Fisheries Centre

The University of British Columbia

Working Paper Series

Working Paper #2015 - 81

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Year: 2015

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RECONSTRUCTING CATCHES ALONG HIGHWAY 101: HISTORIC CATCH ESTIMATES FOR MARINE FISHERIES IN CALIFORNIA, OREGON AND WASHINGTON FROM 1950-2010

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ABSTRACT

Accurate historical data are useful for fisheries management and monitoring long-term changes in marine ecosystems. However, official catch statistics typically only include landings data from commercial fisheries and do not include other important sources of catch such as recreational fisheries, discards, or illegal fishing. Here, we estimate the major sources of marine withdrawals for fisheries in California, Oregon and Washington for the 1950-2010 period by including sources of typically unreported catch (such as discards and recreational fisheries) and by replacing gaps in the time series with actual estimates. The reconstructed catch was 750,000 t in 1950, just before the waning of the sardine fishery, and declined to 545,000 t by 2010, ranging between 380,000 t·year^{-1} and 640,000 t·year^{-1} from 1951-2009. Catches consisted of commercial landings (87%), followed by discards (8%) and recreational take (4%), and were 1.2 times the landings reported by NOAA/NMFS for the West Coast. As part of the *Sea Around Us* database definitions, we split the commercial catches into two fishing sectors: 'industrial' (being large-scale commercial) and 'artisanal' (being small-scale commercial). We hope the results presented here will help improve historic time series of catch and provide a better understanding of important changes that have occurred over the past 6 decades. We also hope that this study may shed some light on the extent of recreational fisheries and discards and will provide justification for continued monitoring of these sources of catch.

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LIST OF ACRONYMS USED

Acronym	Meaning
AK	Alaska
BRD	Bycatch reduction device
CA	California
CDFW	California Department of Fish and Wildlife (previously Department of Fish and Game)
CDFG	California Department of Fish and Game
CPFV	Commercial passenger fishing vessel
CRITFC	Columbia River Inter-Tribal Fish Commission
D/L	Discards to landings ratio
EEZ	Exclusive Economic Zone
FAD	Fish aggregating device
FAO	Food and Agriculture Organization of the United Nations
HI	Hawaii
GBT	Groundfish bottom trawl
IPHC	International Pacific Halibut Commission
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWFSC	Northwest Fisheries Science Center
OR	Oregon
ODFW	Oregon Department of Fish and Wildlife
PacFIN	Pacific Fisheries Information Network
PFMC	Pacific Fishery Management Council
RecFIN	Recreational Fisheries Information Network
RARA	Report of assessment and research activities
SWFSC	Southwest Fisheries Science Center
U.S.	United States of America
UVBV	Univalve and bivalve molluscs
WA	Washington (State)
WDFW	Washington Department of Fish and Wildlife

INTRODUCTION

Accurate historical data are useful for fisheries management and monitoring long-term changes in marine ecosystems (McClenachan *et al.* 2012); however not all sources of catch are included in official catch statistics reported by national agencies or by the Food and Agriculture Organization of the United Nations (FAO) on behalf of member countries. Data reported to, and distributed by the FAO are the only source of global catch statistics and are often used to evaluate the status of both global and regional fisheries (e.g., FAO 2011; Garibaldi 2012; FAO 2014). For the vast majority of countries, these data include only landings from commercial fisheries and do not include other important sources of catch such as recreational fisheries, discards, or illegal fishing (Kelleher 2005a; Agnew *et al.* 2009; The World Bank 2010; Garibaldi 2012). Note that we treat discards as part of 'catch', since we consider fisheries in an ecosystem setting.

This study has two goals. First, this project aims to identify and provide estimates of all sources of marine withdrawals for fisheries in California, Oregon and Washington (Figure 1) for the 1950-2010 period by including sources of typically unreported catch (such as discards) and by replacing gaps in the time series with some estimate of catch. 'Reported' is defined as being included in officially reported national and hence international FAO data. The key hypothesis in this process is that zero data does not represent zero catch (Pauly 1998; Cisneros-Montemayor *et al.* 2013). This would seem obvious, but in practice, missing catch data are often ignored by users of these data under the assumption that this missing catch is negligible or involves too much uncertainty to estimate. In fact, over the past decade, the reconstructions undertaken by the *Sea Around Us* for all of the world's maritime countries have demonstrated that this assumption is very misleading (Pauly *et al.* 2013). The amount of unreported catch in official statistics is often substantial (between 10 and 50% for most developed countries; Zeller *et al.* 2011). Moreover, in many cases, data and information that allow these missing catches to be estimated are available.

The second goal is to contribute to a larger activity of the *Sea Around Us* aimed at improving the quality and comprehensiveness of the catch data that are globally available to fisheries policy makers and researchers, and to provide an improved understanding of the global impacts of fisheries on large marine ecosystems. Essentially this boils down to answering the question: How much fish have humans extracted from the ocean over the past 6 decades?

In general, the reconstruction methods for the western U.S. involved several steps. First, we compiled all sources of available historical catch data for discards, recreational, commercial, subsistence and illegal fisheries that were available to us. These data were obtained through a variety of sources, including regulatory bodies for specific fisheries, state agencies, stock assessments, peer-reviewed literature, grey literature and unpublished datasets. We then compared these sources for overlapping years, and selected the source that was deemed the most comprehensive for the taxa and period in question. Estimates were then made for years and taxa with missing data, predominantly through the use of simple, and sometimes possibly even controversial, assumptions, such as carrying backward catch trends or linear interpolation. For example, recreational catch data were largely unavailable from 1990-1992, and catch for this period was estimated using a linear interpolation between years with data (1989 and 1993). Finally once total catches had been accounted for, we looked to improve the overall taxonomic resolution where possible.

1.0 - SOURCES OF CATCH AND RECONSTRUCTION METHODS

1.1 - Commercial fisheries

1.1.1 - Sources of catch data

Commercial landings data from three different sources in the U.S. were available for CA, OR and WA:

- Catch statistics from 1950-2010 from NMFS's online database (www.st.nmfs.noaa.gov);
- Catch statistics from 1981-2010 from the Pacific Fisheries Information network (PacFIN) (provided by Kara McLean); and
- Unpublished catch statistics from state agencies and reports; 1969-2010 landings data for CA (CDFW, unpubl. data, provided by J. Roberston), 1950-1977 landings for OR (Smith 1956; ODFW 1977; INPFC 1979; Gaumer 1985), 1950-2010 landings data for WA (INPFC 1979; WDFW, unpubl. data, provided by D. Ayres, G. Liepert and M. Morningstar).

We compared total catches from these sources for each state to try and identify any obvious discrepancies in the reported catch. For the most part, catch statistics from state departments of fish and wildlife, PacFIN and NMFS correlated well, and there were no obvious errors suggesting that one source be used over another for overlapping years. For consistency, we used the NMFS commercial landings data as our baseline for national reported commercial catch statistics for CA, WA and OR as these data provided the most complete time series of commercial landings from 1950-2010.

We then compared the NMFS commercial landings data with data reported to the FAO on behalf of the U.S. (FAO 2012) for areas in the Pacific Ocean. To our knowledge, the data reported to FAO represents only commercial landings and does not include catch from recreational fisheries or discards (Garibaldi 2012). The FAO areas 77 (Pacific, Western Central) and 67 (Pacific, Northeast) in the Pacific Ocean were assumed to represent landings that were taken in Hawaii, California, Oregon, Washington, Alaska, high seas waters and regional EEZs for which the U.S. has fisheries access agreements. These landings make up the majority of catch (96%) in the Pacific Ocean that are reported to FAO. The other 4% occur in FAO areas 71 (Pacific, Western Central), 81 (Pacific, Southwest) and 87 (Pacific, Southeast) and are exclusively tuna (mostly skipjack, yellowfin, albacore, and bigeye[1]). The current reconstruction focuses on domestic landings within the U.S. mainland EEZ (or EEZ-equivalent water during the pre-EEZ period) and excludes landings from off-shore tuna fishing fleets, and fisheries in Alaska. The catch data reconstructions for Alaska and Hawaii are being dealt with separately ((Doherty *et al.* 2015; Gibson *et al.* 2015). The off-shore tuna landings will be included in the *Sea Around Us* database through a separate global reconstruction of all targeted oceanic tuna fisheries.

FAO area 77 includes HI and the southern part of CA, while FAO area 67 includes northern CA, OR, WA and AK. Since we did not have landings data for CA separated by north and south, it is difficult to make a direct comparison of NMFS commercial landings by state with the data reported to FAO. Nevertheless, this was attempted in order to accommodate the global reporting structure (Figure 2). Based on this comparison, the data reported to FAO are similar for most years to what are included in the NMFS commercial landings data, however there are discrepancies (See Table 1). Due to the regional differences in reporting areas between NMFS and the data sent to the FAO, we were unable to confirm what caused the discrepancy between the two data sets in all years. The large discrepancies observed for area 67 (Pacific Northeast) in the 1980s are likely due to differences in reporting catches from foreign and joint venture fisheries operating in Alaska (Doherty *et al.* 2015), which were not completely phased out until 1991 (NMFS 1996; Mansfield 2001), although this could not be verified. Furthermore, FAO reconciles and harmonizes datasets received from various sources, such as national reporting entities (i.e., NMFS) as well as Regional Fisheries Management Organizations. Thus, FAO data can be expected to be higher than purely national sources (Table 1).

[1] We abstain here from providing scientific names for many of the fish and invertebrate taxa we mention, as common names, in the USA, are well standardized. If in doubt, see www.fishbase.org.

Table 1 - Comparison of FAO landings data for Area 67 and 77 with NMFS landings for HI, CA, OR, WA and AK for years 1950-2010

Data source	Area/state	Total landings (t)	Annual % difference for years 1950-1960			
			Min.	Max.	Average	Median
FAO	Area 67 - North CA, WA, OR, AK	79,958,552	-35	182	13	1
NMFS	WA, OR, AK (incl. at-sea processed)	71,664,260				
FAO	Area 77 - South CA, and HI	16,361,324	-15	47	8	5
NMFS	CA, HI	15,348,462				

We use the NMFS national data in our reconstructed estimates of commercial catch since it provided better spatial information (i.e., catches by state) and to remain consistent with other reconstructions by the *Sea Around Us* for the U.S.

We removed all freshwater taxa (including rainbow trout) as well as aquatic mammals, reptiles, amphibians, coral, roe and seaweeds, since these taxa are not commonly included in fisheries databases, including that of the *Sea Around Us*. However, we include all sturgeon and salmon catch. Additionally, several taxa in the NMFS landings database, particularly for earlier years, do not occur in Pacific waters. For example, Atlantic halibut landings are listed from 1950-1961 and Pacific halibut from 1962-2010 for OR and WA. We reassigned Atlantic halibut landings as Pacific halibut, and made similar assumptions for other taxa where such misclassifications occurred.

NMFS Pacific landings data for CA, OR, and WA, as well as those listed as at-sea processing, were used to reconstruct commercial catch. 'At-sea processing' are almost exclusively Pacific hake (*Merluccius productus*) landings and consist of catches taken in WA and OR EEZs that are processed at-sea. At-sea processing of Pacific hake is further discussed in the discards section.

1.1.2 - Shellfish

Data caveats from the NMFS website (www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/data-caveats/index) state that all landings are recorded at the location where the catch was first landed or reported, rather than the geographical location at which they were caught. Catch statistics are reported in round weights, with the exception of univalve and bivalve molluscs (UVBV), which are reported as "pounds of meat", i.e., excluding the weight of the shells. NMFS landings may also include some shellfish aquaculture production for oyster, mussel and clam species.

PacFIN UVBV catch are reported in wet weights and, with the exception of WA, do not include aquaculture production (B. Stenberg, PacFIN, pers. comm.). By comparing NMFS and PacFIN catch data for the same taxa in various years, we were able to estimate conversion factors to convert NMFS landings into wet weights for the 1950-2010 period (Table 2). We were unable to estimate conversion factors for mussels (*Mytilus* spp.) and oysters (*Crassostrea* spp.), due to low or absent catches in the PacFIN data, and used conversion factors from Crapo *et al.* (2004) for these species. For species that could not be identified (2% of shellfish catch) we assumed a conversion factor of 2, assuming a meat yield of 50%.

The portion of shellfish landings in the NMFS landings data derived from aquaculture production is unknown (A. Lowther, NOAA, pers. comm.). NMFS landings data lists UVBV catch by gear type from 1950 to 1980, which for the most part seems to indicate that they originated from wild capture fisheries. However from 1980 to 2010, the gear type is listed as "unspecified".

Table 2 - Conversion factors (CFs) used to convert meat weight to wet weight for major shellfish taxa in the NMFS commercial landings data for WA, OR and CA.

Taxa:	CF
Abalone (*Haliotis* spp.)	2.5
Blue mussel (*Mytilus edulis*)	3.8
Butter clams (*Saxidomus gigantea*)	2.7
California mussel (*Mytilus californianus*)	4.6
Littleneck clams (*Leukoma staminea*)	2.7
Manila clams (*Venerupis philippinarum*)	7.1
Nuttall's cockle (*Clinocardium nuttallii*)	2.4
Oysters [a]	7.1
Pacific clams (unidentified)	2.7
Pacific gaper clam (*Tresus nuttallii*) [b]	3.9
Pacific geoduck (*Panopea generosa*)	3.0
Pacific razor clam (*Siliqua patula*)	2.3
Scallops (Pectinidae)	8.2
Softshell clams (*Mya arenaria*)	2.3

[a] We used the most conservative value in a range presented by Crapo *et al.* (2004) for the weight conversion. There are 4 species of oyster in NMFS landings with Pacific oyster (*C. gigas*) making up most of the catch. [b] Used 3.9 for WA and 3.8 for OR.

With the exception of mussels and oysters, the major shellfish taxa in the NMFS statistics are also reported by PacFIN, which suggests they are wild caught (at least for OR and CA). Through our comparison of the PacFIN and NMFS shellfish landings from 1981-2010 and based on the gear (dredges, rakes, tongs and hand collection) used to harvest most shellfish from 1950-1979, we reasoned that most shellfish recorded in the NMFS data were caught from the wild and so included them in the reconstructed catch. It is possible that some mussel and oyster aquaculture production remains in our data; however, we were unable to determine what this portion might be, and we assume it is small.

In addition to converting shellfish product (meat) weights into wet weight, we also added catch from two taxa which were observed in the CDFW catch statistics but missing from NMFS landings

- California bay shrimp (*Crangon franciscorum*) catch from 1969-1971, 1977 and 1981-2010 (landings are included in the NMFS data from 1973-1976 and 1978-1980); and
- Kellet's whelk (*Kelletia kelletii*) landings from 1979-2010.

1.2 - Recreational fisheries

A variety of data sources were used to reconstruct recreational catches from 1950-2010 for the western United States (Tables 3-5). We used the Recreational Fisheries Information Network (RecFIN) database (www.recfin.org) and unpublished catch data from Figueira and Coleman (2010) to estimate recreational catch of most fish species for the years 1980-2010. Catch data from Figueira and Coleman (2010) were used where available (1981-1989, 1993-2002) and RecFIN for 1980 and 2003-2010. Linear interpolations were used to approximate catches for the years 1990 to 1992 where no additional data were available.

Additionally, estimates of catches from some of the major recreational fisheries, such as Pacific halibut and salmonids relied more heavily on additional data available from the California Department of Fish and Wildlife[2] (CDFW), the Oregon Department of Fish and Wildlife (ODFW), the Washington

[2] Formerly the California Department of Fish and Game.

Department of Fish and Wildlife (WDFW), the International Pacific Halibut Commission (IPHC) and the Pacific Fishery Management Council (PFMC), which are considered more accurate than RecFIN estimates for these species (P. Mirick, ODFW, pers. comm.). For species with overlapping years in different catch datasets, we used only one dataset for the overlapping time period to avoid any double-counting.

There were limited data available for recreational catch during the earlier period from 1950-1979. The reconstructed catch for species during this time was developed from a variety of sources, as well as linear interpolations, linear regression and the backwards extrapolation of more recent catch trends to estimate catch for years and species with zero data (Tables 3-5). Where available, data prior to 1980 were often recorded as numbers of fish, and we converted these numbers to wet weights. The weight conversion factors ($kg \cdot fish^{-1}$) used are listed in Appendix B and were mostly taken from:

- The 1960 saltwater angling survey (Clark 1960); and
- Mean RecFIN weights for landed fish for CA, OR, and WA.

In some cases, where there were missing or incomplete data, we estimated catch based on average annual catches in the preceding or succeeding years. When this was done for salmonids, we took into account the life cycles of individual species and used an average, which would encompass an even amount of different year-classes. For most species of salmon, there is some overlap between the stocks of different years, as not all individuals born in one year will return to spawn on the same year. This is rarely the case for pink salmon (*O. gorbuscha*), which have a 2-year life cycle and often return to spawn in much different run strength in even and odd years (Turner and Bilton 1968; Hart and Clemens 1973; Hard *et al.* 1996). Thus, when this method was employed to estimate pink salmon catches, we looked at odd and even years separately.

In the cases with anadromous species, which migrate between saltwater and freshwater water bodies throughout their lifecycles (such as salmonids and sturgeon), precise catch locations were not always available. We excluded all steelhead catch, as most catches were from rivers well inland. For the case of Columbia River sturgeon, we only included catch from WDFW Reporting Area 1A at the mouth of the Colombia River, located at the ocean-river interface. For other salmon (chinook, coho, pink, chum and sockeye) species, we included landings originating from ocean and freshwater recreational fisheries as both are considered to be the result of ocean productivity.

We found historical time series for the 1950-1979 period to reconstruct catches for most of the species that are frequently targeted by recreational anglers and comprise substantial portions of statewide recreational catches in recent years. These taxa are outlined in Tables 3-5 and represented 99%, 90% and 42% of reconstructed recreational catches from 1980-2010 for CA, WA and OR, respectively. Other taxa landed by recreational fishers are bycatch or less frequently targeted species and assumed to occur in a similar proportion to the overall annual catches. An additional 10% (WA) and 58% (OR) were subsequently added to the annual reconstructed recreational catches of WA and OR for 1950-1979, and assigned proportionally to these less frequently targeted taxa. The assumption is that species without any data for the 1950-1979 period, occupied the same annual proportions of total state catch as their proportion in the total catch over the 1980-2010 period.

Recreational fishing for shellfish such as crabs and a variety of clams are popular activities along the U.S. west coast and were also estimated from 1950-2010. Shellfish harvests are not included in the RecFIN database nor are they in the estimates by Figueira and Coleman (2010); however some data were available from the respective state departments of fish and wildlife and in the scientific literature.

Many of these data were listed as numbers of individuals collected and were converted into wet weights (See Appendix B for conversion factors). Often shellfish estimates were only available for select years or for certain areas and thus assumptions were required to estimate statewide time series from 1950-2010. We used these data as anchor points and generated per-license catch estimates to estimate harvests for years without data (Appendix B). U.S. Fish and Wildlife Service historical fishing license data were

available from 1958-2013[3] (wsfrprograms.fws.gov) and were used as an indicator of overall shellfish collection effort to estimate catch based on catch per-license rates for years with data.

1.2.1 - California

Recreational catch data are available from logbooks of California's commercial passenger fishing vessels (CPFVs) or 'party boats', which have been collected by the California Department of Fish and Game (CDFG) since 1936 (Hill and Schneider 1999). Party boat logbook data are the basis for many recreational catch estimates reported in the scientific literature (Chadwick 1962; Mckechnie and Miller 1971; Collins *et al.* 1980) and were also used in this study as the main source to reconstruct recreational catches from 1950-1979(Table 3)).

Historical records of recreational fisheries in California were also available for Chinook and Coho salmon (INPFC 1979; PFMC 1993, 2013), rockfish(Ralston *et al.* 2010), and Pacific Halibut (Miller and Gotshall 1965; Skud 1975; Blood 1992-2009; Williams 2010, 2011; Hare 2012; Williams 2012). These estimates were more robust for these taxa and were used instead of the CPFV logbook information.

Table 3 - Sources of recreational catch estimates for marine fish in California

Years	Taxa			
	Chinook & coho salmon	**Rockfish**	**Pacific halibut**	**All Others**
1950-1957	INPFC (1979)	California reconstruction project (Ralston *et al.* 2010)[a]	*Assumed catch of 0.1 t based on 1958-1960 catch*	CPFV data [d]
1958-1960			Miller and Gotshall (1965) [b]	
1961			*Linear interpolation*	
1962-1973	PFMC data			
1974			Skud (1975) [b]	
1975-1976			*Linear interpolation*	
1977-1979			IPHC RARAs [c]	
1980				RecFIN
1981-1989		Figueira and Coleman (2010)		Figueira and Coleman (2010)
1990-1992		*Linear interpolation*		*Linear interpolation*
1993-2002		Figueira and Coleman (2010)		Figueira and Coleman (2010)
2003-2010		RecFIN		RecFIN

[a] Ralston *et al.* (2010) compiled estimates of catch for 6 different species of rockfish, as well as catch that was aggregated at the genus level, that are based on CPFV logbook and other historical data. These data were used instead of the 1980 RecFIN data, which is considered questionable for CA rockfish (Ralston *et al.* 2010)

[b] Skud (1975) and Miller and Gotshall (1965) estimates are for CA and OR. Based on proportions observed in IPHC estimates from 1991-2010, we assigned 3% of this catch to CA and 97% to OR

[c] IPHC catch estimates from 1999-2010 include catch caught in southern OR waters (South of Humburg) that was assumed landed in CA and classified as CA catch

[d] Sources of CPFV data include: (Chadwick 1962; Young 1969; Mckechnie and Miller 1971; Collins *et al.* 1980; White 1986; Crone *et al.* 2009; CDFG 2011) and the unpublished CDFG database (provided by J. Robertson). This method was used to reconstruct catches for 68 taxonomic groupings, minor deviations from this method were used for select species (see Appendix B for details)

[3] The 1958 license data were also used for years 1950-1957.

Three main sources of CPFV data were used; 1) Young (1969), 2) CDFG (2001) and 3) the CDFW CPFV database (CDFW, unpubl. data, provided by J. Robertson). These data sets correlated well for 1957 and later for most major species. However, from 1950 to 1957, landings from the CDFG database were substantially lower than those reported by Young (1969) and CDFG (2001). Landings from CDFG (2001) and Young (1969) matched well for major groups between 1950-1957, and were used where available, and when not available, data from the unpublished CDFW database were used.

The party boat logbook data represent a large component of recreational catch; however it is not a complete estimate of total recreational catch as there are also anglers who fish on private boats and from shore (Chadwick 1962; Guel and Clark 1968; Guel 1973; Stevens 1977; Collins *et al.* 1980; White 1986). It was necessary to increase party boat catches by a factor (K_{CA}) to estimate the total recreational catch. The values selected for K_{CA} varied for different species and years and were calculated as:

K_{CA} = *total recreational catch / total charter boat catch*

Data used to calculate K_{CA} were obtained from the following sources, the values of which are shown in Appendix B:

- Catch data from the 1965 and 1970 salt water angling surveys (Guel and Clark 1968; Guel 1973);
- Unpublished catch data from Figueira and Coleman (2010); and
- Independent sources for specific species (Collins *et al.* 1980; White 1986; Crone *et al.* 2009).

In general, we used the more conservative of the two *K* values calculated from the 1965 and 1970 salt water angling surveys. The *K* value from Figueira and Coleman (2010) was calculated based on the ratio of total recreational catch to charter boat catch observed from 1981-2002. *K* values for years in between were linearly interpolated (see Appendix B for details). For a few taxa, where estimates of *K* were unavailable, we assumed a value of 2 (i.e., party boat catch accounted for half of the total recreational catch). This is considered conservative, given that the majority of the species in Figueira and Coleman (2010) have a value for *K* that is greater than 2 and that the *K* ratio for total catch from 1981-2002 is 2.6.

All party boat catch was recorded in numbers of fish and needed to be converted into weights (see Appendix B for specific conversions used) and thus the calculation of total recreational catch was:

Total recreational catch = K_{CA} *x party boat catch no. x weight/fish*

Recreational shellfish catch estimates for CA were made for abalone (*Haliotis* spp.), California spiny lobster (*Panulirus interruptus*), crabs and a variety of clams (Appendix B). In general, statewide and historical time series of shellfish catch estimates for California are sparse.

Catch estimates of abalone (*Haliotis* spp.) were available for select years from 1960-2010 (Haaker *et al.* 2001; Haaker *et al.* 2004; CDFG 2010) (Appendix B). Estimates prior to 1983 include only the catch obtained by diving from boats (Hobday and Tegner 2000; Haaker *et al.* 2001) and thus were adjusted to include the proportion from shore pickers and shore divers. Surveys from 1989-2007 (CDFG 2010), show that shore picking and divers from shore are an important component of the recreational abalone fishery, accounting for 75-92% of catch. We assumed estimates prior to 1983 accounted for only 25% of the recreational catch and adjusted them accordingly. This is considered conservative, given that catch estimates of red abalone account for as much as 7 times the commercial catch in the 1980s and that recreational catch estimates by Frey (1971) are nearly the same as the commercial landings.

Recreational clamming is a popular activity among the intertidal bays of California and for many species makes up the bulk of the total catch (Moore 2001a, 2001c). Catch estimates of clams are available for Humboldt Bay for 1975, 1977-1989 and 2008 (McVeigh *et al.* 2010), for Tomales Bay for 1962-1963 and 1989-1997 (CDFW, unpubl. data, provided by P. Kalvass) and for Morro Bay for 1979-1980 (Mello 1981). These data were used as anchor points to generate estimates of clam catches for 1950-2010 for Humboldt, Tomales and Morro Bay (see Appendix B). Estimates of effort and catches are not available for several other bays such as Bodega Bay, Drakes Estero and Elkhorn Slough, which also provide good recreational catches (Spratt 1982; Moore 2001a, 2001c) and are not included in our estimates.

1.2.2 - Washington

In addition to RecFIN and the data in Figueira and Coleman (2010), the following sources were used to reconstruct recreational catches for WA and are summarized in Table 4:

- Historical records of salmon and marine fish landed by the recreational fishery (WDFW, unpubl. data, provided by E. Kraig) for 1967-2010;
- Historical salmon landings data from the INPFC (1979) for 1946-1976, and the PFMC (1993, 2013) for 1950-2010;
- Historical records of recreational albacore catch from US CPFVs (Holts 1985); and
- Historical estimates of recreational Pacific Halibut landings from reports (Miller and Gotshall 1965; Skud 1975) and IPHC reports of assessment and research activities (RARAs) for 1991-2012 (Blood 1992-2009; Williams 2010, 2011; Hare 2012).

The PFMC (1993) has historical records of the number of chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*) and pink (*O. gorbuscha*) salmon landed at four major WA ports (Neah Bay, Le Push, Westport, and Ilwaco) from 1950 to 1990. Landings from these areas match with those from the same areas reported by the WDFW from 1967 to 1990; however, the PFMC historical records do not include landings from another nine sites in the Puget Sound Area. WDFW data indicate that landings from Puget Sound account on average for approximately 50% and 17% of annual landings of chinook and coho, respectively, between 1967-1976. INPFC catch statistics include landings from Puget Sound and the San Juan Islands and thus were used instead of the PFMC statistics from 1950-1965.

Coastal river catch for coho and chinook were available from 1976-2010 (WDFW, unpubl. data, provided by E. Kraig) and accounted for 1% of average annual landings for both species between 1976-1980. We thus assumed they account for 1% of total landings from 1950-1975 where there were no species-specific data available. This is may be a conservative assumption, as records from 1964-1976 (IPFNC 1979) show higher annual freshwater salmon landings for WA then our estimate. However, we chose not to use the IPFNC (1979) time series for 1964-1976 for two reasons: (1) This time series did not include a species breakdown and thus we were uncertain of what proportion was composed of coho and chinook; and (2) the IPFNC freshwater salmon totals for 1976 were 100,600 individuals and differed greatly from the freshwater totals of 16,000 individuals from WDFW for the same year.

The proportion of salmon caught in freshwater has steadily increased since the 1970s (see Figure 3) and it is unclear if this is primarily due to improved reporting of landings from river fisheries or management changes that have increased river landings over this period.

A variety of recreational shellfish data exist for WA and was obtained from WDFW:

- Dungeness crab (*Metacarcinus magister*) and red rock crab (*Cancer productus*) catches for select years between 1976-1995 (WDFW, unpubl. data, provided by E. Kraig) and for Dungeness crab from 1996-2010 (wdfw.wa.gov[4]);
- Spot prawn (*Pandalus platyceros*) catches from 1977 and 1980-2002 for Hood Canal and Puget Sound, Pacific oyster (*Crassostrea gigas*) catches from 1972-2001, and clam catches from 1972-1986 and 1990-2007 (WDFW, unpubl. data, provided by E. Kraig); and
- Pacific razor clam (*Siliqua patula*) catches for 1950-2010 (WDFW, unpubl. data, provided by D. Ayres).

These data were used in conjunction with U.S. Fish and Wildlife Service historical fishing license data to generate recreational estimates for WA from 1950-2010 (see Appendix B).

Table 4 - Sources of recreational catch estimates for marine fish in Washington State.

Years	Taxa: Ocean chinook, coho & pink salmon	Chum and sockeye salmon	Pacific halibut	Rockfish[c], lingcod, spotted spiny dogfish, walleye pollock, Pacific cod, sturgeon & albacore [d]	All others
1950-1961	INPFC (1979)	*Average annual catch from 1965-1974*	*Assumed 5 t based on 1965 catch*	*Average annual catch from last 5 years, 1975-1979*	*Estimated as 10% of total marine catch [e]*
1962-1964					
1965-1966		INPFC (1979*)*	Skud (1975)		
1967-1974	WDFW unpub. data	WDFW unpub. data			
1975-1976			WDFW unpub. data	WDFW unpub. data	
1977-1979			IPHC RARAs [b]		
1980				RecFIN	RecFIN
1981-1989				Figueira and Coleman (2010)	Figueira and Coleman (2010)
1990				*WDFW data when available and otherwise linear interpolation*	*Linear interpolation*
1991-1992					
1993-1995				Figueira and Coleman (2010)	
1996-2002					Figueira and Coleman (2010)
2003-2009				RecFIN	RecFIN
2010	RecFIN [a]				

[a] PFMC (2013) landings do not include Puget Sound, and thus we accepted the reported landings from RecFIN for 2010 for chinook and coho, for which we did not have data from WDFW. See appendix for details on coastal river catches of Coho and Chinook. [b] IPHC statistics were converted from net weights to wet weights using a conversion factor of 1.3 (FAO 2000; Williams 2012). [c] All catch was assigned as *Sebastes* spp. from 1950-1974, as there was little species specific information for this period. Catch between 1975 and 2010 was assigned to 11 major species (See Appendix B), with less commonly caught species being grouped as *Sebastes* spp. [d] Catch data from Holts (1985) was used for albacore catches from 1950-1982. Small deviations from this method were also used for estimations of black rockfish (*Sebastes melanops*), spotted spiny dogfish (*Squalus suckleyi)* and sturgeon (*Acipenser* spp.*)* for select years, the details of which are listed in Appendix B. [e] Other species accounted for another 10% of total reconstructed marine catch estimates from 1980-2010. We thus assumed an additional 10% of catch annually which was allocated proportionally to 20 taxonomic groupings based on the average catch composition from 1980-2010.

[4]Available at http://wdfw.wa.gov/fishing/shellfish/crab/estimates.html [Accessed: September 1, 2013]

1.2.3 - Oregon

Many of the same data sources used for WA were also used to reconstruct recreational catches for OR and are summarized in Table 5. Chinook and coho have historically accounted for the majority of the OR recreational fishery (Schindler *et al.* 2012). Sport catch statistics for salmon from 1978-2010 are available on the ODFW website (www.dfw.state.or.us/resources/fishing/sportcatch). These data along with ODFW (1977) summarize records of the number of chinook and coho landed in coastal rivers, the Colombia river and from ocean areas for 1967-2010. IPNFC (1979) provide similar estimates for inland and ocean salmon catch for 1949-1976 that were used to reconstruct coho and chinook catch for 1950-1966 (1950-1967 for freshwater catch).

The IPNFC (1979) data only report total salmon landings from the 1956-1963 and does not distinguish between freshwater or marine catch. We performed this separation of freshwater and marine catch based on the average proportions from 1950-1954 (27% marine and 73% freshwater) and the average proportions from 1964-1968 (68% marine and 32% freshwater). We used the 1950-1954 average proportion for 1955 and the 1964-1968 average proportion for 1963, and linearly interpolated between these ratios to estimate the proportion of freshwater and marine landed salmon for the intervening years. We applied a similar method to estimate the proportion of coho and chinook in the ocean landings from 1956-1963. We used the 1952-1955 average proportion for 1956 (51% coho and 49% chinook) and the 1964-1968 average proportion for 1963 (87% coho and 13% chinook), and linearly interpolated between these ratios to estimate the proportion of coho and chinook in the ocean landings for years in between.

INPFC (1979) statistics do not provide a species breakdown for inland salmon landings. To divide total freshwater salmon landings from 1950-1967 between coho and chinook, we used the average annual ratio of these species in the freshwater landings from the 1968-1977 ODFW (1977) statistics (i.e., the first 10 years of freshwater catch with a species breakdown) of 22% coho and 78% chinook. This ratio seems reasonable, given that the proportion of coho and chinook in freshwater landings is fairly consistent between 1967-1977, ranging from 15-31% for coho and 69-85% for chinook.

A variety of recreational shellfish data exist for OR and were obtained from ODFW:

- Dungeness crab catch for 1971 (ODFW 1977) and 2007-2011 (Ainsworth *et al.* 2012);
- Pacific razor clam catch from 1955-2010 (Link 2000; Hunter 2008; ODFW, unpubl. data, provided by M. Hunter); and
- OR bay clam catches for 1970-1983 (Gaumer 1984) and for 2008 (Ainsworth and Vance 2009).

These data were used in conjunction with U.S. Fish and Wildlife Service historical fishing license data to generate recreational estimates for OR from 1950-2010 (see Appendix B).

Table 5 - Sources of recreational catch estimates for marine fish in Oregon.

Years	Taxa: Chinook & coho salmon	Pink & chum salmon	Pacific halibut	All others [e]
1950-1957	INPFC (1979)	*Average of annual catch from 1976-1982 (for even years) and from 1973-1979 (for odd years)*	*Assumed 2 t based on 1958-1960 catch*	*Estimated as 58% of total marine catch* [f]
1958-1960			Miller and Gotshall (1965) [d]	
1961-1966			*Linear interpolation*	
1967	INPFC (1979) & ODFW (1977) [a]			
1968-1972	ODFW (1977)	ODFW data [c]		
1973				
1974			Skud (1975) [d]	
1975-1976			*Linear interpolation*	
1977			IPHC RARAs	
1978-1979	ODFW Sport Catch Statistics [b]			
1980				RecFIN
1981				Figueira and Coleman (2010)
1982-1989				
1990				*Linear interpolation*
1991-1992				
1993-2002				Figueira and Coleman (2010)
2003-2010				RecFIN

[a] INPFC (1979) data was used for freshwater landings and ODFW (1977) was used for marine landings.
[b] Available at: http://www.dfw.state.or.us/resources/fishing/sportcatch. No data was available for 1994 coastal and Colombia river fall chinook catch and these were estimated using the average of annual landings from 1990-1994 and 1995-1998 for fall chinook. [c] Pink and chum salmon (*Oncorhynchus* spp.) are grouped together in ODFW data from 1978-2009. These catches are not disaggregated to individual species in our estimates. [d] Skud (1975) and Miller and Gotshall (1965) estimates are for CA and OR. Based on proportions observed in IPHC estimates from 1991-2010, we assigned 3% of this catch to CA and 97% to OR. [e] Albacore catch between 1975-1991 and for 2003 is estimated based on ODFW data (ODFW 1977; www.dfw.state.or.us/MRP/sportalbacore); as it was unreported in Figueira and Coleman (2010) and RecFIN catch statistics. [f] Other species account for another 58% of total reconstructed marine catches from 1980-2010. We thus assumed an additional 58% of catch annually which was allocated proportionally to 23 taxonomic groupings based on the average catch composition from 1980-2010. The recreational albacore fishery began circa 1975 and had low catches at this time (Holts 1985), and thus we did not allocate any catch as albacore from 1950-1974.

1.3 - Discards

In the context of this study, discards are defined as any catch of a fishery, recreational or commercial, that is not landed. We include discards of fish that are released both alive and dead, and where possible have incorporated post-release mortality rates. We estimated discards for several major US west coast fisheries, which were divided into the following groups (summarized in Table 6):

- Non-hake groundfish bottom trawl;
- California halibut;
- Sablefish fixed gear;
- Pacific halibut;
- Pacific hake;
- Ocean shrimp;
- Salmon; and
- Non-salmon recreational fisheries.

Highly migratory species (i.e., swordfish and tuna) and small pelagic fisheries are not included in our estimates but are briefly discussed.

Table 6 - Grouping of major US Pacific coast fisheries considered in discard estimates.

Fishery	Target species	Predominant gear types
Non-hake groundfish	Flatfish [a] (Pleuronectiformes), rockfish (*Sebastes* spp.), Pacific cod (*Gadus macrocephalus*), sablefish (*Anoplopoma fimbria*), lingcod (*Ophiodon elongatus*), spotted spiny dogfish (*acanthis suckleyi)*, and thornyheads (*Sebastolobus spp.*)	Bottom trawl
California halibut	California halibut	Bottom trawl
Pacific hake	Pacific hake (*Merluccius productus*)	Midwater trawl
Pacific halibut	Pacific halibut (*Hippoglossus stenolepsis*)	Bottom longlines
Sablefish fixed gear	Sablefish (*Anoplopoma fimbria*)	Bottom traps & longlines
Ocean shrimp	Ocean shrimp (*Pandalus jordani*)	Trawl
Salmon	Salmon (*Oncorhynchus* spp.*)*	Trolling, gillnets & seines
Recreational	Various	Hook and line

[a] Excluding Pacific halibut and California halibut

Comprehensive discard mortality estimates of groundfish and some non-groundfish species are available for most of the above fisheries from 2005-2011 (Hastie and Bellman 2006, 2007; Bellman *et al.* 2008; Bellman *et al.* 2010a; Bellman *et al.* 2010b; Bellman *et al.* 2011, 2012) and for Pacific halibut from 2002-2011 (Jannot *et al.* 2012). These data are provided by the Northwest Fisheries Science Center (NWFSC) and are referred to throughout as the NWFSC discard estimates. Discard estimates for Pacific halibut are available in multiple reports. Here we use discard mortality estimates from groundfish fisheries by Jannot *et al.* (2012) for 2002-2010 and from the IPHC (Hare 2012) for the Pacific halibut fishery. Estimates of mortality from incidental bycatch and selective fisheries from commercial and recreational salmon fisheries are available from 1999-2012 from the PFMC stock assessment and Fishery Evaluation (SAFE) documents (PFMC 2000-2013). Detailed observer discard data are also available from NMFS Southwest Fisheries Science Centre (SWFSC) for the swordfish drift gillnet fishery from 1990-2010 and the longline fishery from 2001-2004 (swr.nmfs.noaa.gov). Otherwise, limited information regarding discards or bycatch is available for most west coast fisheries and, where available, additional sources of information used are discussed in the relevant sections.

NWFSC discard estimates apply mortality rates to discards of sablefish, lingcod and Pacific halibut in the groundfish bottom trawl, California halibut and sablefish fixed gear fisheries (Table 7). We use the NWFSC discard mortality estimates where available, rather than total discards, and adjust bycatch rates for earlier years accordingly. Commercial and recreational bycatch estimates by the PFMC also apply estimates of mortality rates for incidental bycatch and mark selective fisheries, and these estimates were

also used rather than total discards. We also applied discard mortality rates to recreational catch-and-release discards (**Table 7**). For other species and fisheries, where there was little information about the proportion of discards released alive or dead, we did not apply any post-release mortality rates, essentially assuming 100% mortality. This is clearly not the case for all the fisheries assessed (particularly the sablefish and halibut fixed gear fisheries) and species in the discards; however, a detailed analysis of post-release mortalities for all fisheries is beyond the scope of the present work.

Table 7 - Discard mortality rates (%) in U.S. west coast fisheries considered in discard estimates.

Fishery & gear	Bycatch species	Discard mortality (%)	Source
Non-hake groundfish	Pacific halibut	20-90	1
	Sablefish & lingcod	50	2
Sablefish pots	Pacific halibut	18	1
	Sablefish	20	2
Sablefish longlines	Pacific halibut	16	1
	Sablefish	20	2
California halibut	Lingcod	50	2
Pacific halibut	Pacific halibut	25	3
Commercial troll salmon	Salmon	26	4
Recreational salmon	Salmon	14-28	4
Non-salmon recreational	All species	2-66	See Table 18

Sources: 1. Jannot *et al.* (2012). Discard mortalities for groundfish bottom trawl are based on assessments of viability by the observer. 2. Hastie and Bellman (2006, 2007); Bellman *et al.* (2008); Bellman *et al.* (2010a); Bellman *et al.* (2010b); Bellman *et al.* (2011, 2012). 3. Gilroy and Hare (2012). 4. PFMC (2000-2013).

We calculated fishery specific discards to landings (D/L) ratios from the NWFSC discard and landings data and other available sources. We used these D/L ratios to estimate discards for years where discard data were not available (thus assuming proportionality), the methods of which are summarized in the relevant sections. D/L ratios were calculated as follows:

$$D/L = \textit{Total dead discarded weight} / \textit{Landed weight of target species}$$

Over the last six decades, management, economic and technological changes have influenced these fisheries and impacted the amount of fish discarded. We attempted to consider these changes in our discard estimates; however, we acknowledge that there is considerable uncertainty for many years in which data are limited. This is particularly the case prior to 1979, where we found zero records of discard or bycatch information.

Most discard estimates available (e.g., IPHC RARAs; Harrington *et al.* 2005; NWFSC estimates; Bellman and Heery 2013) do not specify the uncertainty involved therein. Since these discard data were used to calculate D/L ratios that were extrapolated to the earlier period, it is thus difficult to quantify uncertainty using traditional statistical methods. Alternatively, we quantify high and low ranges of the reconstructed discards by applying the lowest and highest D/L ratios observed for a given period for the various fisheries assessed (Table 8).

Table 8 - Range of *D/L* ratios estimated for different fisheries which were used to estimate a high and low range for discards.

Fishery	Period	Low value	High value	Value used
Groundfish bottom trawl	1950-1995	0.380	0.58	0.450
	1996-2001	0.290	0.74	0.450
California halibut	1950-2006	2.100	3.70	2.900
Pacific halibut – non-halibut discards [a]	1950-2010			0.150
Pacific halibut - halibut discards	1950-1973	0.004	0.03	0.010
Sablefish pots - WA and OR	1950-2004	0.050	0.36	0.180
Sablefish pots - CA	1950-2004	0.040	0.37	0.190
Sablefish longlines - WA and OR	1950-2004	0.260	0.63	0.500
Sablefish longlines - CA [b]	1950-2004	0.130	0.48	0.450
Pacific hake - shoreside hake	1965-2004, 2007-2010	0.015	0.10	0.060
Pacific hake - at-sea	1990-2004	0.004	0.02	0.008
Ocean shrimp discards	1950-1988	0.490	3.30	1.010
	1989-2000	0.750	1.61	1.280
	2001-2002	0.020	1.61	0.700
	2003,2004,2006	0.020	0.30	0.120
	2005	0.070	0.13	0.090
Chinook - commercial troll	1950-2000	0.120	0.33	0.180
Chinook - recreational	1950-1999	0.100	0.34	0.140
Coho - commercial troll [c]	1950-1999	0.170	0.89	0.430
Coho - recreational	1950-1998	0.120	0.64	0.430
Non-salmon recreational discards - WA	1950-1980	0.030	0.09	0.060
Non-salmon recreational discards - OR	1950-1980	0.030	0.14	0.070
Non-salmon recreational discards - CA	1950-1981	0.010	0.01	0.010

Notes: [a] We only had one *D/L* ratio (0.15) for non-halibut bycatch in the halibut directed fishery and thus a low and high range are not given. [b] Excluded 2007 outlier value. [c] Excluded 2002 and 2003 outlier values.

1.3.1 - Non-hake groundfish bottom trawl fishery

Observer coverage of groundfish fisheries on the U.S. west coast started in 2001, and averaged 13% coverage for limited entry bottom trawlers during the first year (NWFSC 2004). Since this time, observer coverage has steadily increased and since 2005 has been at a level that allows the NWFSC to provide discard and bycatch estimates for the entire groundfish bottom trawl (GBT) fishery (Hastie and Bellman 2006). A recent study by Bellman and Heery (2013) updated these estimates of groundfish discards from 2002-2009. We use the most recent Bellman and Heery (2013) discard estimates where available and NWFSC discard estimates for other taxa and years not included in the recent Bellman and Heery (2013) study (Table 9). NWFSC discard estimates include a discard mortality rate for Pacific halibut, lingcod and sablefish, whereas only total discards are shown in Bellman and Heery (2013). To maintain consistency with other NWFSC estimates used, we apply a 50% mortality rate to sablefish and lingcod discards from 2002-2010.

Table 9 - Sources used for estimating discards for different taxa in the non-hake groundfish bottom trawl fishery from 2002-2010.

Taxa	Period	Source
Pacific halibut	2002-2010	Jannot *et al.* (2012)
Crabs	2005-2010	Hastie and Bellman (2006-2007); Bellman et al. (2008-2011)
Other groundfish	2002-2009	Bellman and Heery (2013)
	2010	Bellman *et al.* (2011)

Prior to this, there are two studies which provide comprehensive information on discarding by US west coast trawl fisheries: 1) a 1985-1987 study by Pikitch *et al.* (1988) evaluating the effectiveness of trip limits; and 2) a 1988-1990 study by Pikitch *et al.* (1990), which investigated the impacts of different cod-end mesh sizes.

At-sea sampling for the 1985-1987 study occurred under typical commercial fishing conditions onboard 40 different vessels operating out of OR, and fishing both in OR and WA waters (Pikitch *et al.* 1988; Pikitch *et al.* 1998). Vessels sampled in the 1988-1990 study did not operate under normal fishing conditions as they used experimental gears and were allowed to exceed trip weight limits under an experimental fishing permit (Pikitch *et al.* 1990; Pikitch *et al.* 1998). As a result, we only used results from the 1985-1987 study to estimate discard rates for the GBT fishery.

We utilize unpublished discard data (provided by J. Wallace, NOAA) from the Pikitch *et al.* (1988) study of 1381 trawls, each of which was assigned to one of five trawl-fishing strategies: 1) bottom rockfish, 2) deepwater dover sole, 3) nearshore mixed species, 4) midwater, and 5) shrimp (Pikitch *et al.* 1988).

The bottom rockfish, deepwater Dover sole and nearshore mixed species bottom trawl strategies are not highly selective and target multiple groundfish species. These trawl strategies are considered indicative of the GBT fishery and we use data from their 1108 trawls to calculate *D/L* ratios from 1985-1987 (Appendix C).

We sorted NMFS commercial landings by bottom trawl gear to determine the primary target species of the groundfish bottom trawl fleet. Three gear types listed in the NMFS data were considered representative of this fishery: "otter trawl bottom, fish", "otter trawl bottom, other" and "trawls, unspecified". This indicated that the target species from Table 6, Pacific hake and ocean shrimp accounted for 98% of the landed catch by bottom trawls from 1950-2010.

We excluded Pacific halibut, California halibut, Pacific hake and ocean shrimp from the GBT target species as discards from these fisheries are assessed separately in this study. Select species of rockfish[5] and flatfish[6] taxa represent 99% of the landed bottom trawl rockfish and flatfish catch by weight and value from 1950-2010 (NMFS commercial data) and are considered the primary target groups; however, much of the landings are recorded only as "soles" (prior to 1972) or "rockfish" in the commercial landings data. Because of this, it is difficult to know exactly which species were landed and for simplicity we include all rockfish and flatfish taxa in our target landings denominator, resulting in a more conservative *D/L* ratio.

We estimated *D/L* ratios for 1985-1987 and 2002-2010 for the multispecies groundfish bottom trawl fishery (Appendix C). NWFSC estimates include a discard mortality rate of 50% for lingcod and sablefish

[5] Bocaccio rockfish, canary rockfish, chilipepper rockfish, widow rockfish, yellowtail rockfish, Pacific Ocean perch and unidentified rockfish. Unidentified rockfish comprised the bulk of commercial bottom trawl catch (68%) between 1950-2010 and along with Pacific Ocean perch, were the only rockfish taxa recorded prior to 1979.

[6] Arrowtooth flounder, Dover sole, English sole, petrale sole, sand sole, starry flounder, rex sole and unidentified soles and flounders.

(Bellman *et al.* 2012). NWFSC estimates for Pacific Halibut, apply a discard mortality rate of 22%, 55% or 90% to discarded fish based on assessments of viability by the observer (Jannot *et al.* 2012). Based on these assessments, approximately 48% of estimated gross discards of Pacific halibut were estimated to have died in the 2011 bottom trawl fishery (Jannot *et al.* 2012). Here we apply a similar discard mortality of 50% for lingcod, sablefish and Pacific halibut when calculating the 1985-1987 *D/L* ratios.

We took the weighted average (by number of hauls) of *D/L* ratios from 1985-1987 to estimate a *D/L* ratio for this time period. *D/L* ratios from 1985-1987 ranges from 0.38-0.58 (see Appendix C), but were based on different numbers of hauls observed, and thus a weighted average of these years may be the best approach to estimate discards for the entire GBT fleet. We also estimated *D/L* ratios from 2002-2010 by dividing the discard estimates from sources in Table 9 by the landings of target species from 2002-2010 (Bellman *et al.* 2011; Bellman and Heery 2013).

We took the average of the 2002-2010 *D/L* ratios (Table 10) and applied these to NMFS commercial landings of target species (Table 6) by bottom trawl gear to estimate discards in earlier years. This is considered conservative since discard rates have trended downwards from 2002-2009 (Bellman and Heery 2013).

Commercial landings of skates (Rajiformes) from bottom trawls are dominated by the longnose skate (*Raja rhina*) and have increased substantially since 1996 due to increased demand in the Asian market (Gertseva and Schirripa 2008). Gertseva and Schirripa (2008) assume lower discard rates of skates since 1996 and we make a similar assumption here. We thus apply the 1985-1987 *D/L* ratio, which had a higher concentration of skates, to estimate discards from 1950 to 1995 and the 2005-2010 *D/L* ratio to estimate discards from 1996-2001.

Table 10 – *D/L* ratios used to estimate discards from groundfish bottom trawl fisheries from 1950-2004.

Period	1950-1995	1996-2001
D/L ratio	**0.45**	**0.45**
Species composition of discards by weight (%)		
Skates	13.3	9.7
Spotted spiny dogfish	14.5	8.5
Pacific hake	13.3	17.2
Other gadiformes	0.6	0.4
Rockfish	18.9	6.5
Thornyheads	4.3	5.1
Lingcod [a]	<0.1	1.1
Arrowtooth flounder	10.2	11.2
Dover sole	2.4	8.5
English sole	1.2	3.1
Pacific halibut [a]	<0.1	2.5
Petrale sole	0.3	1.2
Other flatfish	7.3	7.2
Sablefish [a]	4.5	3.9
Other marine fish	5.0	6.0
Crabs [b]	2.5	7.8
Others	1.7	

[a] D/L ratios are for total discards with the exception of sablefish, lingcod and Pacific halibut, which incorporate discard mortality rates. [b] Crab D/L ratio was estimated based on 2005-2010 data as there were none from 2002-2004.

1.3.2 - California halibut

NWFSC discard estimates from the limited entry and open access California halibut fishery are available from 2007-2011. We used these data to calculated annual *D/L* ratios from 2007-2011, which ranged from 2.1 to 3.7. We took the average *D/L* rate from 2007-2011 (Table 11) and applied this to NMFS commercial catches of California Halibut from bottom trawl gear to estimate discards from 1950-2006.

Table 11 - *D/L* ratios used to estimate discards from the California halibut bottom trawl fishery from 1950-2006,

D/L ratio	2.9
Species composition of discards by weight (%)	
Skates and rays	20.1
Sharks	1.8
California halibut	5.9
Other flatfish	4.8
Other marine fish	20.0
Dungeness crab	47.3

1.3.3 - Pacific halibut

In CA, WA and OR, 95% of commercial Pacific halibut landings are caught from bottom longlines (Harrington *et al.* 2005). Commercial landings data are available from the International Pacific Halibut Commission (IPHC) and NMFS. IPHC data records halibut catch based on where the fish are caught whereas NMFS data records catch based on where the fish was landed or reported from (Harrington *et al.* 2005; www.st.nmfs.noaa.gov). Here we used the NMFS commercial data to maintain consistency in our methods.

We used the 2002 expanded longline bycatch data from Harrington *et al.* (2005) to estimate a *D/L* ratio of 0.15 for non-target species in the Pacific Halibut Fishery (Table 12). This ratio excludes discards of Pacific halibut, which we obtained from IPHC data. We multiplied this ratio by the NMFS commercial landings of Pacific Halibut by longline gear to estimate discards of non-target species from 1950-2010.

The IPHC provides discard mortality estimates of sublegal (U32) Pacific halibut that are discarded in the directed commercial halibut fishery 1974-2010 (Gilroy and Hare 2012). In order to remain consistent in our methods, which reconstruct catch based on where it was landed and not necessarily where it was caught, we allocate the U.S. discards proportionally among WA, OR, CA and AK in accordance with the reported annual NMFS commercial landings for these states.

To estimate U32 halibut discards prior to 1974, we apply a *D/L* ratio of 0.01 (calculated as the average ratio of undersized halibut discards to IPHC commercial landings for OR, WA and CA) to NMFS commercial longline landings of Pacific Halibut.

Table 12 - *D/L* ratios used to estimate non-halibut discards from the Pacific Halibut fishery from 1950-2010.

D/L ratio	0.15
Species composition of discards by weight (%)	
Spotted spiny dogfish	21.7
Skates	11.1
Other sharks	20.4
Rockfish	1.6
Lingcod	3.7
Arrowtooth flounder	7.2
Other flatfish	0.3
Sablefish	33.1
Other marine fish	0.9

1.3.4 - Sablefish fixed gear

Commercial domestic landings were small (< 5000 t) and were mostly caught by line and trawl fisheries until the 1970s (NMFS landings data; Stewart *et al.* 2011). NMFS commercial landings of sablefish indicate they are caught mainly by trawl (47%), lines (34%) and pot (17%) gear from 1950-2010. Here, we discuss estimates of discards from the sablefish fixed gear (i.e., lines and pots) fishery. Discards from trawls are included in GBT fishery estimates.

NWFSC discard estimates are available for the nearshore sablefish fishery from 2005-2010. We used these estimates to generate annual *D/L* ratios for the pot and longline fisheries by region from 2005-2010. We took the average *D/L* ratios (weighted by the number of sets observed in a given year) for 2005-2010 (Table 13) and applied these to NMFS commercial landings of sablefish by pot and longline gear from 1950-2004. For most years, the NWFSC discards and landings data are separated by regions north and south of $40^{0}10'$ N Lat. *D/L* ratios for the north were applied to Oregon and Washington landings while *D/L* ratios for the south were applied to California landings[7].

Table 13 - *D/L* ratios used to estimate discards for Sablefish fixed gear fishery from 1950-2004.

Gear	Longline		Pots	
Region	**N. Pacific**	**S. Pacific**	**N. Pacific**	**S. Pacific**
D/L ratio	**0.50**	**0.45**	**0.18**	**0.19[b]**
Species composition of discards by weight (%)				
Skates and rays	10.3	9.7	<0.1	0.0
Spotted spiny dogfish	27.8	15.7	3.9	1.5
Pacific cod and hake	0.1	0.3	<0.1	0.0
Rockfish	3.7	2.9	1.1	1.3
Thornyheads	0.4	1.7	0.1	0.0
Lingcod	0.8	0.4	3.7	2.6
Arrowtooth flounder	9.2	4.0	1.7	0.8
Pacific halibut [a]	6.1	-	-	-
Other flatfish	0.3	0.8	0.6	1.0
Sablefish	25.8	37.5	80.8	83.9
Other marine fish	15.4	26.4	3.1	4.2
Crabs	<0.1	0.6	4.8	4.7

[a] The Pacific halibut discards used to estimate D/L ratios were from Jannot *et al.* (2012) and were attributed to longline gear in the N. Pacific.
[b] Excludes 2007 data for which there was no pot-specific discard information for the S. Pacific

1.3.5 - Pacific hake

The domestic Pacific Hake fleet can be broken down into two sectors; those delivering to at-sea processors and those delivering to shore-side processors. Shore-side processing on the Pacific west coast has been active since the late 1960s, with catch being landed at shore for processing (Nelson Jr. 1985). NMFS commercial landings for the at-sea processing fishery are first listed in 1990, although U.S. trawlers are known to have operated in joint venture agreements with Soviet factory trawlers since the late 1970s (Nelson Jr. 1985).

NWFSC discard estimates are available for at-sea hake fisheries from 2005-2011 and for shore-side hake fisheries for 2005, 2006, and 2011 (Hastie and Bellman 2006, 2007; Bellman *et al.* 2008; Bellman *et al.* 2010a; Bellman *et al.* 2010b; Bellman *et al.* 2011, 2012; Jannot *et al.* 2012). We used this information to generate annual *D/L* ratios for at-sea and shore-side hake fisheries for years with data. Unpublished data

[7] We excluded NWFSC 2011 discard data from our calculations of *D/L* ratios as it was not separated by regions (i.e., North and South Pacific).

from a 1985-1987 survey by Pikitch *et al.* (1988) includes landings and discards data from four midwater trawls which were actively targeting and landing Pacific Hake. These trawls were considered representative of the shore-side hake fishery and had a *D/L* ratio of 0.06, with Pacific hake composing 99.6% of total discards over the four trawls. This correlates well with the shore-side *D/L* ratio in Table 14 providing some justification to its use to estimate discards for earlier years.

We take the average of the 2005-2010 *D/L* ratios for the at-sea fishery (Table 14) and apply this to NMFS at-sea landings of Pacific hake to estimate discards from 1990-2004. We used the average of the 2005 and 2006 *D/L* ratios for the shore-side fishery (Table 14) and apply this to NMFS shore-side landings of Pacific hake to estimate discards from 1965-2010 and 2007-2009. We excluded 2011 discard data from our estimates of the shore-side *D/L* ratio as the fishery switched to Individual Fishing Quotas (IFQ) in that year. Due to this change, we assumed discard trends in 2011 were not a good representation of trends in earlier years. We assumed that the Pacific Hake landed prior to 1965 was mostly bycatch from other fisheries (Nelson Jr. 1985) and a discard rate was not applied to these landings.

Table 14 - *D/L* ratios used to estimate discards for Pacific Hake at-sea and shore-side fisheries.

Years	**1990-2004**	**1965-2004, 2007-2010**
Fishery	**At-sea**	**Shore-side**
D/L ratio	**0.008**	**0.06**
Species composition of discards by weight (%)		
Pacific hake	44.4	96.8
Spotted spiny dogfish	35.8	<0.1
Rockfish	16.9	3.1
Others	2.9	<0.1

1.3.6 - Ocean shrimp

A variety of sources were used to estimate discards for the west coast ocean shrimp fishery:

- NWFSC discard estimates from 2007 to 2011 (Bellman *et al.* 2008; Bellman *et al.* 2010a; Bellman *et al.* 2010b; Bellman *et al.* 2011, 2012);
- Logbook and bycatch data from the 2005 OR ocean shrimp fishery for different bycatch reduction devices (BRDs), presented by (Hannah and Jones 2007);
- Seven datasets from control nets from research surveys between 1981 and 2000 compiled by (Hannah and Jones 2007); and
- Bycatch and landings data from a 1979 survey by (Demory *et al.* 1980).

We used these sources to generate *D/L* ratios (summarized in Table 16), which were applied to NMFS commercial landings of ocean shrimp to estimate discards from 1950-2006. With the exception of the NWFSC discard estimates from 2007-2011, data sources did not indicate the proportion of bycatch which was landed and what may have been discarded. NWFSC discard estimates indicate that on average 1% of ocean shrimp catch is discarded, and thus we assume 1% of shrimp is discarded when calculating *D/L* ratios from 1979 to 2005. Otherwise, *D/L* ratios prior to 2007 include landed bycatch of marketable groundfish. Different *D/L* ratios were applied to different periods based on historic developments in the fishery, as explained in Table 16

Table 15 - *D/L* ratios used to estimate discards for Ocean shrimp fisheries from 1950-2006.

Applied to Period	1950-1988	1989-2000	2001-2002	2003, 2004, 2006	2005
	Pre-BRD period		Transition period	Post-BRD period	
D/L ratio [a]	**1.01**	**1.28**	**0.70**	**0.12**	**0.09**
Species composition of discards by weight (%)					
Skates	0.5	0.6	0.4	0.1	0.1
Spotted spiny dogfish	-	-	0.2	0.4	-
Smelts	22.3	9.1	5.5	1.8	7.8
Pacific hake	31.5	64.1	61.5	58.9	44.0
Rockfish	14.3	3.3	3.7	4.0	12.5
Thornyheads	0.3	0.1	0.1	<0.1	0.1
Lingcod	0.9	0.6	0.3	<0.1	-
Arrowtooth flounder	2.6	2.0	1.7	1.5	1.7
Dover sole	2.2	1.0	0.9	0.8	1.7
Pacific halibut	0.2	3.2	1.6	<0.1	-
Pacific sanddab	<0.1	0.7	0.5	0.2	0.9
Petrale sole	0.1	-	0.1	0.1	-
Slender sole	3.4	2.8	4.4	5.9	10.3
Rex sole	2.0	1.2	1.3	1.5	4.4
Other flatfish	4.4	0.4	4.0	7.5	1.2
Hagfish	0.1	0.2	0.1	0.1	0.5
Sablefish	7.9	2.8	1.4	0.1	0.1
Other marine fishes	5.7	6.9	4.9	3.0	3.8
Dungeness crab	-	-	<0.1	<0.1	-
Ocean shrimp	1.6	0.9	7.4	13.9	10.9

[a] D/L ratios and sources for individual years are shown in Appendix C. The 1950-1988 and 1989-2000 D/L ratios were calculated as weighted averages, based on the number of research hauls, of annual D/L ratios during these periods. The 2003, 2004, 2006 ratio was calculated as the average of the ratios from 2005 and 2007-2011. The 2001-2002 ratio was calculated as the average of 1989-2000 and 2003, 2004, 2006 ratio. The 2005 ratio was calculated using catch composition data for different BRDs weighted by the number of trips by vessels using these BRDs, calculated from (Hannah and Jones 2007)

We did not have estimates of total discards for all years, but rather catch compositions from surveys from 1979-2000. In this case, *D/L* was calculated as follows:

$$D/L = B / S$$

Where B = the percentage of non-ocean shrimp species in the catch by weight, and S = the percentage of ocean shrimp in the catch by weight. As we assumed that 1% of the ocean shrimp caught was discarded, this then becomes:

$$D/L = \frac{(B + 0.01S)}{(S - 0.01S)}$$

Table 16 - Justification for *D/L* ratios used for different years in the ocean shrimp fishery.

Time Period	Justification
1950-1988	Due to lack of additional information, we assumed the discard data from surveys in 1979, 1981 and 1986-1987 provided the best estimates of discards from 1950-1989
1989-2000	Discards increased in 1989 and through the 1990s due to an increased abundance of Pacific hake in the shrimp fishing grounds (Hannah *et al.* 1996) and are expected to have remained high until 2001 when BRDs were implemented on a large-scale
2001-2002	BRDs were mandatory for only part of the season in 2001 and 2002 (Hannah and Jones 2000) and thus we assumed an average of the pre-BRD and post-BRD D/L ratios
2003-2004, 2006	There has been a large decrease in bycatch since BRDs became mandatory in 2003 (Hannah and Jones 2007).
2005	Catch compositions for different BRDs and trip numbers for shrimp vessels in Oregon are available for 2005 (Hannah and Jones 2007). The weighted average % catch composition was assumed the best representation for the entire west coast.
2007-2010	Used NWFSC discard estimates

Historically, only certain marketable taxa were retained for sale and some processing plants are reported to have not accepted bycatch from the shrimp fishery. The retention of bycatch on any particularly trip is highly variable and depends on a variety of factors such as the quantity of fish being caught, space onboard the vessel and market demand (Robert Hannah, ODFW, pers. comm.). Based on consultation with Robert Hannah (ODFW), ex-vessel prices from the Pacific Fisheries Information Network (pacfin.psmfc.org) and landed bycatch reported by Demory *et al.* (1980), we considered lingcod, sablefish, yellowtail rockfish, canary rockfish, rougheye rockfish, Dover sole, English sole, petrale sole and rex sole to be the most likely species of bycatch to have been landed.

To correct for landed bycatch of marketable species and potential double-counting in our discards we made an adjustment. We subtracted NMFS commercial landings caught by "Otter Trawl, Shrimp" for marketable species of groundfish from our estimated discards from 1950-2006. This catch was considered to be the landed bycatch of groundfish from the ocean shrimp fishery and amounted to slightly over 30,000 t from 1950-2006.

1.3.7 - Salmon

Salmon are discarded for three main reasons in commercial trolling and recreational fisheries: (1) regulatory discards of salmon that are below the legal size limit, (2) regulatory discards of legal sized fish in directed fisheries for other species (i.e., coho caught in chinook-directed fisheries), and (3) discards of non-marked fish in mark-selective fisheries which allow only for the retention of hatchery fish. Discarding of other non-salmon species is low (Harrington *et al.* 2005).

Estimates of bycatch mortality (in numbers of fish) from commercial troll and recreational salmon fisheries are available in the PFMC Stock Assessment and Fishery Evaluation (SAFE) reports from 1999-2012 (PFMC 2000-2013). These reports provide estimates of all three of the above sources of discards and apply a post-release mortality rate to estimate the portion of dead discards (Table 7). They also assume a drop-off mortality rate of 5% of all encounters, to account for predation of hooked fish that do not reach the boat.

We summed the total annual discards and landings for recreational and commercial sectors from 1999-2012 divided total discards by total landings to estimated *D/L* ratios for coho and chinook fisheries. Coho landings were reported in both tables for mark-selective and incidental discards for select areas, and were carefully assessed to avoid double counting of landings when estimating *D/L* ratios for all discards. We took the median value of these *D/L* ratios (Table 17), and multiplied these by the commercial troll landings (obtained from the NMFS database) and reconstructed recreational landings of coho and chinook to estimate discards from the salmon fishery for earlier years where no discard estimates were available. As we had no way of distinguishing between fish caught in mark-selective fisheries, we applied the *D/L* values calculated from total discards.

Table 17 - *D/L* ratios for coho and chinook fisheries in western U.S. waters, calculated based on discard mortality and landings estimates from PFMC SAFE reports for 1999-2012.

Fishery and discard type	Years with data	Median D/L ratio	Range
Chinook:			
Commercial troll - incidental	2001-2012	0.18 [b]	0.12 - 0.33
Recreational - incidental	2000-2012	0.12	0.10 - 0.20
Recreational - mark selective	2003-2012	0.56	0.14 - 0.99
Recreational - all discards	2000-2012	0.14 [b]	0.10 - 0.34
Coho:			
Commercial troll - incidental	2000-2012	0.39	0.13 - 1.85
Commercial troll - mark selective	2000-2012	0.39	0.14 - 12.15
Commercial troll - all discards	2000-2012	0.43 [b]	0.17 - 2.69
Recreational - incidental	2000-2012	0.25	0.14 - 0.42
Recreational - mark selective	1999-2012	0.23	0.10 - 0.38
Recreational - all discards	1999-2012	0.43 [b]	0.12 - 0.64

[a] Numbers of fish were converted into weights using RecFIN mean values of landed fish and released fish for WA from 2004-2012, both of which are 5.5 kg for chinook and 2.4 kg for coho.
[b] Denotes values applied to landings to estimates discards for earlier years

It is possible that as regulations in U.S. fisheries have tightened, the amount of regulatory discards from salmon fisheries will have increased in recent years, in which case our *D/L* ratios would overestimate discards in the earlier period. However, size regulations for salmon fisheries have existed throughout most of the period assessed (PFMC 1985), and we found little information on discards from salmon fisheries prior to the late 1990s. Managers with more detailed knowledge of the history of specific salmon fisheries may provide better estimate for certain areas; however, this is currently beyond the scope of our work.

The *D/L* ratios in Table 17 are in a similar range as those estimated by Harrington *et al.* (2005) and PSC (2011) for salmon fisheries on the Pacific west coast during the same time period. We feel this is a reasonable estimate and that total salmon discards are conservative given that we do not include discards from salmon fisheries using gillnets, seines and other gears, which account for nearly half of NMFS commercial coho and chinook landings from 1950-2010. We assumed average weights of 5.5 kg and 2.4 kg for chinook and coho discards, respectively, (based on RecFIN mean weights of released fish from 2004-2010 for WA) to convert the 1999-2010 PFMC discards into weights.

1.3.8 - Non-salmon recreational fisheries

In general, there is thought to be low discards in the recreational sector and that discards are composed mainly of unwanted species, such as sharks (PFMC 2011a) and fish of sub-legal sizes (Harrington *et al.* 2005). Estimates of discards are recorded in the RecFIN database in two ways: (1) B1 catch; fish that are released dead, used for bait or filleted on board, and (2) B2 catch; fish that are released alive. The B1 catch estimates were included in the recreational landings estimates, as it was not possible to disaggregate dead discards from filleted or bait fish.

Estimates of fish that are released alive (B2) by recreational anglers are available from 1980-1989 and 1993-2010 from the RecFIN database. Estimates by weight and the number of released fish are available from 2004-2010, while estimates from 1980-1989 and 1993-2003 include only the number of released fish. Average weights of different species or higher order taxa of released fish are available by year and state from 2004-2010. We used the mean average weights from 2004-2010 for specific taxa to convert the

1980-2003 estimates from numbers of released fish into weights. State specific mean weights were used where available, and when not available we used the mean weight for total west coast landings. Where mean weights were not available for released species we used the mean weight of landed fish from 1989-2003 (RecFIN). This is an important distinction as anglers are likely to discard smaller fish than those landed and thus one would expect the mean weights of landed fish to be larger. This is not expected to have substantially influenced our results, since the portion of total B2 catch that was converted this way accounted for only 1% of our total estimated weight of discards from 1981-2003. We excluded the data from 1980, as estimates for this year were over 20 times the average from 1981-2003, suggesting that there may be an error in the 1980 values.

We then applied post-release mortalities to estimate the portion of released fish (B2) that do not survive. There is little known about the long-term survival of many fish species that are caught and released in recreational fisheries. Discard mortalities vary by species depending on many factors such as: gear type, handling and release techniques, playing time, hook size, hook type, fish size, water temperature, and capture depth. For example, discard mortalities for sharks are thought to be low (PFMC 2011a), whereas discard mortalities for some species of rockfish may be higher than 60% due to barotrauma (Jarvis and Lowe 2008; PFMC and NMFS 2009). A meta-analysis of 274 catch-and-release mortality estimates for 48 species targeted by recreational fisheries in the U.S. found estimates ranging from 0-95% (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005).

Given all of these factors, we recognize that there is uncertainty with estimating post-release survival rates that may be applied to west coast recreational fisheries from 1950-2010. Furthermore, many of the studies that are available are based on limited sample sizes and thus there is risk with extrapolating these results to larger populations. Nonetheless, this exercise has been attempted here as we feel this provides more valuable information than the alternative of listing only total discards (dead and alive).

Estimates of post-release mortality were compiled from a variety of sources (Table 18) Where available, we applied species-specific post-release mortality rates for hook and line fisheries to the major taxa discarded by recreational fisheries. When these were not available, we used a median value of 11% for teleost species, obtained from the meta-analysis of the 274 studies conducted by Bartholomew and Bohnsack (2005) and Muoneke and Childress (1994).

Table 18 - Post-release mortality rates used to estimate mortality from catch-and-release discards in CA, OR, and WA non-salmon recreational fisheries from 1981-1989 and 1993-2010.

Scientific name	Common Name	Release mortality (%)	Source	% of B2 catch
Teleosts and Acipenseriformes				
Acipenser transmontanus	White Sturgeon [a,b]	3	6	3.7
Ophiodon elongatus	Lingcod	2	1	4.0
Morone saxatilis	Striped Bass	17	1	1.0
Hippoglossus stenolepis	Pacific Halibut	16	1	0.4
Atractoscion nobilis	White weakfish	10	4	0.9
Thunnus albacares	Yellowfin tuna	30	1	0.0
Sebastes spp.	Rockfish	16-66[c]	5	3.6
Other teleost species	Median value (n=274)	11	1	59.3[d]
Elasmobranchs				
Alopias vulpinus	Thresher shark	26	7	0.9
Prionace glauca	Blue shark	15	3	2.5
Isurus oxyrinchus	Shortfin mako shark	20	9	0.5
Myliobatis californica	Bat ray [e]	15	8	3.1
Squalus acanthias	Spiny dogfish [b]	24	2	8.1
Other Batoidea	Median value (n=3)	7	8	3.1
Other Selachimorpha	Median value (n=4)	22	10	8.8

[a] This mortality rate was applied to all *Acipenser* spp. discards. [b] Mortality rates may be an overestimate due to the holding conditions used (Robichaud *et al.* 2006; Mandelman and Farrington 2007). [c] Range shows mortality rate for 8 rockfish species, a median value of 31.5% was used for all other rockfish species. [d] Includes 126 tonnes of spotted rattail (*Hydrolagus colliei*). [e] This rate was an estimate for the Southern Eagle Ray (*Myliobatis australis*) of the same genus. Sources: 1. Average release mortality calculated from meta-analyses by Bartholomew and Bohnsack (2005) and Muoneke and Childress (1994), 2. Mandelman and Farrington (2007), 3. Musyl *et al.* (2011), 4. Aalbers *et al.* (2004), 5.PFMC and NMFS (2009) 6. Robichaud *et al.* (2006), 7. Heberer *et al.* (2010), 8. Braccini *et al.* (2012), 9. Hight *et al.* (2007), 10. Median value of rates from 4 species shown in table.

With the exception of leopard sharks, we were able to find species-specific post-release mortality estimates for hook and line fisheries for major elasmobranch species (Table 18) that were present in RecFIN B2 discards. Post-release mortality rates ranged between 15-26% for four species of shark commonly present in the discards and we applied a median value of 22% to estimate post-release survival of the remaining shark species in the discards.

For skate and ray species, we found no studies estimating post-release discard mortality from hook and line fisheries, however several studies estimating post-release mortality from trawling (Laptikhovsky 2004; Enever *et al.* 2009) and gillnet fisheries (Braccini *et al.* 2012). We applied the post-release mortality rates from the study by Braccini *et al.* (2012) for the Southern eagle ray (*Myliobatis australis*) to bat rays, as these species are from the same genus, and used the median value from the three Batoidea species in this study (7%) to estimate discard mortalities for other skate and ray species. We found no estimates of post-release mortalities for chimaeras from recreational fisheries, and thus we also applied the 11% median value for teleosts to spotted rattail (*Hydrolagus colliei*).

Using these estimates of dead catch-and-release fish from 1981-1989 and reconstructed estimates of recreational fisheries, we calculated an average annual *D/L* ratio for each state (Table 19). The landings denominator included all recreational fish catch (i.e., excluding shellfish and crustacean taxa), with the exception of salmon caught in coastal rivers, as we assumed these would be associated with less non-salmon bycatch (Table 19). We did not have CA salmon separated by marine and freshwater landings and thus all salmon catch was included in the denominator used to calculate the CA *D/L* ratios. We then multiplied these ratios by the reconstructed recreational ocean fish landings (excluding river salmon catches) for each state, to estimate the portion of dead catch-and-release catches from 1950-1980 and 1990-1992 (1990-1995 for WA). Discards for WA from 2004-2010 do not include spotted spiny dogfish, which is the most commonly discarded taxon, contributing 71% of total WA discards from 1980-2003. The average annual *D/L* ratio from 1981-2003 for spotted spiny dogfish in WA is 0.07 (ranging between 0.02-0.13), and we used this ratio to estimate dogfish discards in WA from 2004-2010.

Table 19 – Average discard (excluding salmon) to landings ratios in CA, WA, and OR for recreational ocean fisheries from 1981-1989.

State	Average D/L ratio (total discards)	Range	Average D/L ratio (dead discards only) [a]	Range
CA	0.50	0.25-0.73	0.06	0.03-0.09
WA	0.35	0.19-0.75	0.07	0.03-0.14
OR	0.09	0.05-0.13	0.01	0.01-0.01

[a] These D/L ratios were calculated using dead discards as the numerator, which were estimated using post-release mortality rates from Table 18

1.3.9 - Highly migratory and small pelagic species

Estimates of discards from highly migratory species such as tuna and swordfish are not included in this study as these will be estimated in a separate, global study of oceanic fisheries by the *Sea Around Us* . The important tuna landings (yellowfin, skipjack and albacore) are caught primarily by trolling and purse seines, gears which are not associated with high discards (Kelleher 2005b). Childers and Aalbers (2006) note low discards in the albacore fishery and we also assume low discards in the offshore yellowfin and skipjack fisheries, most of which occurred from 1950-1984 before FADs were commonplace. This is not the case for swordfish drift gillnet and longline fisheries, which became common in the 1980s and 1990s, respectively, and are associated with higher discard rates (Morgan and Chuenpagdee 2003) (see Table 20). Although not included in our estimate, discard rates for swordfish drift gillnet and longline fisheries are among the highest discard rates observed for the west coast of the U.S. and it is likely that they make up an important portion of actual total discards.

Table 20 - Average discards to landings ratios (by number of individuals and weighted by % observer coverage) for the California drift gillnet and longline swordfish fishery.

Fishery	Average D/L ratio (total discards)[a]	Range	Average D/L ratio (excluding live discards)[a]	Range
Drift gillnet[a]	1.66	1.01 - 2.65	0.54	0.11 - 0.96
Longline	1.39	1.36 - 1.42	0.68	0.63 - 0.74

Sources: Drift gillnet discards are from observer data from 1991-2010 (obtained from the SWFSC website; swr.nmfs.noaa.gov) with an average coverage of 17%. Longline discards are based on limited observer data (SWFSC, unpub. data, provided by L. Enriquez) from 2 seasons (2002/2003 and 2003/2004). D/L ratios exclude birds, cetaceans, turtles and pinnipeds.

Small pelagic species occupy a substantial portion of the total NMFS commercial landings from 1950-2010; Pacific sardine (*Sardinops sagax;* 9%), California market squid (*Loligo opalescens*; 6%), California anchovy (*Engraulis morda;* 6%), jack mackerel (*Trachurus symmetricus;* 4%), chub mackerel (*Scomber japonicas*; 3%), Pacific herring (*Clupea pallasii pallasii*; 1%), and Pacific bonito (*Sarda chiliensis lineolata*; 1%). Fisheries targeting these species use roundhaul gear such as purse seines or lampara nets (Harrington *et al.* 2005; PFMC 2011b). Discards and bycatch are generally low for coastal pelagic species due to the gear used in these fisheries and the most common bycatch are other coastal pelagic species (Harrington *et al.* 2005). Bycatch of non-prohibited larger species are often retained for personal use or commercial sale (PFMC 2011b). If not retained, larger fish can often be released by lowering a portion of the net or using a dip net (Harrington *et al.* 2005; PFMC 2011b).

1.4 - Illegal fishing

Illegal commercial catches can compose a substantial portion of total catches, with recent estimates of global illegal catches ranging from 11-26 million tonnes (Agnew *et al.* 2009). There have been only a few attempts to quantify the extent of reported catch that is illegal in various fisheries throughout the United States (see Table 21). These estimates of illegal catch pertain to any catch that is in violation of state or federal management regulations (e.g., fishing in restricted areas, use of illegal gears, fishing during seasonal closures). Studies of the northeast groundfish trawl fishery (Sutinen *et al.* 1989; King *et al.* 2009) provide the only comparison for a given fishery over time and suggest that there may have been a small increase in illegal fishing over the last 20 years. This is consistent with the idea that increased regulation

since the inception of the Magnus Stevens Fishery Conservation and Management Act (MSFCA), passed in 1976, has led to increased non-compliance as regulations have tightened. For the data purposes of the *Sea Around Us*, domestic illegal fishing (i.e., fishing in violation of state or federal regulations) are treated as either 'unreported' data (if missing from official records) or as 'reported' data (if included in official data, as is the case for the West Coast of the U.S.), but not specifically as 'illegal'. This is purely due to the global definition of 'illegal' as applied by the *Sea Around Us*, namely 'fishing in the EEZ or territorial waters of a foreign country without traditional or negotiated access permission'. Thus, the U.S. domestic definition of 'illegal' is not applied within the context of the *Sea Around Us*.

Table 21 – Examples of estimates of illegal catch in U.S. fisheries.

Year	Fishery	% of catch [a]	Range (%)	Source
1980s	Massachusetts lobster	6		Sutinen and Gauvin (1989)
1980s	Rhode island quahog	5		Bean (1990)
1988	Northeast groundfish trawl	10	6-14	Sutinen *et al.* (1989)
1988	Atlantic scallop	7	6-7.5	Sutinen *et al.* (1989)
2007	Northeast groundfish trawl	13	9-24	King *et al.* (2009)
2007	Gulf of Mexico red snapper	17	10-20	King *et al.* (2009)
2007	Pacific groundfish trawl	11	3-28	King *et al.* (2009)

[a] When only a range was given, this column shows the midrange value. Ranges from 2007 represent the lowest and highest mean estimates from the four groups interviewed (fishers, regulators, enforcement personnel and research scientists).

It is difficult to determine the percentage of reported commercial catch that violates domestic fishing regulations, as the violations occur mostly at sea where they are not observed and there may be no indication of the infraction at the time the catch is landed. King *et al.* (2009) conducted surveys with fishery regulators, scientists, enforcement officers and fishers for the Pacific groundfish trawl fishery. Overall, 90 surveys were completed by fishers and 19 by non-fishers. The mean estimate of the percent total catch due to illegal fishing was 5%, while fishing enforcement personnel estimated that it was as high as 28%. King *et al.* (2009) suggest the midpoint of fishers and non-fishers responses, i.e., 11%, is a reasonable estimate for this fishery.

We did not find evidence to suggest there are large unreported domestic illegal commercial catches in CA, OR or WA; however, the respondents from King *et al.* (2009) thought that reporting and bycatch were the 5th and 2nd most significant violations in the Pacific groundfish trawl fishery. This suggests there are likely some unreported landings and/or discarded bycatch; however, there is no information to estimate the extent of this. We do not include any specific estimate of domestic illegal (unreported or reported) catch in the overall reconstructed catches; however, this is an area that warrants further study.

1.5 - Tribal fisheries

Since 1970, WDFW commercial catch statistics are classified as treaty and non-treaty landings. The NMFS commercial landings for WA used as the baseline to reconstruct commercial landings does not separate the landings as such, but based on the total catches reported by WDFW and NMFS, it was inferred that both WA treaty and non-treaty commercial landings are included in NMFS commercial statistics. Since 1983, a breakdown of subsistence and ceremonial catches is also present in the WDFW data (unpubl. data, provided by T. Gibbs). Reported ceremonial catch ranges from 3-300 t·year^{-1} for 1984-2010, with salmonid species representing 94% of the catch. These catches represent less than 0.1% of the overall commercial landings during this period.

Commercial tribal landings in OR are recorded on fish landing receipts (P. Mirick, ODFW, pers. comm.) and thus would be reported in the commercial datasets. Tribal catches are also included in state estimates of total recreational shellfish catch; however, are not available separated from the overall catch (M. Vance, ODFW, pers. comm.).

We found little information on treaties for commercial tribal fishing rights in CA, but we assume potential tribal catches would be reported in the commercial database as is the case for OR and WA. The survey designs for recreational finfish fisheries in CA since 1980 account for unlicensed anglers (A. Sadrozinski, CDFW, pers. comm.).

There are a variety of consumption surveys that have also been conducted for tribal fisheries along the west coast of the U.S. (Table 22).These estimates range between 22-140 kg·year^{-1} for various tribes in WA in recent years, and were much higher in the earlier period (Hewes 1947). To obtain an indication of the total amount of tribal consumption, we extracted population data for ages 18 and over for populations listed as "American Indian or Alaska Native" from the 2010 U.S. Census. We included only populations from counties in coastal areas and those that were adjacent to Puget Sound, which summed to 82,000 people. Extrapolating the low and high consumption rates observed for WA tribes to this population yields estimates of tribal consumption ranging from 1,800–11,000 t·year^{-1}. This is substantially lower than the portion of subsistence and ceremonial catch reported in the official statistics.

Table 22 - Summary of tribal seafood consumption rates from various studies in the western U.S.

State	Tribe	Year	kg·year^{-1} [a]	Study
WA	Squaxin Island	1994	27	Toy *et al.* (1996
	Tulalip	1994	27	Toy *et al.* (1996)
	CRITFC	1991-1992	21	CRITFC (1994)
	Suquamish	1998	78	Suquamish Tribe (2000)
	Lummi	1985	140[b]	Freimund *et al.* (2012)
	Makah	1998	46	Sepez (2001)
	Various	1800s[c]	140-270[c]	Hewes (1947)
OR	Various	1800s[c]	140-180[c]	Hewes (1947)
CA	Various	1800s[c]	90-200[c]	Hewes (1947)

[a] When consumption rates were presented as g/day per body weight of consumer, consumption rates were converted to kg·year^{-1} using the mean weight of survey respondents. [b] includes only the male population. [c] Consumption rates from Hewes (1947) are noted in the source material as being from "aboriginal" times, which we assumed are representative of consumption rates in the 1800s. They include only salmon consumption.

It is often not clear in these reports whether tribal seafood consumed is caught commercially or recreationally. Some of the catch is reportedly gifted but otherwise there is little information to indicate whether this catch might be included in official catch statistics. It is thus very difficult to ascertain what portion (if any) of tribal subsistence catch is unreported. Furthermore, consumption studies caution against extrapolating these consumption rates to a wider population as has been done here (CRITFC 1994; Toy *et al.* 1996; Suquamish Tribe 2000).

Due to this uncertainty and to avoid double counting, we do not include any additional catch for tribal fisheries above what has been estimated from recreational and commercial catch. It is possible that there are unreported tribal catches; however, a more detailed assessment of catch by individual tribes and time series of tribal populations, and an evaluation of their integration into national datasystems would be required to make such an estimate.

2.0 - RESULTS

2.1 - Reconstructed total catches

The reconstructed total catch (including discards) for the west coast of the United States for the 1950-2010 period was just over 31 million tonnes. The reconstructed catch (including discards) ranged from over 750,000 t·year^{-1} in 1950 to 545,000 t in 2010. The highest catches for the 61-year period occurred in 1950 when the California fishery caught over 300,000 tonnes of Pacific sardine prior to the collapse of this fishery. Catches also peaked in 1981 at 630,000 t and 2000 with almost 642,000 t (Figure 4). Total catch for the 61-year period is composed primarily of commercial landings (87%), followed by discards (8%) and recreational landings (4%) (Figure 4; annual reconstructed catches by sector are available in Appendix D).

2.2 - Commercial catches

Commercial catch accounts for the bulk of the total reconstructed catch with 27.2 million tonnes during the 61-year period. NMFS reports 25.4 million tonnes of marine catches during this period, and we estimated an additional 1.8 million tonnes of shellfish after converting meat weights to whole weights. The majority of commercial landings over the 1950-2010 period occurred in CA (56%), followed by WA (21%), OR (14%) and processing at-sea (9%) (Figure 5). The domestic at-sea processing fleet for Pacific hake has only been active since 1990 and since this time they have accounted for nearly one quarter of total catches for the western U.S.

2.3 - Recreational catches

Recreational catch ranged from nearly 17,000 t in 1950 to just over 12,000 t in 2010, peaking at nearly 31,000 t in 1980. Total recreational catch for the 1950-2010 period was over 1.3 million tonnes and averaged about 22,000 t annually. CA, WA and OR accounted for 63%, 24% and 13%, respectively, of total recreational catch (Figure 6).

RecFIN landings totalled around 381,000 t for years reported from 1980-1989 and 1993-2010. In comparison, reconstructed catch for this period was 565,000 t, about 1.5 times what is reported by RecFIN. The difference is largely due to coho and chinook landings, for which we used state data considered to be more accurate, and due to shellfish and crustaceans, which are almost completely unreported by RecFIN. Salmon (20%), rockfish (16%), and tunas and mackerels (16%) were the most important contributors to the recreational catch from 1950-2010 (Figure 6).

Most of the reconstructed recreational catch (84%) was compiled from existing historical catch data from a variety of sources (Figure 7), and was either accepted as is or multiplied by some proxy to account for an unreported component of the catch (e.g., CPFV logbook data). Data from RecFIN and Figueira and Coleman (2010) accounted for 25% of total reconstructed catch, while estimates derived from CPFV logbooks and State agencies (WDFW, ODFW, CDFW) accounted for another 24% and 19%, respectively.

2.4 - Discards

Total discards were estimated at over 2.5 million t for commercial and recreational fisheries in CA, WA and OR (Figure 8), with discards from the groundfish bottom trawl (54%) and ocean shrimp fishery (27%) contributing the most. Discards peaked at nearly 86,000 t in 1989 prior to the introduction of BRDs in the ocean shrimp fishery, and ranged from around 24,000 t in 1950 to around 14,000 t in 2010 (See Figure 8). The most common taxonomic groups in the discards were Pacific hake (23%), flatfish (17%), rockfish (12%), spotted spiny dogfish (9%), and skates and rays (8%) (Figure 8).

2.5 – Reconstructed catch as utilized by the Sea Around Us

The *Sea Around Us* uses the following fishing sectors in its global catch database: 'industrial' (i.e., large-scale commercial), 'artisanal' (i.e., small-scale commercial), 'subsistence' (i.e., small-scale non-commercial with primary purpose being self- or family-consumption), and 'recreational' (i.e., small-scale non-commercial with primary purpose being pleasure). As the reconstruction for the U.S. west coast as outlined above used 'commercial' as sectoral data label, a subsequent split of 'commercial' catches was required to assign these catches to one of the two commercial sectors as defined by the *Sea Around Us*. Commercial catch was divided into artisanal and industrial sectors based on gear types listed in the NMFS commercial landings data. Using the definitions of the *Sea Around Us*, catches from towed gears such as trawls, dredges and roundhaul gear (i.e. ,purse seines and lampara nets), were labeled as industrial, while all other commercial landings were labeled artisanal. Note also that the global standard for the *Sea Around Us* is to compare reconstructed catches to what is presented by the FAO, and although the NMFS commercial landings data for some shellfish is not reported in wet weight FAO reporting standards are that landings are reported in wet weight. Therefore, although the difference between the wet weight and reported weight was considered unreported catch in relation to the NOAA/NMFS baseline data, it is considered reported in comparison to the FAO data and is treated as reported in the final Sea Around Us database.

Note that this commercial sectoral assignment is approximate and indicative only, and non-binding in any form, as no legal definition of 'industrial' or 'artisanal' could be found for the USA. Thus, theses sectoral assignments are purely for the purposes of the *Sea Around Us*, and suggest that industrial catches accounted for 65% of total catches (including discards), artisanal for 30%, and recreational for 5% (Figure 9). Overall, reconstructed total catches were 1.2 times the data officially reported.

3.0 - DISCUSSION

Total reconstructed catches from 1950-2010 for California, Oregon and Washington were 22% higher than what is officially reported in the NMFS official commercial landings data. It is evident that even for a developed country like the US that has extensive programs for monitoring and recording catch data, there are still sources of unreported catch. Commercial catches were considered to be fully reported (an assumption that may warrant further investigation), and the major adjustment to commercial landings was to convert shellfish from meat weight into wet weights, yielding an additional 7% of catch. Recreational fisheries and discards make up the remaining 5% and 10% of the total 22% catch increase mentioned above.

National and state agencies have collected recreational catch statistics for recreational fisheries that are reported in the RecFIN database since 1980. We still found that total recreational fisheries were underreported by RecFIN, largely due to differences in salmon catches and the exclusion of shellfish.

Discard estimates have mostly occurred in the last decade, but in contrast to recreational and commercial fisheries, there is no central reporting database for discards on the U.S. West Coast. Existing discard estimates were primarily compiled from five sources as part of the reconstruction effort: 1) Bellman and Heery (2013) discard estimates for the groundfish trawl fishery (2002-2009); 2) NWFSC annual discard reports (2005-2010); 3) recreational discards in RecFIN (2003-2010); 4) salmon discard mortality estimates by the PFMC (1999-2010); and 5) IPHC estimates of Pacific halibut discard mortality in the directed Halibut fishery (1974-2010). It would appear that since at least 2005 (earlier for some fisheries) most major sources of discards on the U.S. West Coast are being accounted for by the various agencies responsible for management.

Although some recreational catch and discard statistics are collected nationally, they are considered 'unreported' in the *Sea Around Us* database (and in calculating the 22% figure above), since our investigations suggested that these catches are not reported by the U.S. authorities to FAO. This focus on reporting primarily commercial data is not unusual (Garibaldi 2012). Indeed, this is one of the reasons for this reconstruction process, and we hope that, in the spirit of ecosystem-based considerations of fisheries,

future reporting of catch statistics to FAO may include these sources of catch. We have attempted here to compile all existing information for the earlier period to provide a historic baseline for these sectors that were unreported in earlier years. This is especially important for species for which recreational fisheries and discards make up a large portion of total catch, such as rockfish, elasmobranchs and salmon.

It should be acknowledged that the U.S. has some of the most extensive sources of fisheries data in the world, much of which is easily accessible by the public. In many cases, data that were not publicly available were readily shared by various agencies throughout all states, further adding to the transparency of official catch statistics in the western U.S. For this level of public accountability and transparency, the U.S. deserves recognition, as it is clear that recording and freely providing accurate catch data to the public are a priority. Sadly, this is not always the case for many countries and associated data agencies around the world (Zeller *et al.* 2011).

3.1 - Recommendations

Further work is required to evaluate the extent of tribal subsistence and ceremonial fisheries along the U.S. west coast, particularly for earlier years, as consumption surveys suggest that these sources of catch may be substantial. Similarly, there is little research available on the extent of illegal fishing in the area, and results from King *et al.* (2009) suggest this also warrants further investigation.

Our results indicate that discards were highest from the mid-1970s to the early 2000s, during peak landings from the ocean shrimp and groundfish bottom trawl fishery, and prior to the introduction of mandatory BRDs in the ocean shrimp fishery in 2003 (Hannah and Jones 2007). Estimates of discards for these fisheries exist only since 2002 and 2007. Estimates of discard mortality dating further back than the past decade should be considered in management plans, particularly for species of conservation concern.

3.2 - Limitations

Sources of catch not explicitly accounted for in our estimates include: ghost fishing, fish taken home for personal consumption by commercial fishers, research take, and foreign fisheries. Catch from these sources were not included in our estimates such as to avoid double counting and/or due to lack of data, but are not negligible (Gilardi *et al.* 2010; Anon. 2011; Hare 2012). This is particularly true for the foreign fishery for Pacific hake that operated in the U.S. EEZ-equivalent waters prior to the establishment of the EEZ (Nelson Jr. 1985).

We acknowledge that there is considerable uncertainty in our discard estimates prior to 2000, mostly since there is little observer data and few estimates for discards from most fisheries for the early time period. Given the information available to us, we feel the reconstructed discards are a reasonable estimate for fisheries on the West Coast of the U.S., and although they may lack a measure of their uncertainty, they are bound to be more accurate than the default assumption that zero data are equivalent to zero catch. However, users of these data should be aware of their limitations, particularly regarding the difficulties in reporting uncertainty in total discards as well as changes in species composition that may have occurred over time. Given that most of the discard-to-landings ratios used are based on bycatch data from the past 10 years, most of our results will not reflect changes in the taxonomic composition of discards that may have occurred over time. Some bycatch data from research trawls for the groundfish trawl fishery (1985-1987) and the ocean shrimp fishery (1979-1999) is available for the earlier time period and was incorporated into our estimates.

Error estimates are available for recreational catch data from the RecFIN survey, however they were not available for most other historical recreational data used in the reconstruction and thus are not included in our estimates.

3.3 - Conclusion

This is a first attempt to estimate the major sources of total fisheries related mortality for fisheries in the western U.S. from 1950-2010. It is our goal that these estimates may be improved, for example through more complex models that take into account spatial fishing effort. However, we feel our estimates are a reasonable starting point given the data available to us. It is not our goal to replace existing estimates, but rather to complement them by providing a bigger picture of total marine catches and highlight sources of unreported catch that may be substantial and warrant further consideration in fisheries management or stock assessment practices for U.S fisheries. More statistically robust methods or simulation models may allow for a greater degree of precision and estimates of uncertainty necessary for management purposes in specific fisheries.

We acknowledge that there is uncertainty in our estimates and a lack of precision for some years. Criticism of this work solely on these grounds without any effort to provide alternative estimates is unproductive and does not provide further insight into the situation of U.S fisheries. We welcome constructive criticisms that improve this work by providing new data or catch estimates.. Similarly, we hope that our estimates can be part of an ongoing effort to improve catch statistics for global fisheries and that as new data surface, these can be incorporated into the database. The reconstructed catch data will be made freely available on the *Sea Around Us* website at www.seaaroundus.org.

The results presented here can contribute to improved historic time series of catch and provide a better understanding of important changes that have occurred over the past 6 decades. We also hope that this report has shed some light on the extent of recreational fisheries and discards in the U.S. and will provide justification for continued monitoring of these sources of catch in future years. Finally we hope that this work may draw attention to other sources of catch such as ghost fishing, tribal fisheries and illegal fishing, that may represent sources of unreported catch for which there are very few data.

ACKNOWLEDGEMENTS

Beau Doherty and Ashley McCrea Strub would like to acknowledge the *Sea Around Us*, a collaboration between The University of British Columbia and The Pew Charitable Trusts. We thank Bob Hannah for helpful feedback and comments on early drafts explaining discards for the ocean shrimp fishery. In addition to those listed in Figueira and Coleman (2010), the authors would also like to thank the following people for their help in obtaining, compiling and interpreting historical data: Daniel Ayres (WDFW), Shari Beals (ODFW), Marlene Bellman (NOAA), John Carlile (PSC), Theresa Gibbs (WDFW), Matthew Hunter (ODFW), Peter Kalvass (CDFW), Eric Kraig (WDFW), Kara McLean (PacFIN), Patrick Mirick (ODFW), Marjorie Morningstar (WDFW), Patrick Patillo (WDFW), Jana Robertson (CDFW), John Wallace (NOAA).

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FIGURES

Figure 1: The Exclusive Economic Zone (EEZ) and shelf area (to 200m depth) of the USA West Coast.

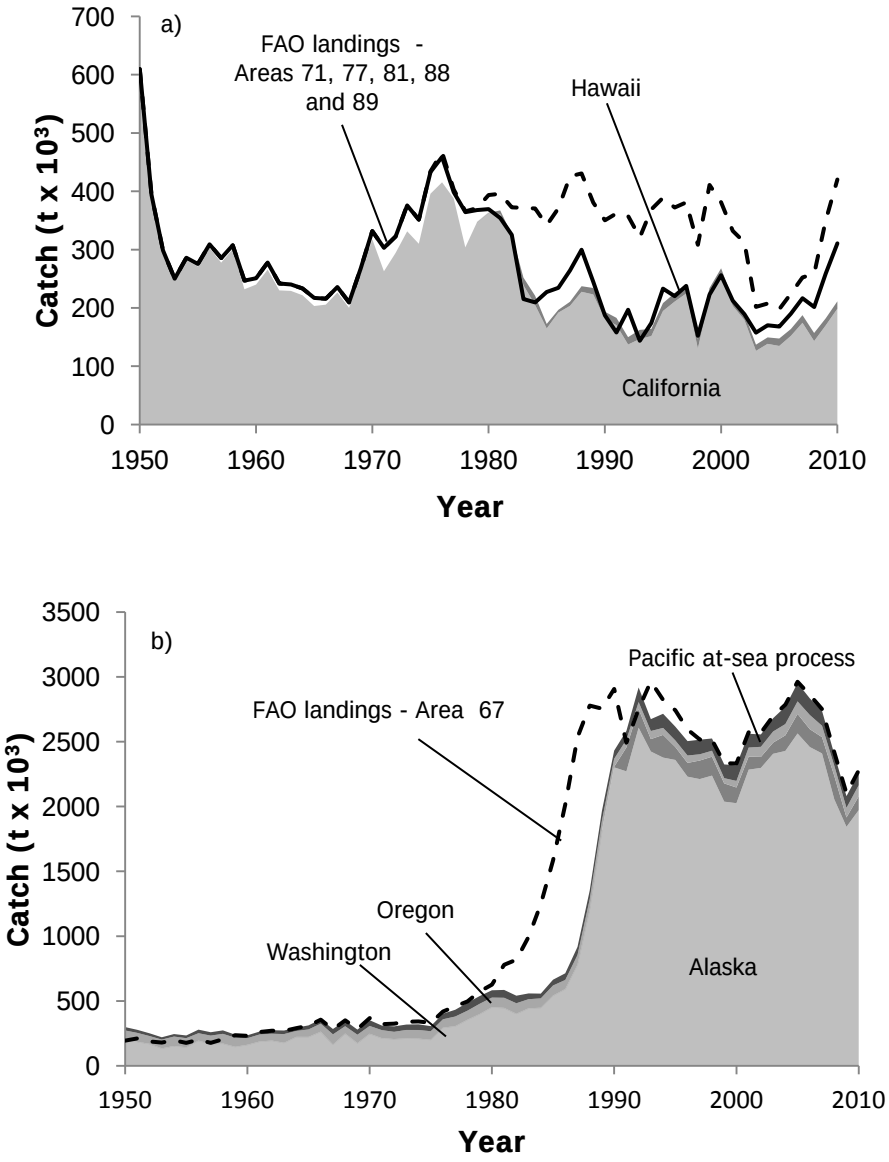
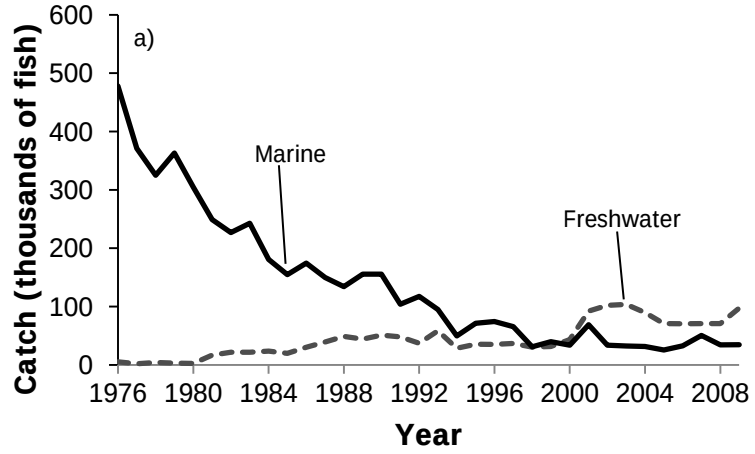
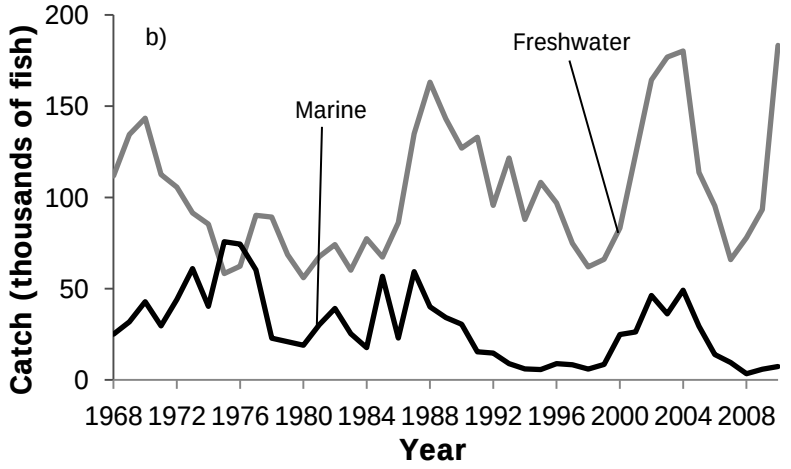


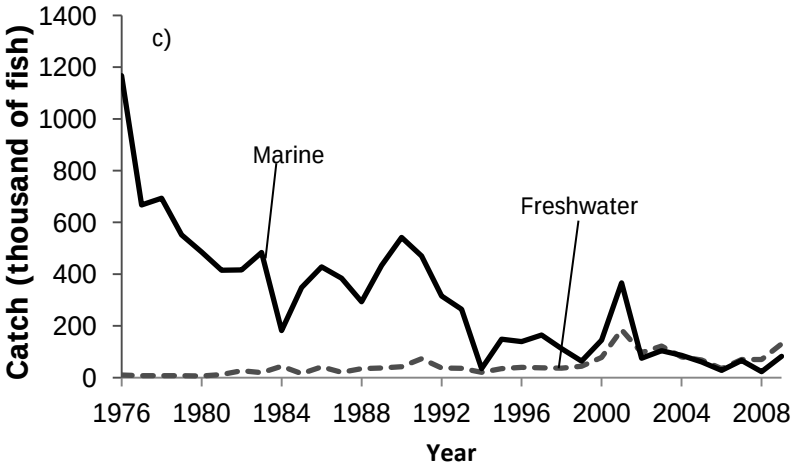
Figure 2 – Comparing NMFS commercial landings statistics with those reported to the FAO on behalf of the U.S.A. Figure a) compares NMFS landings for HI and CA to FAO landings for areas 71, 77, 81, and 87. Figure b) compares NMFS landings for OR, WA, AK and Pacific hake landings processed at-sea with those for FAO area 67. Landings exclude freshwater taxa (including rainbow trout) as well as aquatic mammals, reptiles, amphibians, coral, roe and seaweeds, since these taxa are not included in the *Sea Around Us* database.



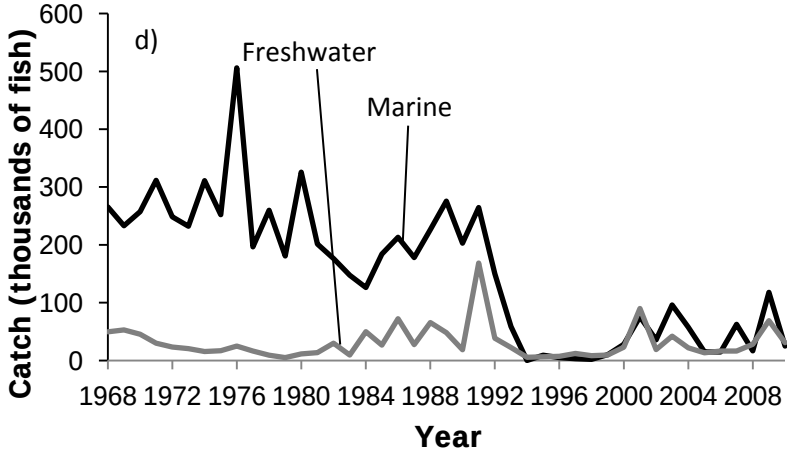
a) Washington chinook



b) Oregon chinook



c) Washington coho



d) Oregon coho

Figure 3. Recreational landings of chinook (a&b) and coho (c&d) for Washington (a&c source: WDFW unpublished data, provided by E. Kraig) and Oregon (b&d source: ODFW unpublished data, provided by S. Beals and ODFW (1977)) from ocean areas (black line) and from coastal rivers (grey line). OR Fall chinook catch for 1994 was unavailable and was estimated (See Table 5).

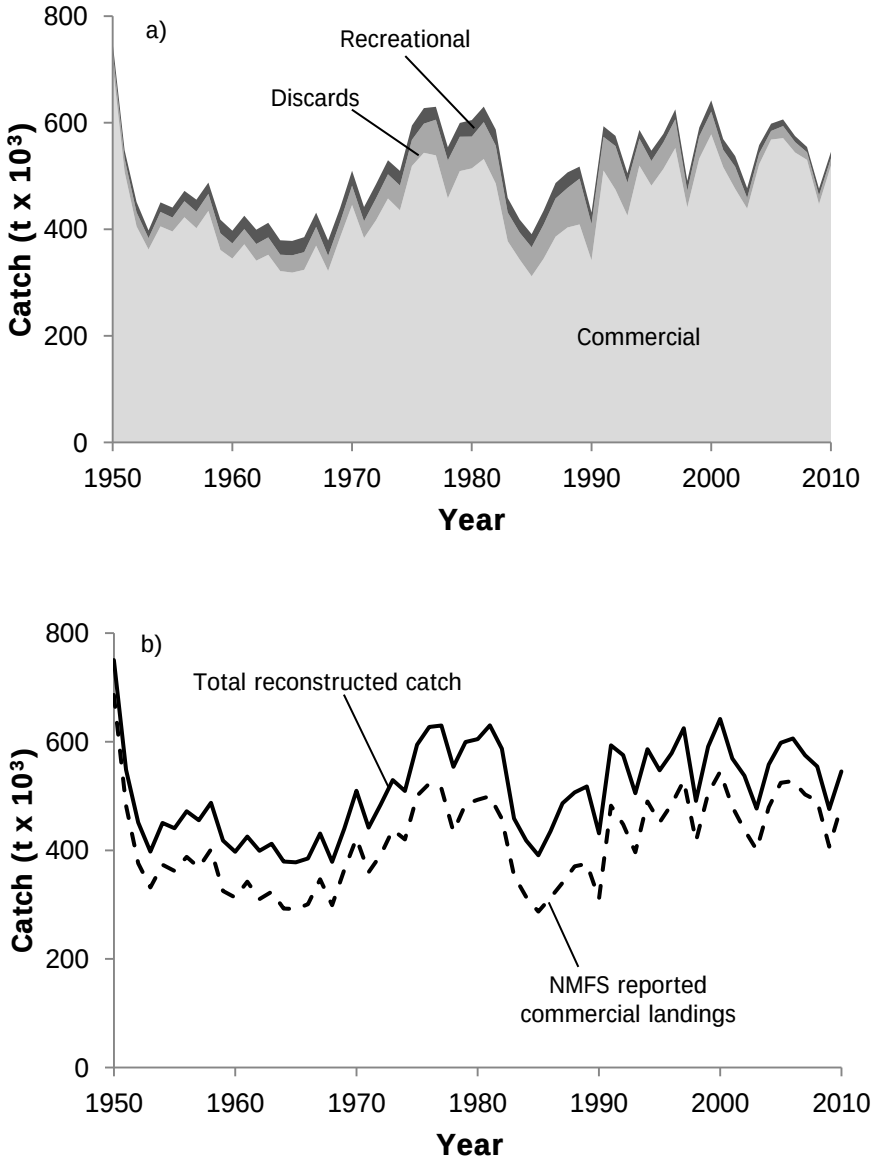


Figure 4. a) Total reconstructed catch by sector for the U.S. West Coast from 1950-2010. b) Comparing total reconstructed catch to the NMFS reported commercial landings for the U.S. West Coast

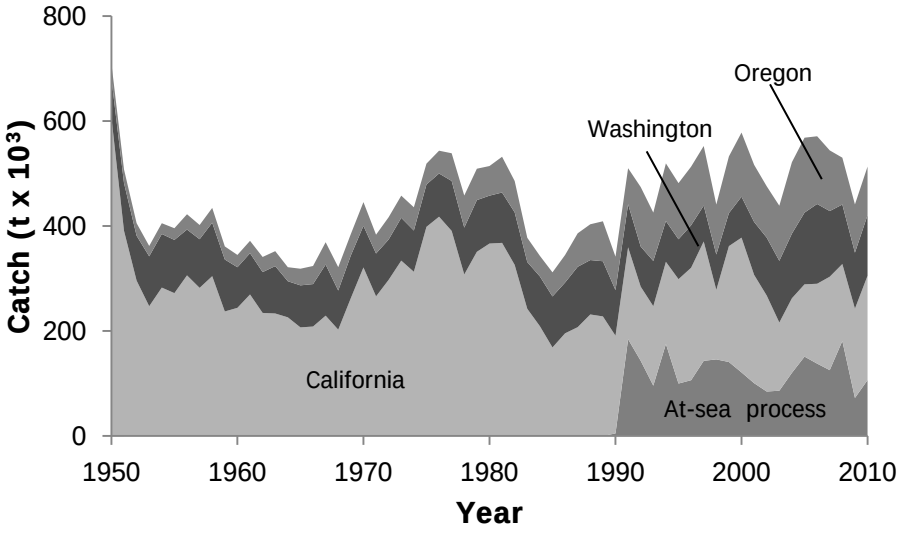


Figure 5. Total reconstructed commercial catch by landing area. At-sea process refers to catch from the Pacific hake fishery that is processed at-sea.

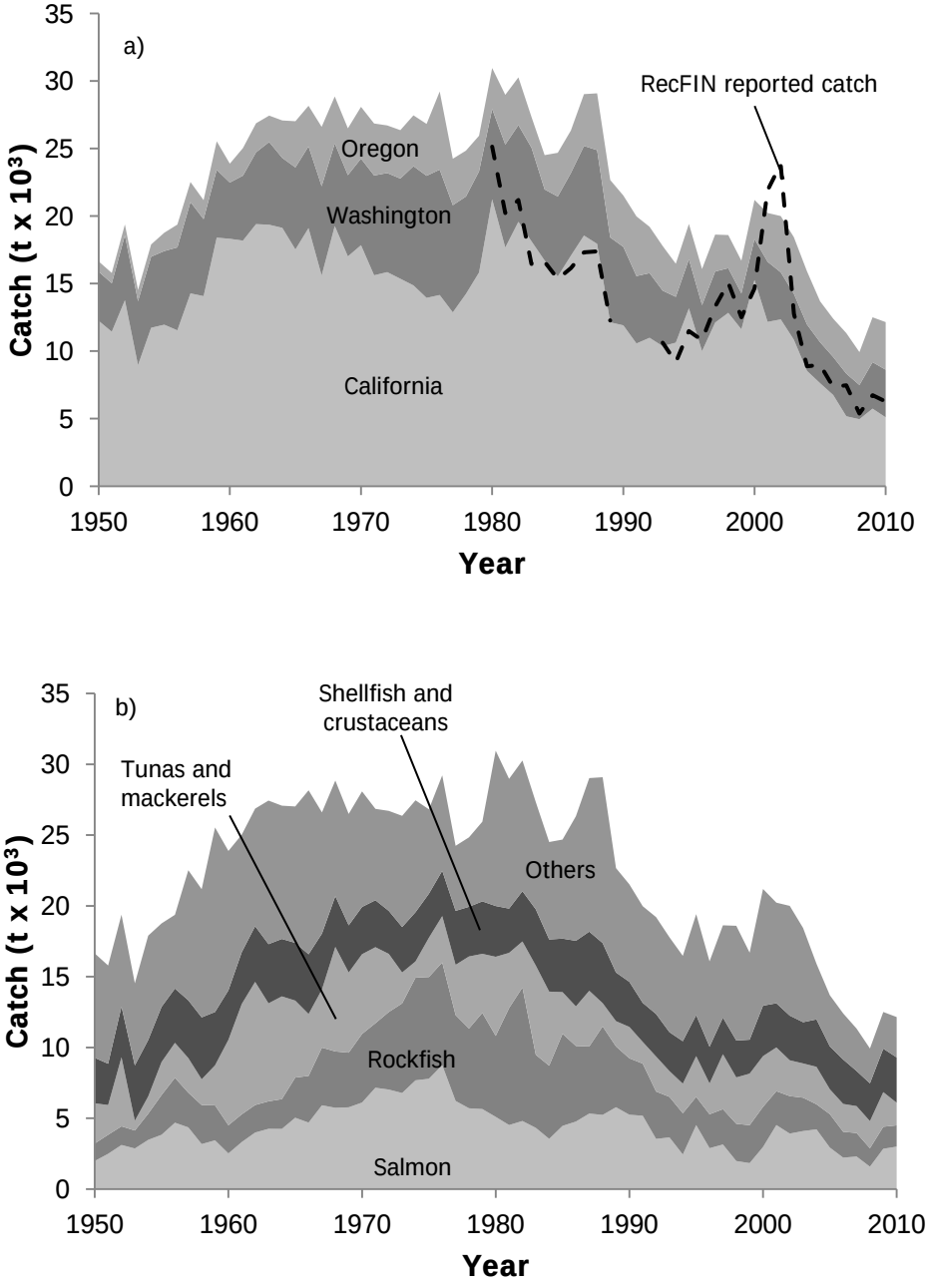


Figure 6. Total reconstructed catches by a) state along with reported RecFIN catch for years available (1980-1989,1993-2010), and by b) major taxonomic groups.

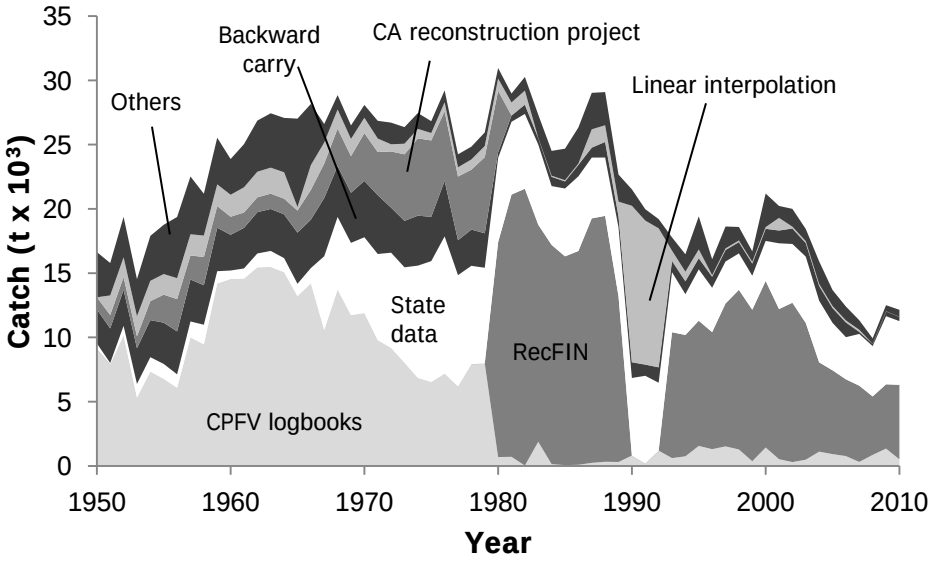


Figure 7. Total reconstructed recreational catch shown by the type of source used for the reconstruction. Backwards carry represents catch estimated through the use of: linear regression, catch-per-recreational licenses and backwards extrapolation of catch trends (i.e., assuming a taxonomic group contributes the same proportion of catch in 1950 as in 1980 or that total catch of a taxon in 1950 was the same as in 1960). State data refers to data obtained from WDFW, ODFW and CDFW, while others refers to data from INPFC (1979), PFMC reports, IPHC RARAs and other stock assessments or reports. RecFIN data included the Figueira and Coleman (2010) dataset that was used for years 1981-1989 and 1993-2002.

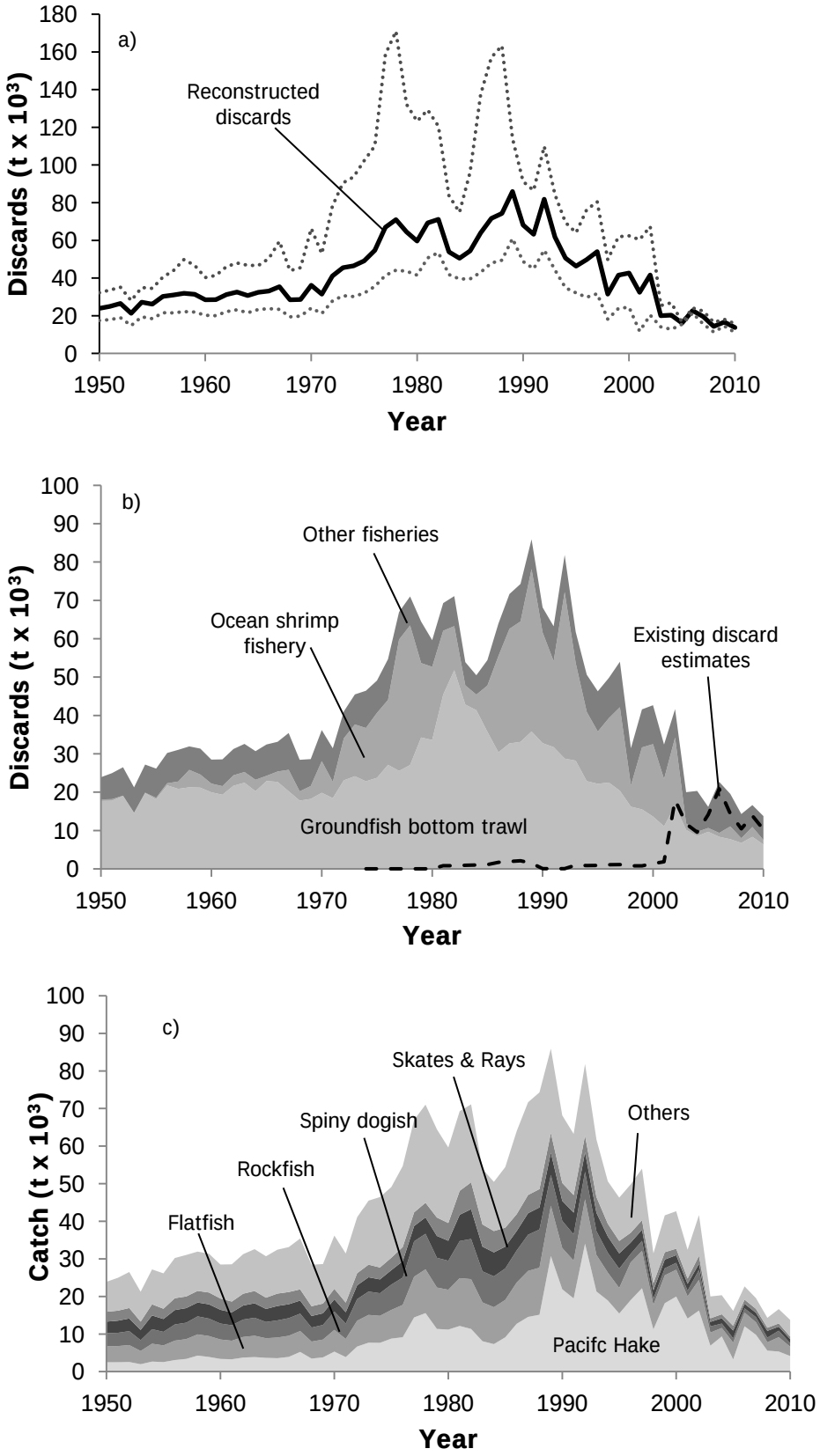


Figure 8. Total reconstructed discards for fisheries in CA, OR and WA. a) Dashed lines represent lower and upper bounds of estimate, based on range of D/L ratios observed for different fisheries over the 61-year time period. b) Discards from other fisheries include: commercial troll salmon, Pacific hake, sablefish pot and longline, Pacific halibut longline, California halibut trawl and recreational discards. Existing discards were available for select fisheries in reports published by the IPHC, the NWFSC, the PFMC and Bellman and Heery (2013). c) Major taxonomic groups in reconstructed discards.

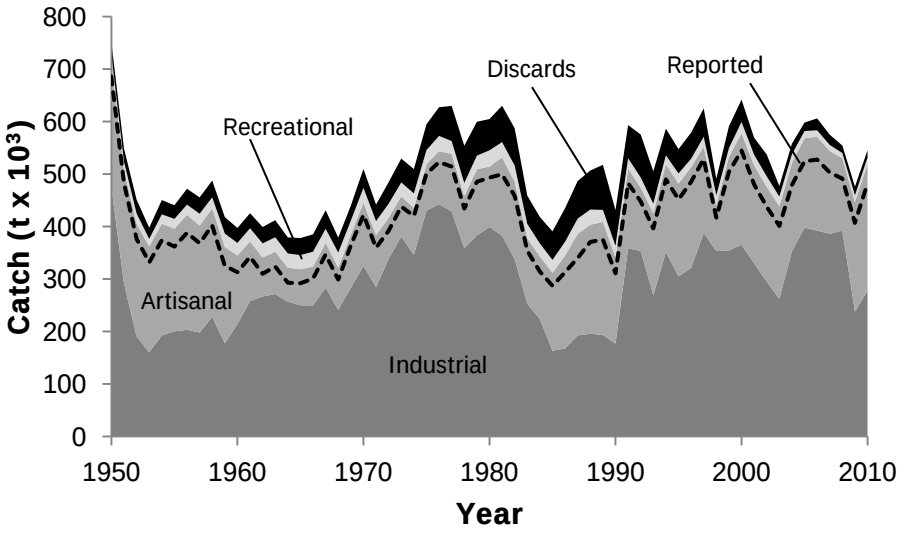


Figure 9. Total reconstructed catch by sector (for *Sea Around Us* purposes), with reported data overlaid as a line graph, and discards shown separately.

Appendix Table A1. Reconstructed common names and equivalent scientific names of some of the taxa referred to in report

Taxon name and rank	Common name
Species	
Atheresthes stomias	Arrowtooth flounder
Microstomus pacificus	Dover sole
Parophrys vetulus	English sole
Ophiodon elongatus	Lingcod
Pandalus jordani	Ocean shrimp
Sarda chiliensis lineolata	Pacific Bonito
Gadus macrocephalus	Pacific cod
Merluccius productus	Pacific hake
Clupea pallasii pallasii	Pacific herring
Sebastes alutus	Pacific ocean perch
Siliqua patula	Pacific razor clam
Citharichthys sordidus	Pacific Sanddab
Microgadus proximus	Pacific tomcod
Eopsetta jordani	Petrale sole
Glyptocephalus zachirus	Rex sole
Lyopsetta exilis	Slender sole
Squalus suckleyi	Spotted spiny dogfish
Genyonemus lineatus	White Croaker
Anarrhichthys ocellatus	Wolf-eel
Genus	
Haliotis spp.	abalone
Mytilus spp.	mussels
Crassostrea spp.	oysters
Sebastes spp.	rockfish
Acipenser spp.	Sturgeon
Sebastolobus spp.	thornyheads
Family	
Hagfish	Myxinidae
Pectinidae	Scallops
Smelts	Osmeridae
Order	
Gadiformes	Cods, hake and grenadiers
Pleuronectiformes	Flatfish

Appendix Table B1. Information used to reconstruct U.S. west coast recreational fisheries. For data sources that listed only the number of fish landed, a weight conversion was used to estimate landings by weight.

Taxa	Estimated # of Fish or Catch		Estimated Weight per fish			Estimated k ratio		
	Time Period	Source/Method	Time Period	kg/fish	Source/Method	Time Period	K value	Source/method
All species, unless indicated otherwise	1980, 2003-2010	RecFIN						
	1981-1989, 1993-2002	(Figueira and Coleman 2010)						
	1990-1992	Linear interpolation						
CALIFORNIA								
Finfish and Cephalopods:								
Albacore (*Thunnus alalunga*)	1950-1981,1993	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1993	10.4	RecFIN (1980-1985)	1950-1965	2.5	(Guel and Clark 1968)
						1966-1969		Linear interpolation
						1970	2.7	(Guel 1973)
						1971-1979	-	Linear interpolation
						1980, 1981, 1993	2.3	Figueira and Coleman (2010)
Barred sandbass (*Paralabrax nebulifer*)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	0.7	RecFIN (1980-1985)	1950-1979	1.8	Figueira and Coleman (2010)
Cabezon (*Scorpaenichthys marmoratus*)	1950-1979	(CDFG 2001)	1950-1979	1.2	RecFIN (1980-1985)	1950-1970	9	Mean from Guel and Clark (1968) & Guel (1973)
						1971-1979	-	Linear interpolation
						1980	13.1	Figueira and Coleman (2010)
California Halibut (*Paralichthys californicus*)	1950-1979	(CDFG 2001)	1950-1979	2.8	RecFIN (1980-1985)	1950-1979	8.8	Figueira and Coleman (2010)
California scorpionfish (*Scorpaena guttata*)	1950-1979	(CDFG 2001)	1950-1979	0.5	RecFIN (1980-1985)	1950-1979	1.1	Figueira and Coleman (2010)

California sheephead (*Semicossyphus pulcher*)	1950-1979	(2001)	1950-1960	1.8	(Clark 1960)	1950-1970	3.5	Guel (1973)
			1961-1979	-	Linear interpolation	1971-1979	-	Linear interpolation
			1980	1.1	RecFIN (1980-1985)	1980	2.7	Figueira and Coleman (2010)
Chinook Salmon (*Oncorhynchus tshawytsch*)	1950-1961	INPFC (1979)	1950-1960	5.6	Clark (1960)			
	1962-1975	(PFMC 1993)	1961-1999	-	Linear interpolation			
	1976-2010	(PFMC 2013)	2000-2010	5.8	RecFIN (2000-2010)			
Chub mackerel (S*comber japonicas*)	1950-1961	(Young 1969)	1950-1961	0.7	Clark (1960)	1950-1961	2.6	Crone *et al.* (2009) [b]
	1962-1979	(Crone *et al.* 2009)						
Coho salmon (*Oncorhynchus kisutch*)	1950-1961	INPFC (1979)	1950-1960	3.4	Clark (1960)			
	1962-1975	PFMC (1993)	1961-1999	-	Linear interpolation			
	1976-2010	PFMC (2013)	2000-2010	3.4	RecFIN (2000-2010)			
Halfmoon (*Medialuna californiensis*)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1960	0.5	Clark (1960)	1950-1980	1.9	Figueira and Coleman (2010)
			1961-1979	-	Linear interpolation			
			1980	0.4	RecFIN (1980-1985)			
Jack Mackerel (*Trachurus symmetricus*)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1960	0.9	Clark (1960)	1950-1970	2.5	Guel (1973)
			1961-1979	-	Linear interpolation	1971-1979		Linear interpolation
			1980		RecFIN (1980-1985)	1980	1.2	Figueira and Coleman (2010)
Jumbo flying squid (*Dosidicus gigas*)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	1.5	Fishbase [c]	1950-1979	2	Assumed
Kelp bass (*Paralabrax clathratus)*	1950-1980	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	0.6	RecFIN (1980-1985)	1950-1979	1.9	Figueira and Coleman (2010)

Lingcod (*Ophiodon elongatus*)	1950-1979	(CDFG 2001)	1950-1960	3.9	Clark (1960)	1950-1970	6.3	Mean from Guel and Clark (1968) & Guel (1973)
			1961-1979	-	Linear interpolation	1971-1979	-	Linear interpolation
			1980	2.9	RecFIN (1980-1985)	1980	3.5	Figueira and Coleman (2010)
Ocean whitefish (*Caulolatilus princeps*)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1960	1.2	Clark (1960)	1950-1965	1.2	Guel and Clark (1968)
			1961-1979	-	Linear interpolation	1966-1979		Linear interpolation
			1980	0.7	RecFIN (1980-1985)	1980	1.4	Figueira and Coleman (2010)
Pacific barracuda (*Sphyraena argentea*)	1950-1979	CDFG (2001)	1950-1960	1.2	Clark (1960)			
			1961-1979	-	Linear interpolation			
Pacific bonito (*Sarda chiliensis lineolata*)	1950-1978	(Collins *et al.* 1980)	1950-1979	1.6	Collins *et al.* (1980)	1950-1979	2	Collins *et al.* (1980)
	1979	(CDFG 2001)						
Pacific Halibut (*Hippoglossus stenolepsis*)	1950-1957	Assumed 0.1 MT based on 1958-1960 catch						
	1958-1960	(Miller and Gotshall 1965)	1958-1974	5.4	Skud (1975)			
	1961-1973	Linear interpolation						
	1974	(Skud 1975)						
	1975-1976	Linear interpolation						
	1977-2010	IPHC RARAs [d]						
Rockfish (*Sebastes spp.*)	1950-1980	(Ralston *et al.* 2010)						
Sandbass genus (*Paralabrax* spp.)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1960	0.6	RecFIN (1980-1985)	1950-1979	2	Assumed
Spotted grouper (*Epinephelus analogous*)	1950-1980	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	3.6	Fishbase [c]	1950-1979	2	Assumed

Striped bass (*Morone saxatilis*)	1950-1959	Chadwick (1962)	1950-1959	1.3-5.3 [e]	Chadwick (1962)	1950-1968	5.0 [f]	(White 1986)
	1960-1963	Mckechnie and Miller (1971)	1960	1.8	Clark (1960)			
	1964-1968	CDFG Partyboat database, unpub. data, provided by J. Robertson	1961-1979	-	Linear interpolation			
	1969-1979	(White 1986)	1980	1.7	RecFIN (1980-1985)			
Unidentified sharks (Selachimorpha)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	9.3	RecFIN (2000-2010)	1950-1979	2	Assumed
Wahoo (*Acanthocybium solandri*)	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	14.4	Fishbase [c]	1950-1979	2	Assumed
White croaker (*Genyonemus lineatus*)	1950-1979	CDFG (2001)	1950-1979	0.2	RecFIN (1980-1985)	1950-1970	8.6	Guel (1973)
						1971-1979	-	Linear interpolation
						1980	14.4	Figueira and Coleman (2010)
White weakfish (*Atractoscion nobilis*)	1950-1979	CDFG (2001)	1950-1960	7.7	Clark (1960)	1950-1970	3.1	Mean from Guel and Clark (1968) & Guel (1973)
			1961-1979	-	Linear interpolation	1971-1979	-	Linear interpolation
			1980	2.3	RecFIN (1980-1985)	1980	3.4	Figueira and Coleman (2010)
Yellowfin tuna (*Thunnus albacares*)	1950-2010	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	7.7	RecFIN (1993-1999)	1950-2010	2.1	Figueira and Coleman (2010)
Yellowtail amberjack (*Seriola lalandi*)	1950-1979	CDFG (2001)	1965-1972	0.0	Linear interpolation	1966-1969		Linear interpolation
			1973	3.4	Crooke (1983)	1970-1979	2.6	Guel (1973)
			1974-1979	7.3	Crooke (1983)			
Others [g]	1950-1979	CDFG Partyboat database, unpub. data, provided by J. Robertson	1950-1979	0.3-33	RecFIN (1980-1985)	1950-1979	2	Assumed

Shellfish:								
Abalone (*Haliotis* spp.)	1950-1959	Assumed same catch as 1960	1950-2010	0.8-1.7 [h]	(Pinkas *et al.* 1974)			
	1960, 1972, 1986, 1989	(Haaker *et al.* 2001)				1960, 1972	4	Assumed based on observations from (CDFG 2010)
	1961-1971, 1973-1982	Linear interpolation						
	1983-1985, 1987,1988, 2000	(Haaker *et al.* 2004)						
	1990-1999, 2002-2008	(CDFG 2010)						
	2001	Average catch from 2002-2010						
	2009-2010	(CDFW, unpub. data, provided by P. Kalvass)						
California Spiny lobster (*Panulirus interruptus*)	1950-1964	Assumed 32 MT based on 1965-1972 catch						
	1965-2009	(Neilson 2011)						
	2010	Assumed 41% of commercial catch (Neilson 2011)						
Dungeness crab (*Metacarcinus magister*)	1950-2010	1% of Commercial catch (Hankin *et al.* 2004)						
Pacific Razor Clams (*Siliqua patula*) [i]	1950-1952, 1971-1973	Assume 80,000 clams for entire beach based on average catch from 1974-1989	1950-1989	0.09 [j]	(Hirschhorn 1962)			
	1953-1970 (odd years)	Assumed 50,000 clams for N. Clam beach based on average catch from 1974-1989						
	1953-1970 (even years)	Assumed 30,000 clams for S. Clam beach based on average catch from 1974-1989						
	1974-1989	(CDFW, unpub. data for Clam beach, provided by P. Kalvass)						

Pismo clams (*Tivela stultorum) at Pismo beach* [k]	1950	Assumed same catch as 1949 (Pattison and Lampson 2008)	1950, 1975-1983	0.5	(Weymouth 1922)			
	1951-1964	Linear interpolation						
	1965	4 million pounds reported by (Frey 1971) were assumed to have been harvested c1965						
	1966-1974	Linear interpolation						
	1975-1983	(Wendell *et al.* 1986)						
	1984-2010	Assumed negligible catch after 1983						
Rock crabs (*Cancer* spp.*)*	1950-2010	Assumed ratio of 1:21 per kg of Dungeness crab [l]						
Other clams (Humboldt Bay) [m]	1950-1974	Used 1975-1989 average annual catch						
	1976	Linear interpolation						
	1975, 1977-1989, 2008	(McVeigh *et al.* 2010)	1975, 1977-1989, 2008	0.06-0.19	(McLean 1978; Lauzier *et al.* 1998; Bradbury *et al.* 2005)[m]			
	2009-2010	Assume same catch as 2008						
Other clams (Morro Bay) [m]	1950-1990	Assumed 25% of Humboldt Bay Harvest based on the proportion in 1979-1980						
	1979-1980	(Mello 1981)	1979-1980	0.06-0.19	(McLean 1978; Lauzier *et al.* 1998; Bradbury *et al.* 2005)[m]			
	1991-2010	Assumed 10% of 1980 harvest due to reduced effort (Mello 1981)						
Other clams (Tomales Bay) [m]	1950-1967	Used 1968-1969 average annual catch						
	1970-1988	Linear interpolation						
	1968,1969, 1989-1998	(CDFW, unpub. data, provided by P. Kalvass)	1962,1963, 1989-1998	0.06-0.19	(McLean 1978; Lauzier *et al.* 1998; Bradbury *et al.* 2005)[m]			

	1999-2010	Assume 25% of average catch from 1989-1998(Moore 2001a)						
WASHINGTON								
Finfish:								
Albacore (*Thunnus alalunga*)	1950-1982	Holts (1985)	1980-1982	7.7	RecFIN (1980-2010)			
	1983-1986, 1988-1992	Linear interpolation						
	1987, 1993-2002	Figueira						
Black Rockfish (*Sebastes melanops*)	1975-1983, 1991-1992	WDFW, unpub. data, provided by E. Kraig	1975-1983, 1991-1992	1.1	RecFIN (1980-2010)			
Chinook salmon (*Oncorhynchus tshawytsch*) – marine	1950-1966	INPFC (1979)	1950-2009	6.7				
	1967-2009	WDFW, unpub. data, provided by E. Kraig						
	2010	RecFIN						
Chinook salmon – freshwater	1950-1975	Assumed 1% of total recreational chinook catch	1950-2010	6.7	RecFIN (1980-2010)			
	1976-2010	WDFW, unpub. data, provided by E. Kraig						
Chum salmon (*Oncorhynchus keta*)	1950-1964	1965-1974 average annual catch	1950-2010	4.8	RecFIN (1980-2010)			
	1966-1967	INPFC (1979)						
	1967-2010	WDFW, unpub. data, provided by E. Kraig						
Coho salmon (*Oncorhynchus kisutch*) – marine	1950-1966	INPFC (1979)	1950-2009	2.0	RecFIN (1980-2010)			
	1967-2009	WDFW, unpub. data, provided by E. Kraig						
	2010	RecFIN						
Coho salmon – freshwater	1950-1975	Assumed 1% of total recreational coho catch	1950-2010	2.0	RecFIN (1980-2010)			
	1976-2010	WDFW, unpub. data, provided by E. Kraig						

Lingcod	1950-1974	1975-1979 average annual catch	1950-1979, 1990-1992	3.1	RecFIN (1980-2010)			
	1975-1979, 1990-1992	WDFW data						
Pacific Cod (*Gadus macrocephalus*)	1950-1974	1975-1979 average annual catch						
	1975-1979, 1990-1995	WDFW, unpub. data, provided by E. Kraig	1950-1979, 1990-1995	1.4	RecFIN (1980-2010)			
Pacific Halibut (*Hippoglossus stenolepsis*)	1950-1964	Assumed 5 MT based on 1965 catch						
	1965-1974	Skud (1975)	1965-1974	5.4	Skud (1975)			
	1975-1976	WDFW, unpub. data, provided by E. Kraig	1975-1979	5.9	RecFIN (1980-1985)			
	1977-2010	IPHC RARAs [d]						
Pink Salmon (*Oncorhynchus gorbusch*)	1950-1966 (odd years)	INPFC (1979)	1950-2010	2.0	RecFIN (1980-2010)			
	1960, 1962, 1964	PFMC (1993)						
	1967-2010	WDFW, unpub. data, provided by E. Kraig						
Rockfish (10 species [p])	1950-1974	Used 1974-1979 average annual catch						
	1975-1979, 1991-1992	WDFW, unpub. data, provided by E. Kraig	1975-1979, 1991-1992	0.2-3.6 [p]	RecFIN (1980-2010)			
Spiny dogfish (*Squalus suckleyi*)	1950-1979	1980-1984 average annual catch						
	1990-1995	Linear interpolation						
Sockeye salmon (*Oncorhynchus nerka*)	1950-1966	1965-1974 average annual catch	1950-2010	2.2	RecFIN (1980-2010)			
	1966-1967	INPFC (1979)						
	1969-2010	WDFW, unpub. data, provided by E. Kraig						
Walleye Pollock (*Theragra chalcogramma*)	1950-1974	1975-1979 average annual catch						
	1975-1979	WDFW, unpub. data, provided by E. Kraig	1975-1979	0.5	RecFIN (1980-2010)			

White sturgeon (*Acipenser transmontanus)*	1950-1979	1980-1984 average annual catch						
	1989-2001	WDFW, unpub. data, provided by E. Kraig	1988-2001	10.6	RecFIN (1980-2010)			
Other fish [q]	1950-1979	Estimated based on average annual catch composition from 1980-2010						
	1990-1995	Linear interpolation						
Shellfish:								
Dungeness crab	1950-1975,1978, 1979, 1982-1994 (even years)	Estimated using average catch per license from 1976-1995						
	1976, 1977, 1980, 1981-1995 (odd years)	WDFW, unpub. data, provided by E. Kraig	1976-1995	.64 [r]	(Ainsworth *et al.* 2012)			
	1996-2010	Data obtained from WDFW website: wdfw.wa.gov/fishing/shellfish/crab/estimates.html						
Pacific Oyster (*Crassostrea gigas*)	1950-1971	Estimated using average catch per license from 1972-1981						
	1972-1986	Hood canal harvest from WDFW, unpub. data, provided by E. Kraig				1972-1986	1.3	Ratio of total harvest to hood canal harvest from 1990-2001
	1990-1999	WDFW, unpub. data, provided by E. Kraig						
	2000-2001	WDFW, unpub. data, provided by E. Kraig	2000-2001	0.026	Average weight from 1990-1999			
	1987-1989, 2002-2010	Estimated using average catch per license from 1990-2001						
Pacific Razor clam	1950-2010	WDFW, unpub. data, provided by D. Ayres	1950-2010	0.09 [j]	(Hirschhorn 1962)			

Red rock crab (*Cancer productus*)	1950-1975,1978, 1979, 1982-1994 (even years)	Estimated using average catch per license from 1976-1995						
	1976, 1977, 1980, 1981-1995 (odd years)	WDFW, unpub. data, provided by E. Kraig	1976-2010	0.5 [s]	(Caroll 1982)			
	1996-2010	Estimated using average catch per license from 1976-1995						
Spot prawn (*Pandalus Platyceros*	1950-1976, 1978,1979	Estimated using average catch per license from 1980-1989						
	1977, 1980-2003	WDFW, unpub. data, provided by E. Kraig						
	2003-2010	Estimated using average catch per license from 1993-2002						
Other clams (7 species [t])	1950-1971	Estimated using average catch per license from 1972-1976						
	1972-1986, 1990-2001, 2003-2007	WDFW, unpub. data, provided by E. Kraig						
	1987-1989	Linear interpolation						
	2002, 2008-2010	Estimated using average catch per license from 2003-2007						
OREGON:								
Finfish:								
Albacore (*Thunnus alalunga*)	1975-1976, 1978-1992	Estimated as 0.2% of commercial landings based on average proportion observed in 1977 and 1993-1996 catch						
	1977	ODFW (1977)	1977	7.2	RecFIN (1993-2010)			
	2003	ODFW Ocean Recreational Boat Survey; www.dfw.state.or.us	2003	9.2	RecFIN (2000-2010)			

Chinook salmon (*Oncorhynchus tshawytsch*) – marine	1950-1966	INPFC (1979)	1950-1970	5.6	Clark (1960)			
	1967-1977	ODFW (1977)	1971-1979	-	Linear interpolation			
	1978-2010	ODFW (www.dfw.state.or.us)[u]	1980-2010	6.7	RecFIN (1980-2010)			
Chinook salmon – freshwater	1950-1967	INPFC (1979)	1950-1970	5.6	Clark (1960)			
	1968-1977	ODFW (1977)	1971-1979	-	Linear interpolation			
	1978-2010 [u]	ODFW (www.dfw.state.or.us) [u]	1980-2010	6.7	RecFIN (1980-2010)			
Coho salmon (*Oncorhynchus kisutch*) – marine	1950-1966	INPFC (1979)	1950-1970	3.4	Clark (1960)			
	1967-1977	ODFW (1977)	1971-1979	-	Linear interpolation			
	1978-2010	ODFW (www.dfw.state.or.us)[u]	1980-2010	2.9	RecFIN (1980-2010)			
Coho salmon – freshwater	1950-1967	INPFC (1979)	1950-1970	3.4	Clark (1960)			
	1968-1977	ODFW (1977)	1971-1979	-	Linear interpolation			
	1978-2010	ODFW (www.dfw.state.or.us)[u]	1980-2010	2.9	RecFIN (1980-2010)			
Pacific Halibut (*Hippoglossus stenolepsis*)	1950-1957	Assumed 2 MT based on 1958-1960 catch						
	1958-1960	Miller and Gotshall (1965)	1958-1974	5.4	Skud (1975)			
	1961-1973	Linear interpolation						
	1974	Skud (1975)						
	1975-1976	Linear interpolation						
	1977-2010	IPHC RARAs [c]						
Pink and Chum salmon (*Oncorhynchus* spp.)	1950-1971 (odd years)	Average of annual catch from 1973-1979 (odd years)	1950-2010	1.3	Mean Pink salmon weight for OR - RecFIN (1980-2010) [v]			
	1950-1972 (even years)	Average of annual catch from 1976-1982 (even years)						
	1973-2010	ODFW (1977); ODFW (www.dfw.state.or.us)[u]						

Other fish [w]	1950-1979	Estimated based on average annual catch composition from 1980-2010						
Shellfish:								
Dungeness crab	1950-1970	Estimated using average catch per license from 1971						
	1971	ODFW (1977)	1971	.64 [r]	(Ainsworth *et al.* 2012)			
	1972-2005	Estimated using catch per license rates, linearly interpolated between 1971-2006 rates						
	2006	Estimated using average catch per license from 2007-2011						
	2007-2010	Ainsworth *et al.* (2012)						
Pacific Razor clam	1950-1954	Estimated using average catch per license from 1955-1959	1950-2010	0.09 [j]	Hirschhorn (1962)	1950-2010	1.05	ODFW (1977); www.dfw.state.or.us[x]
	1955-2010	ODFW, unpub. data, provided by M. Hunter						
Red rock crab	1950-2010	Assumed ratio of 1:27 per kg of Dungeness crab [l]						
Other clams (5 species [y])	1950-1969	Estimated using average catch per license from 1970-1974						
	1970-1983	Gaumer (1984)						
	1984-2007	Linear interpolation						
	2008	Ainsworth and Vance (2009)						
	2009-2010	Estimated using catch per license from 2008						

Notes:
[a] 1/2 the max weight listed on Fishbase.
[b] Average of annual ratios used by Crone at al. (2009) from 1962-1980.
[c] Assumed 1/2 the max length and converted to weight using weight-length conversions.
[d] The 1991-2010 sport catch presented in the annual IPHC RARAs from 1992-2011 were separated by state, while the 1977-1990 estimates, taken from (Hare 2012), were not. We allocated 59%, 40%, and 1% of annual sport catch from 1977-1990 to WA, OR, and CA, respectively, based on the average distribution in the catch from 1991-2000.
[e] Different mean weight values used for different areas and years.

[f] White (1986) estimates party boat catch is 14% of total catch, we assume a more conservative value of 20% for the earlier period;

[g] Other taxonomic groups reconstructed using party boat data include; *Acipenser* spp., *Alopias vulpinus, Amphistichus argenteus, Anoploma fimbria,* Atherinidae, *Atherinopsis californiensis, Auxis rochei, Chondrichthyes, Citharichthys sordidus, Clupea pallasii pallasii, Coryphaena hippurus, Cottidae, Embiotoca lateralis,* Embiotocidae, Engraulidae, *Eopsetta jordani, Galeorhinus zyopterus, Girella nigricans, Hermosilla azurea, Heterodontus francisci,* Hexagrammidae, *Hexagrammos decagrammus, Hippoglossus stenolepis, Hypomesus pretiosus, Isurus oxyrinchus, Katsuwonus pelamis,* Labridae, *Menticirrhus undulatus, Merluccius productus, Mustelus henlei, Myliobatis californica,* Osmeridae, Osteichthyes, Pleuronectiformes, *Prionace glauca,* Rajiformes, Sciaenidae, Scombridae, Scorpaenidae, *Seriphus politus,* Serranidae, *Squalus suckleyi, Stereolepis gigas, Tetrapturus audax, Thunnus orientalis, Triakis semifasciata, Umbrina roncador* and marine fish not identified. Species specific mean weights from RecFIN were used to convert fish numbers to weight;

[h] 1.7 kg for Red Abalone, 0.8 kg for white abalone and 0.9 for other species (Pinkas *et al.* 1974);

[i] From 1953-1970 and 1974-1989, South and North clam beaches had alternating seasonal closures. No estimates were made for years after 1989 as clam populations declined in the mid-1990s (Moore 2001b);

[j] We assumed that the majority of sport catch are at least 1-year old (ODFW 1977). Due to alternating seasonal closures, clams in CA may be slightly larger, however we conservatively maintained the same estimate as for OR and WA;

[k] Pismo clam harvests declined in the late 1970s and early 1980s due to increased sea otter predation, effectively putting an end to the recreational fishery (Spratt 1982; Wendell *et al.* 1986; Pattison and Lampson 2008). Weight calculations are based the minimum 5 inch size limit from 1949-1986 (Pattison and Lampson 2008), and conversions from (Weymouth 1922)

[l] We used Dungeness crab catch as an indicator of rock crab catch for OR and CA as they are caught using the same gear. We assumed a ratio of 1 kg of rock crab for every 21 kg of Dungeness crab in CA, which was the geometric mean of the average ratio observed in the CPFV logbooks from 1994-2010. We assumed a ratio of 1 kg of red rock crab for every 27 kg of Dungeness crab caught annually based on the average ratio observed in the WA recreational catch data.

[m] Includes estimates of gaper clams (*Tresus* spp.), Washington clams *(Saxidomus* spp.), littleneck clams (*Leukoma staminea*), Nuttall's cockle (*Clinorcardium nuttallii*) and Pacific geoduck (*Panopea generosa*). Assumed an average size of 4 inches for gaper clams (Moore 2001a) and middle range of lengths from (McLean 1978) for other species. Wet weights were obtained using L-W conversions from (Lauzier *et al.* 1998; Bradbury *et al.* 2005). Tomales Bay estimates were only for gaper clams and we estimated the percentage of other clams harvested based on the proportion of those species harvested in Humboldt bay.

[p] Copper rockfish (*S. caurinus*), quillback rockfish (*S. maliger*), yelloweye rockfish (*S. ruberrimus*), brown rockfish (*S. auriculatus*), canary rockfish (*S. pinniger*), yellowtail rockfish (*S. flavidus*), China rockfish (S. *nebulous*), blue rockfish (*S. mystinus*), bocaccio rockfish (*S. paucispinis*), and widow rockfish (*S. entomelas*). Species-specific values were used for weight conversions and were taken from mean lengths in the RecFIN database over the 1980-2010 period. All reconstructed rockfish catch was assigned as *Sebastes* spp. from 1950-1974, as there was little species specific information for this period;

[q] Other species accounted for another 10% of total reconstructed catch estimates for WA from 1980-2010. From 1950-1979, an additional 10% of catch was allocated to these species in 20 major taxonomic groupings (*Anoplopoma fimbria*, Chondrichthyes, *Citharichthys sordidus*, *Clupea pallasii pallasii*, Clupeiformes, Cottidae, Embiotocidae, Gadidae, Hexagrammidae, Hexagrammos decagrammus, *Hypomesus pretiosus*, *Merluccius productus*, Osmeriformes, Pleuronectiformes, Rajiformes, Scombridae, *Scorpaenichthys marmoratus*, Scorpaeniformes, Selachimorpha, and marine fishes not identified);

[r] Midrange of the mean weights observed between 2007-2011 by (Ainsworth *et al.* 2012);

[s] Assumed an average length of 5 inches (based on the minimum retention size for WA) and estimated weights using length-weight conversions from (Caroll 1982). As both females and males are retained in WA, we used the average of the weights calculated for the two sexes;

[t] Butter clam (*S. gigantea*), Manila clam (*Venerupis philippinarum*), Nuttall's cockle, littleneck clam, Pacific gaper clam (*T. nuttallii*), Pacific geoduck, and softshell clam (*Mya arenaria*). Individual clam species were not identified from 1972-1986, and we divided this catch among the 7 species based on the catch composition from 1990-1994.

[u] Sport catch statistics for salmon are available on the ODFW website (http://www.dfw.state.or.us/resources/fishing/sportcatch). This data was provided to us in excel by S. Beals

[v] We used the mean weight for pink salmon, rather than chum, as this leads to a more conservative estimate. No data was available for 1994 coastal and Colombia river fall chinook catch and these were estimated using the average annual landings from 1990-1994 and 1995-1998.

[w] Other species accounted for another 58% of total reconstructed catch estimates for OR from 1980-2010. From 1950-1979, an additional 58% of catch was thus allocated to these species in 23 major taxonomic groupings (*Acipenser* spp., *Anoplopoma fimbria,* Atherinidae, Chondrichthyes, *Clupea pallasii pallasii,* Clupeiformes, Cottidae, Embiotocidae, Gadidae, Hexagrammidae, *Hexagrammos decagrammus, Hypomesus pretiosus, Ophiodon elongatus,* Osmeriformes, Pleuronectiformes, Rajiformes, Scombridae, *Scorpaenichthys marmoratus,* Scorpaeniformes, *Sebastes spp.*, Selachimorpha, *Squalus suckleyi,* and marine fishes not identified

[x] ODFW estimates are for Clatsop beach, which accounts for 90-95% of state harvest (ODFW 1977; www.dfw.state.or.us/mrp/shellfish/razorclams). We assumed an additional 5% of harvest from other OR beaches.

[y] Butter clam, Nuttall's cockle, littleneck clam, Pacific gaper clam and softhell clam. Softshell harvests were < 1 t from 1974-1983 and no additional harvests were estimated after 1983

Appendix Table C1. Discard to Landings (D/L) ratios for Groundfish Bottom Trawl Fleet

	1985	1986	1987	2002	2003	2004	2005	2006	2007	2008	2009	2010
# of research hauls observed	**251**	**453**	**404**									
Total DL ratios [a]:	**0.58**	**0.38**	**0.45**	**0.74**	**0.51**	**0.43**	**0.50**	**0.48**	**0.38**	**0.29**	**0.33**	**0.30**
							Species composition of discards by weight (%):					
Skates	14.8	11.8	13.5	12.5	7.7	10.4	10.2	10.1	11.5	9.8	7.1	7.7
Spotted spiny dogfish	7.0	19.0	16.2	6.0	5.6	8.0	16.0	8.2	7.8	15.0	7.2	7.2
Pacific hake	5.4	19.2	14.1	16.2	27.4	37.3	9.4	13.0	14.9	19.2	11.5	6.2
Other gadiformes	0.3	0.4	1.0	0.6	0.2	0.1	0.1	0.1	0.2	<0.1	0.1	3.0
Rockfish	39.2	13.4	7.7	5.7	5.2	4.7	4.6	7.5	8.4	8.6	9.9	9.3
Thornyheads	5.8	3.8	3.5	6.3	8.0	4.6	2.6	2.6	3.7	3.9	7.7	7.5
Lingcod	<0.1	<0.1	<0.1	1.0	0.9	1.0	2.4	2.1	1.0	0.6	0.7	0.1
Arrowtooth flounder	9.9	8.7	12.0	10.4	5.7	7.1	22.9	9.2	9.9	9.3	18.3	11.8
Dover sole	1.5	3.9	1.7	7.7	8.4	5.4	7.5	12.1	12.5	8.7	9.2	8.2
English sole	0.5	1.2	1.8	3.9	5.4	2.3	3.0	4.9	2.8	1.1	1.7	1.3
Pacific halibut	0.1	0.2	<0.1	2.4	1.4	1.8	3.1	3.0	2.8	3.1	3.1	2.8
Petrale sole	0.2	0.2	0.4	1.4	0.8	0.8	0.6	1.4	1.3	0.7	2.6	2.0
Other flatfish	2.7	7.5	11.0	10.3	10.1	6.0	5.8	7.9	6.6	2.6	7.0	5.6
Sablefish	4.1	3.0	6.1	8.3	4.1	4.8	2.8	2.2	2.5	1.4	2.0	3.7
Other marine fishes	5.0	4.8	5.1	7.4	8.9	5.7	3.6	4.8	4.8	4.3	3.4	12.1
Crabs	2.7	2.0	2.7				5.5	10.9	9.3	11.7	8.5	11.3
Echinoderms	0.6	1.0	2.8									
Others	0.2	<0.1	0.3									

[a] D/L ratios are for total discards with the exception of sablefish, lingcod and Pacific halibut, which include discard mortality.

1985-1987 D/L ratios are calculated using unpublished data from Pikitch *et al.* (1988). We assumed a 50% discard mortality for sablefish, lingcod and Pacific halibut.

2002-2010 D/L ratios are calculated using 2002-2009 groundfish discards and landings estimates from Bellman and Heery (2013) and Bellman *et al.* (2011) , 2002-2010 Pacific halibut discard estimates from Jannot *et al.* (2012) and 2005-2010 crab discards from NWFSC (Hastie and Bellman 2006, 2007; Bellman *et al.* 2008; Bellman *et al.* 2010a; Bellman *et al.* 2010b; Bellman *et al.* 2011). The NWFSC reports included discard mortality estimates for sablefish, lingcod and Pacific halibut and we apply a 50% discard mortality rate to sablefish and lingcod discards from Bellman and Heery (2013)

Appendix Table C2. Discard to landings (D/L) ratios for the ocean shrimp fishery from 1979-2011

Year	1979	1981	1986-1987	1993	1995	1997	1999	2000	2005	2007	2008	2009	2010	2011
D/L ratio	**3.3**	**0.97**	**0.49**	**0.98**	**1.61**	**0.75**	**0.77**	**0.79**	**0.09**	**0.30**	**0.08**	**0.18**	**0.06**	**0.02**
# of research hauls	114	151	486	11	166	34	34	32	1533					
Species composition of discards by weight (%):														
Skates			0.8	0.7	0.9	0.3	0.3	0.2	0.1	<0.1	0.1	<0.1	<0.1	0.3
Spotted spiny dogfish										<0.1	0.3	<0.1	1.4	0.6
Smelts	7.5	49.5	17.3	0.7	2.1	1.8	1.4	64.3	7.8	0.1	1.0	0.4	1.6	
Pacific hake	25.2	20.2	36.5	77.6	69.9	82.0	73.3	0.5	44.0	84.4	55.8	75.1	34.1	60.2
Rockfish [a]	27.5	10.4	12.5	7.4	2.7	5.4	3.2	3.1	12.5	1.9	3.1	1.0	1.4	4.2
Thornyheads	<0.1	0.3	0.3	<0.1	0.1	<0.1	<0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Lingcod [a]	0.5		1.3	1.8	0.5	0.4	0.7	1.1		<0.1	<0.1	<0.1	<0.1	0.1
Arrowtooth flounder	0.9	1.7	3.3	1.1	2.1	0.5	0.6	5.0	1.7	0.3	2.5	0.8	1.9	1.6
Dover sole [a]	2.3	0.2	2.8	0.9	1.2	1.2	0.4	0.4	1.7	1.0	1.1	0.3	0.3	0.7
Other flatfish [a]	14.7	2.8	2.5	0.2	0.7	0.1			1.2	9.8	14.8	3.9	14.3	1.2
Pacific halibut			0.2		1.1	0.8	1.9	19.6		<0.1				<0.1
Pacific sanddab	0.1				1.1	<0.1	0.1	<0.1	0.9					0.6
Petrale sole [a]	0.3									0.1	0.1	<0.1	0.1	0.4
Slender Sole	0.4	0.1	5.2	2.1	2.9	2.5	2.7	2.5	10.3					25.4
Rex Sole [a]	0.7		2.9	0.3	1.7	1.0	0.3	0.2	4.4					4.5
Other marine fishes	1.8	1.9	7.9	5.7	9.7	1.3	5.3	0.3	3.8	2.3	4.7	1.3	5.8	<0.1
Hagfish			0.1		0.1	<0.1	0.7	<0.1	0.5					
Sablefish [a]	17.6	12.0	4.4	0.4	2.6	1.2	7.8	1.1	<0.1	<0.1	0.1	<0.1	0.1	<0.1
Dungeness crab										<0.1	0.1	<0.1	<0.1	<0.1
Ocean shrimp [b]	0.3	1.0	2.1	1.0	0.6	1.4	1.3	1.3	10.9		16.3	17.0	38.9	

Sources: 1979 data (Demory *et al.* 1980), 1981-2005 data (Hannah and Jones 2007), 2007-2011 data (Bellman *et al.* 2008; Bellman *et al.* 2010a; Bellman *et al.* 2010b; Bellman *et al.* 2011, 2012)

[a] 1979-2005 D/L ratios include landed bycatch of marketable groundfish taxa

[b] 1979-2005 D/L ratios assumed 1% of shrimp catch was discarded

Appendix Table D1: Total reconstructed catches (tonnes) by sector for CA, WA and OR, years 1950-2010

Year	NMFS commercial	Total reconstructed catch	Reconstructed commercial	Discards	Recreational
1950	686,189	750,484	23,762	23,891	16,641
1951	482,624	548,514	25,142	24,960	15,787
1952	376,113	451,224	29,235	26,500	19,377
1953	331,753	397,722	30,185	21,253	14,531
1954	373,561	450,382	31,732	27,191	17,898
1955	361,866	440,658	33,885	26,144	18,762
1956	387,949	471,979	34,438	30,223	19,369
1957	368,103	455,470	33,809	31,039	22,518
1958	401,880	487,537	32,546	31,933	21,177
1959	325,279	417,980	35,810	31,357	25,533
1960	312,962	397,237	31,905	28,492	23,878
1961	342,217	425,311	29,513	28,549	25,032
1962	310,028	399,109	30,961	31,252	26,868
1963	323,705	412,084	28,361	32,582	27,436
1964	292,750	379,265	28,748	30,690	27,077
1965	291,881	378,054	26,715	32,437	27,020
1966	300,831	385,103	22,978	33,132	28,162
1967	346,609	431,099	22,469	35,418	26,603
1968	298,863	378,856	22,706	28,436	28,851
1969	364,176	439,821	20,533	28,619	26,492
1970	422,039	509,797	23,484	36,190	28,084
1971	359,641	441,728	23,799	31,437	26,851
1972	391,867	484,545	24,909	41,061	26,708
1973	438,029	529,635	19,763	45,483	26,359
1974	420,067	509,523	15,606	46,394	27,455
1975	500,597	594,661	18,199	49,045	26,821
1976	522,778	627,319	20,687	54,635	29,219
1977	514,126	629,759	24,473	66,918	24,242
1978	434,416	553,844	23,651	70,936	24,840
1979	485,180	599,409	23,950	64,335	25,944
1980	493,207	604,818	21,047	59,606	30,958
1981	499,513	630,144	32,402	69,257	28,972
1982	458,193	587,067	27,559	71,050	30,266
1983	353,442	458,749	24,132	53,848	27,326
1984	314,070	418,114	29,079	50,455	24,510
1985	287,136	390,777	24,559	54,399	24,683
1986	312,851	435,013	31,895	63,936	26,331
1987	340,221	486,746	45,843	71,657	29,026
1988	370,567	506,652	32,724	74,276	29,085
1989	375,272	517,539	33,693	85,907	22,668
1990	310,811	431,202	30,712	68,159	21,520
1991	482,346	593,304	27,739	63,244	19,976
1992	447,898	575,288	26,358	81,828	19,205
1993	396,386	505,120	29,191	61,763	17,781
1994	489,817	586,363	29,459	50,619	16,468
1995	451,542	547,420	30,169	46,291	19,417
1996	485,010	578,927	28,059	49,780	16,079
1997	528,401	625,025	24,003	53,995	18,627
1998	416,794	490,962	24,120	31,455	18,593
1999	504,533	590,880	28,075	41,578	16,694
2000	544,751	641,867	33,254	42,668	21,193
2001	480,349	569,194	36,202	32,416	20,227
2002	437,746	537,294	37,905	41,644	20,000
2003	400,953	477,039	37,656	19,994	18,436
2004	479,402	557,851	42,217	20,319	15,912
2005	524,375	598,090	43,864	16,162	13,689
2006	527,510	606,052	43,465	22,676	12,401
2007	502,840	574,946	41,222	19,550	11,334
2008	491,162	554,386	38,992	14,304	9,928
2009	406,800	470,255	34,317	16,634	12,505
2010	482,208	539,144	31,025	13,764	12,147