.

Eschmeyer, W. N. and E. S. Herald. 1983. A field guide to Pacific Coast fishes of North America From the Gulf of Alaska to Baja California. Houghton Mifflin, Boston.

Farrugia, T.J., Goldman, K.J., Tribuzio, C., and Seitz, A.C. 2016. First use of satellite tags to examine movement and habitat use of big skates beringraja binoculata in the Gulf of Alaska. Marine Ecology Progress Series, 556: 209-221.

Gertseva, V. V., S. E. Matson, I. G. Taylor, J. Bizzaro, Wallace, J. R., 2019. Stock assessment of the Longnose Skate (*Beringraja rhina*) in state and Federal waters off California, Oregon and Washington. Pacific Fishery Management Council, Portland, OR.

Gertseva, V.V. and Matson, S.E., 2021. Right on target: using data from targeted stocks to reconstruct removals of bycatch species, a case study of longnose skate from Northeast Pacific Ocean. Fisheries Research, 236: 105841.

Gertseva, V.V., 2009. The population dynamics of the longnose skate, *Raja rhina*, in the northeast Pacific Ocean. Fisheries Research, 95(2-3): 146-153.

Haddon, M. 2011. Modelling and Quantitative Methods in Fisheries. 2nd Edition. Chapman and Hall/CRC.

Harry, G., Morgan, A.R. 1961. History of the trawl fishery, 1884-1961. Oregon Fish Commission Research Briefs, 19: 5-26.

Hilbe, J.M., 2009. Logistic regression models. Chapman and hall/CRC.

Hilborn, R, Walters, C.J., 2003. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Springer.

Hilborn, R., Branch, T.A., Magnusson, E., Minte-Vera, C.V., Scheuerell M.D., Valero J.L., 2003. State of the world's fisheries. Annual Review of Environment and Resources, 28(1): 359-99.

Karnowski, M., Gertseva, V.V., Stephens, A. 2014. Historical Reconstruction of Oregon's Commercial Fisheries Landings. 2014-02, Oregon Department of Fish and Wildlife, Newport, Oregon.

Keller, A.A., Wallace, J.R., and Methot, R.D. 2017. The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey: history, design, and description. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-136. https://doi.org/10.7289/V5/TM-NWFSC-136.

King, M. 2013. Fisheries biology, assessment and management. John Wiley & Sons.

King, J.R., McFarlane, G.A., 2003. Marine fish life history strategies: applications to fishery management. Fisheries Management and Ecology, 10(4): 249-264.

King, J. R., G. A. McFarlane, Gertseva, V. V., Gasper, J., Matson, S. E., Tribuzio, C. A., 2017. Shark Interactions With Directed and Incidental Fisheries in the Northeast Pacific Ocean: Historic and Current Encounters, and Challenges for Shark Conservation, in: Larson, S., Lowry, D. (Eds.), Northeast Pacific Shark Biology, Research, and Conservation, Part B. Academic Press, London, pp. 9-44.

Love, M.S., Bizzarro, J.J., Cornthwaite, A.M., Frable, B.W. and Maslenikov, K.P., 2021. Checklist of marine and estuarine fishes from the Alaska–Yukon border, Beaufort Sea, to Cabo San Lucas, Mexico. Zootaxa, 5053(1): 1-285.

Love, M. S., M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley.

Maier, M., 2014. DirichletReg: Dirichlet regression for compositional data in R. Research Report Series / Department of Statistics and Mathematics; No. 125.

Martin, L., Zorzi, G.D. 1993. Status and review of the California skate fishery. In Conservation biology of elasmobranchs (Ed. Branstetter, S.), p 39-52. NOAA Technical Report NMFS 115.

Matson, S.E., Taylor, I.G., Gertseva, V.V. and Dorn, M.W., 2017. Novel catch projection model for a commercial groundfish catch shares fishery. Ecological modelling, 349, pp.51-61.

Matson, S. E., Gertseva, V. V., 2020. Resolving associative patterns in life history parameters among marine fish stocks in the Northeast Pacific Ocean. Journal of Sea Research, 156: 101837.

Matson, S.E., Taylor, I.G., Gertseva, V.V. and Dorn, M.W., 2017. Novel catch projection model for a commercial groundfish catch shares fishery. Ecological Modelling, 349: 51-61.

McEachran, J., and Miyake, T. 1990. Zoogeography and bathymetry of skates (chondrichthyes, rajidae). Elasmobranchs as living resources. Advances in biology, Ecology, Systematics and the status of the fisheries, pp. 305-326.

Mecklenburg, C. W., T. A. Mecklenburg, and L. K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.

Miller, R.R., Field, J.C., Santora, J.A., Schroeder, I.D., Huff, D.D., Key, M., Pearson, D.E. and MacCall, A.D., 2014. A spatially distinct history of the development of California groundfish fisheries. PLoS One, 9(6): e99758.

Moran, P., Tuttle, V.J., Bishop, S. and LaVoy, L., 2021. Compositional forecasting of Chinook Salmon Evolutionarily Significant Units in bycatch for Pacific Hake fisheries. bioRxiv. doi: https://doi.org/10.1101/2021.11.29.470462

Rogers, J.B. 1994. Assemblages of groundfish caught using commercial fishing strategies off the coasts of Oregon and Washington from 1985-1987. Ph.D. Dissertation, Oregon State University, Oregon.

Somers, K. A., C. E. Whitmire, K. E. Richerson, and V. J. Tuttle. 2023. Fishing Effort in the 2002–21 U.S. Pacific Coast Groundfish Fisheries. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-184.

Snytko, V.A. 1987. New data on the distribution of some species of fish in the North Pacific. Journal of Ichthyology, 27:142-146.

Taylor, I.G., Gertseva, V., Methot Jr, R.D. and Maunder, M.N., 2013. A stock–recruitment relationship based on pre-recruit survival, illustrated with application to spiny dogfish shark. Fisheries Research, 142: 15-21.

Taylor, I.G., Gertseva, V., Stephens, A., Bizzarro, J., 2019. Status of Big Skate (*Beringraja binoculata*) Off the U.S. West Coast, 2019. Pacific Fishery Management Council, Portland, OR.

Tolimieri, N. and Levin, P.S., 2006. Assemblage structure of eastern Pacific groundfishes on the US continental slope in relation to physical and environmental variables. Transactions of the American Fisheries Society, 135(2): 317-332.

Last, P.R., White, W.T., Carvalho, M.R. de, Séret, B., Stehmann, M.F.W and Naylor, G.J.P. 2016. Rays of the World. CSIRO Publishing, Melbourne.

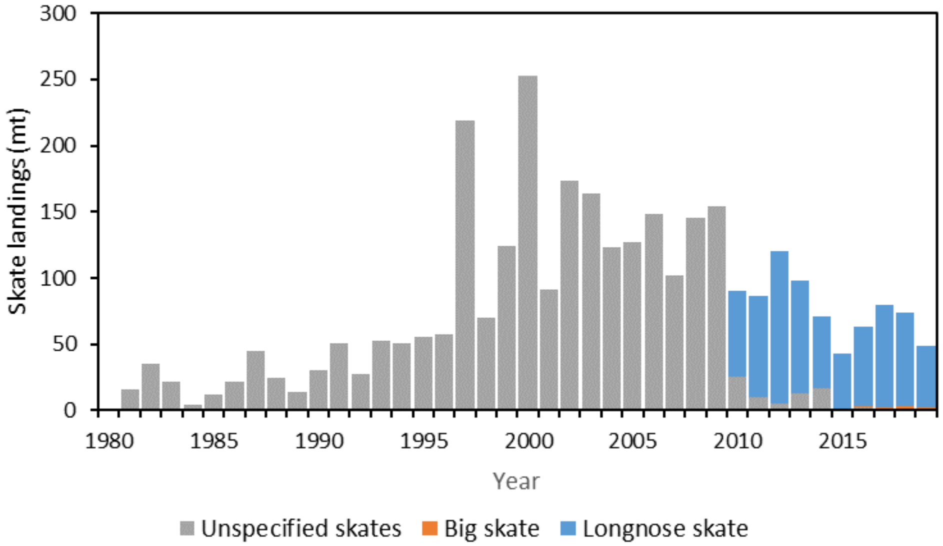


Figure 1. Commercial catch of skates in the U.S. West Coast groundfish demersal trawl fishery landed in Washington State ports, between 1981 and 2019, as reported in fish tickets. Longnose skate and big skate have been reported separately since 2010 and 2015, respectively.

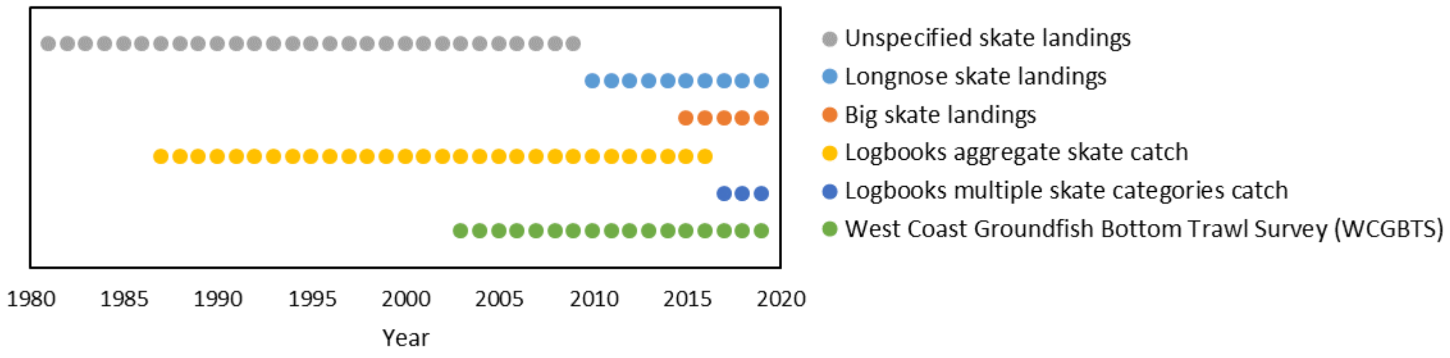


Figure 2. Summary of data sources used in the analysis by year.

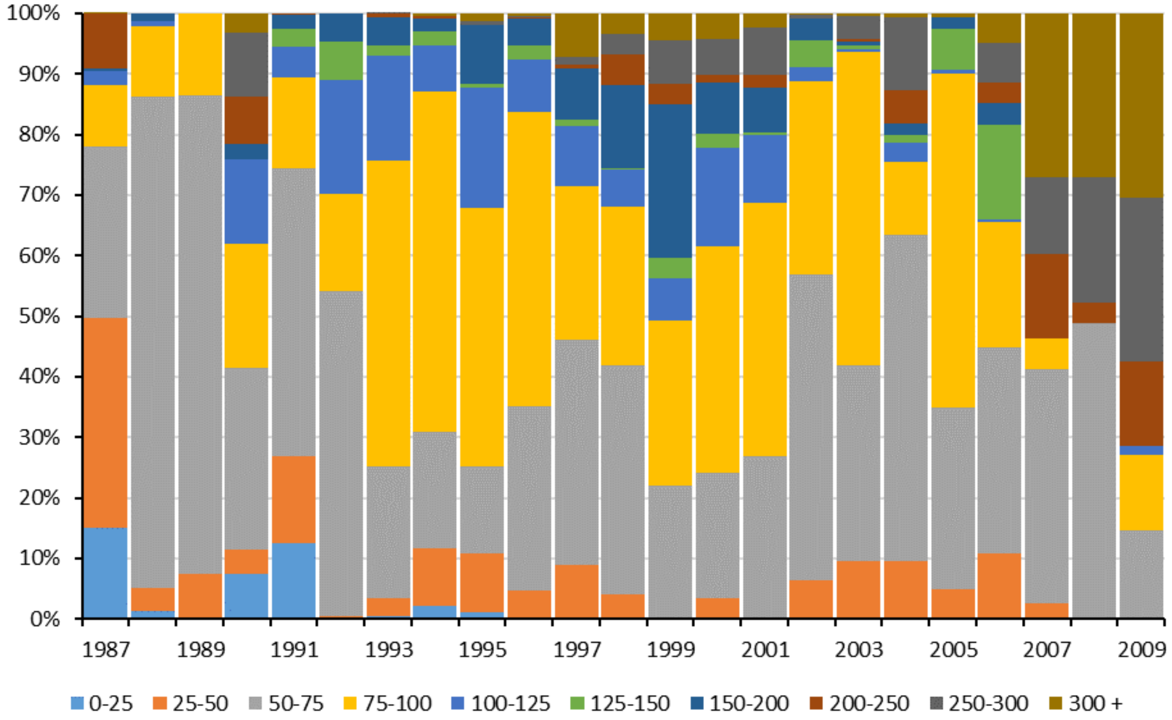


Figure 3. Annual aggregate skate catch landed in Washington State ports, by depth bin (in fm), informed by logbook data. Depth bins are sorted, from shallow at the bottom, growing deeper toward the top of the plot.

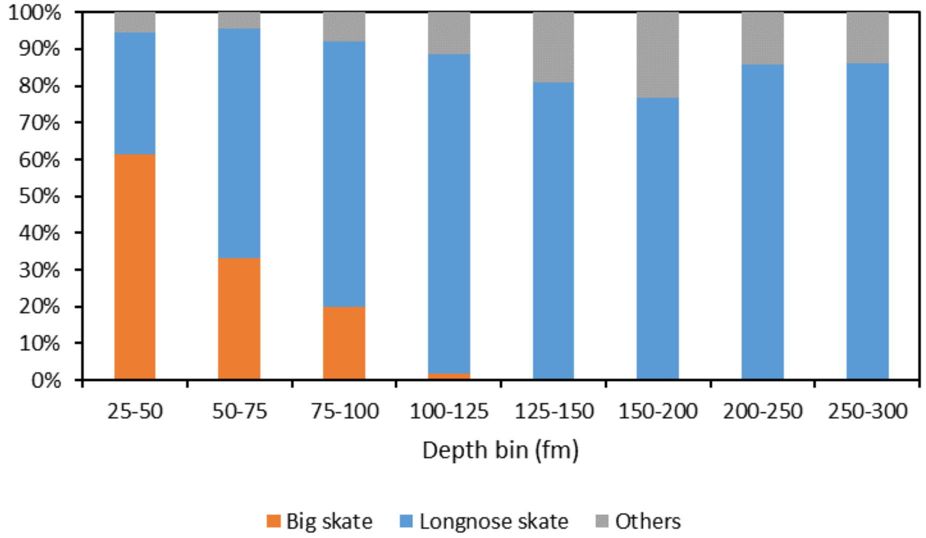
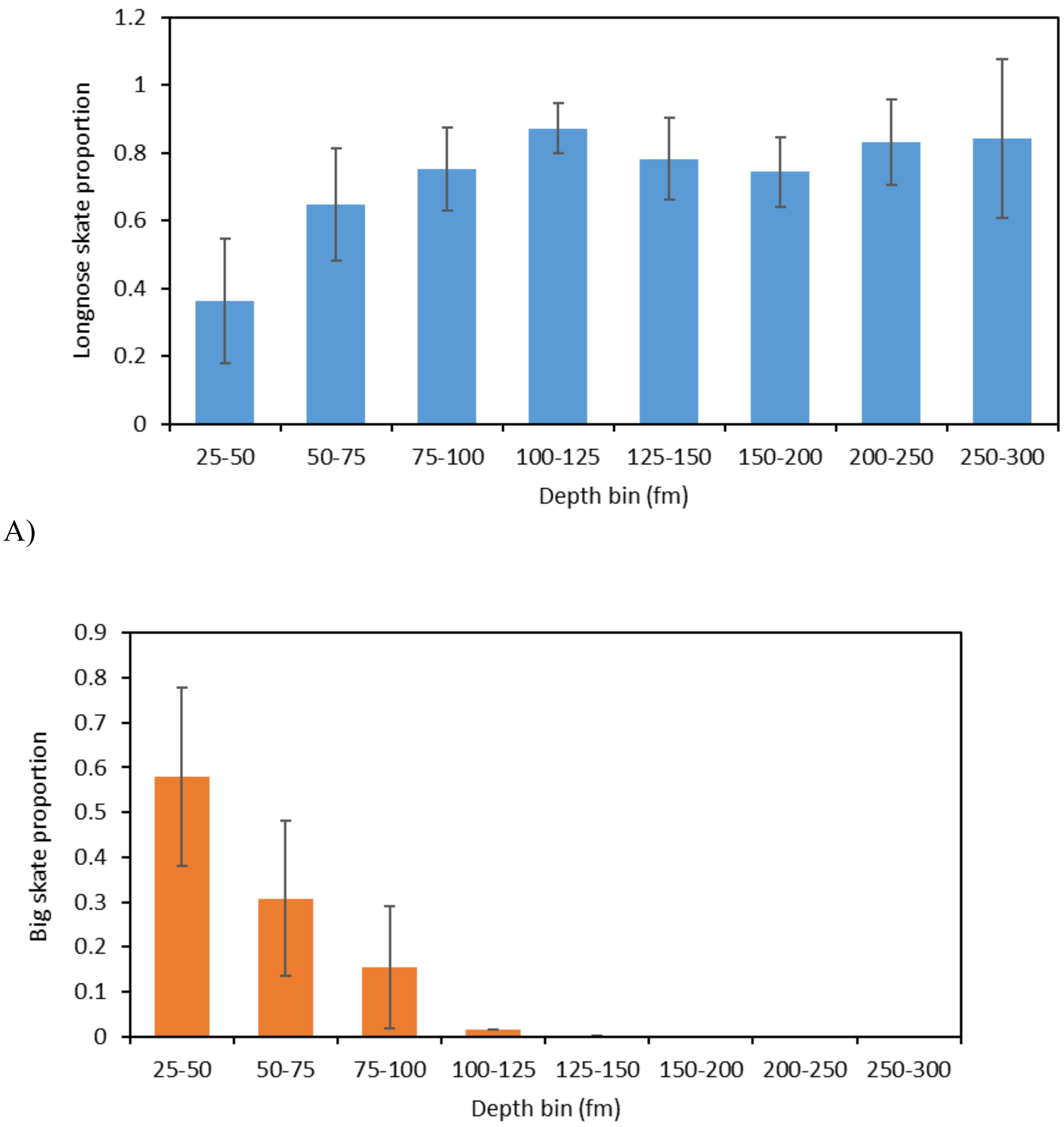


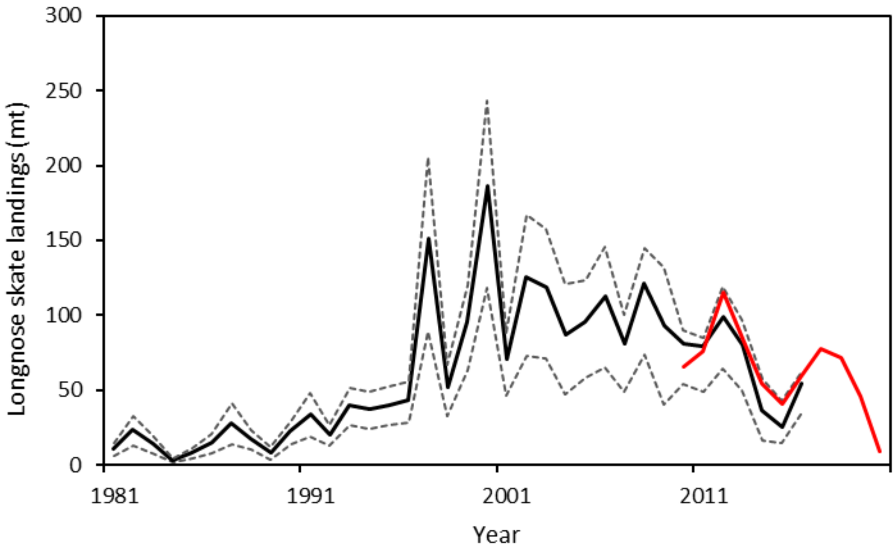
Figure 4. Average percent contribution of individual skate species to the aggregate skate catch by depth bins during the West Coast Groundfish Bottom Trawl Survey, years 2003 – 2019. Other skates primarily consist of sandpaper skate (*Bathyraja kincaidii*) and roughtail skate (*Bathyraja trachura*).



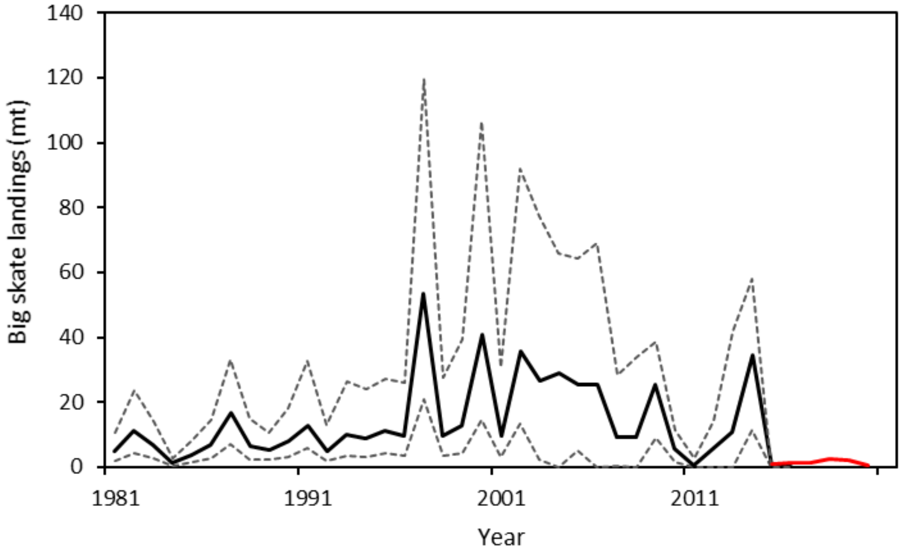
A)

B)

Figure 5. Mean proportion of longnose skate (A) and big skate (B) by depth bin in the West Coast Groundfish Bottom Trawl Survey (WCGBTS), 2003 – 2019. Error bars represent one standard deviation bove and below the mean (calculated across all years).



A)



B)

Figure 6. Estimated landings of longnose skate (A) and big skate (B) based on combination of survey and logbook data (black lines). Dashed lines show uncertainty intervals around the reconstructed landings for each species, calculated from applying ± 2 standard deviations of depth specific proportions for each species within WCGBTS data. Red lines are landings

reported in PacFIN, calculated based on species composition port sampling (longnose skate landings reported separately from other skate from 2010 forward and big skate from 2015 forward).

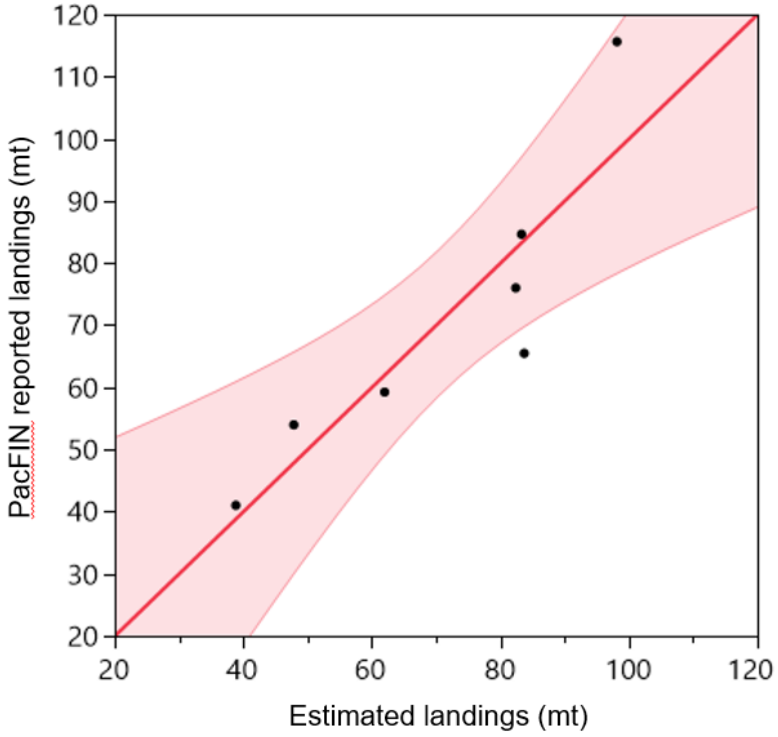


Figure 7. Comparison of fit between estimated longnose skate landings, versus longnose skate landings reported in PacFIN for 2010-2016 (R^2=0.795, p=0.0007). Colored area around the line represented 95% confidence region. Prior to 2010, longnose skate landings were reported in PacFIN as part of skate aggregate; after 2016, longnose skate data was reported separately from other skates in logbooks.