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U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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Cover photo: Fisher catching Kona crab in a net. Photo credit: John Wiley / Poseidon Fisheries Research.

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Executive Summary

The catch, catch rate, and fishing effort for Kona crab in the main Hawaiian Islands were investigated to determine the need for conducting a stock assessment. The current annual catch limit (ACL) for Kona crab in the main Hawaiian Islands is 30,802 lb based on results from the latest stock assessment (Kapur et al., 2019). In the years since the assessment, the annual commercial catch was always less than 6,000 lb, well below the ACL.

The commercial catch reported from inshore reporting areas (extending to ~2 nautical miles from shore) accounted for more than 80% of the total commercial catch in 2014-2024. Before then, catch from Penguin Bank (>3 nautical miles from shore, in federal waters) accounted for 50% of the total catch. However, there was minimal catch reported from Penguin Bank since 2014 and catch from federal waters as a whole was minor.

The inshore reporting areas for the commercial fisher reporting system (FRS) only extend to about 2 nautical miles from shore and do not include all state waters, which extend to 3 nautical miles from shore. The actual annual catch in state waters may have accounted for ~90% or more of the total catch in 2014–2024. Considering the recent low annual commercial catch (average of 3,400 lb or 10% of ACL) and the small proportion of total catch in federal waters, an update stock assessment for Kona crab may not be warranted at this time.

Introduction

Kona crabs *Ranina ranina*, or pāpa'i kualoa, are marine brachyurans inhabiting sandy substrate at depths ranging from 2 to 200 meters, in areas subject to strong currents and adjacent to coral reefs (Vansant, 1978; Thomas et al., 2013). Kona crabs begin life as planktonic larvae in the water column. The larvae settle on benthic substrate as juveniles and grow into adults in sandy habitats. Mature female crabs receive sperm from males via copulation and externally fertilize their eggs. Females externally brood their eggs until they hatch into larvae and are released into the water column (Onizuka, 1972). Adult Kona crabs are opportunistic scavengers and spend the majority of time buried in the sand to avoid predators, emerging only to feed and mate (Skinner & Hill, 1986).

In Hawai'i, Kona crab is a targeted fishery that deploys hoop nets (tangle nets) which are circular frames 24 to 30 inches in diameter with 1 cm to 1 inch mesh (Kapur et al., 2019). The hoop nets are baited and deployed in tethered daisy chains and set over sandy bottom for an average soak time of one hour (Kennelly & Craig, 1989). When baited hoop nets are deployed, some Kona crabs will often emerge from the sand and quickly find the bait. The crab's spiny appendages tangle it in the net (see cover photo and Figure 2 in Wiley et al., 2020).

Since the 1970s, a variety of restrictions have been used to manage the Kona crab fishery in Hawai'i. The fishery is closed during the spawning season. The closure was first established to happen between June 1 – August 31 in the late 1970s. In 1993, the season closure was extended to between May 1 – August 31, and the closure was further extended to between May 1 – September 30 in 2024, based on observations of berried females in September 2019 (John Wiley, personal communication; Hawai'i Division of Aquatic Resources, 2024). There is a 4-inch minimum size for sold catch, first described by Onizuka (1972). The size limit applied to all sectors (both sold and unsold catch) starting in 2002. Spearfishing has been prohibited for crabs and lobsters since 1958. In 1998, Kona crab gear was prohibited to be on a vessel in possession of bottomfish species gear, but this regulation was repealed in 2010. Harvesting of female crabs was prohibited starting in 2006 and this prohibition was lifted in 2024. However, Kona crabs berried with eggs are still not allowed to be taken. Since the closure of the Northwestern Hawaiian Islands under Proclamation 8031, all Kona crab fishing has taken place in the main Hawaiian Islands.

The first formal stock assessment of the Hawai'i Kona crab fishery indicated that the stock was experiencing overfishing and was overfished in 2007 (Thomas et al., 2015). The second and most recent stock assessment addressed some of the concerns noted

by an independent reviewer of the first assessment. It concluded that the stock was not overfished and not experiencing overfishing in 2016 (Kapur et al., 2019). The annual catch limit (ACL) was set at 30,802 lb following the most recent stock assessment.

The current ACL applies to the fishing years 2024–2026 (Federal Register FR37985, Vol. 89, No. 89, May 2024). The fishing year begins on January 1 and ends on December 31. Commercial catches from both state and federal waters are counted towards the ACL. Individuals or vessels taking, selling, or offering for sale any marine life for commercial purposes must obtain a commercial marine license (CML). Every commercial marine licensee is required to furnish a monthly report concerning their marine life harvest regardless of whether the catch was sold or not.

Given the elapsed time since the most recent stock assessment, it is necessary to revisit the current management measures and examine available fishery data. To evaluate the necessity of a rigorous updated stock assessment, we analyzed catch data from the commercial fishing reports to detect catch trends, with an emphasis on catch since 2016 and to compare the catch in state waters versus federal waters. In addition, we examined the catch rate and fishing effort in different zones including state waters, Penguin Bank, and federal waters outside of Penguin Bank to evaluate the necessity of an updated stock assessment mainly designed for managing the fishery in federal waters.

Methods

The Fisher Reporting System (FRS) data collected by the Hawai'i Division of Aquatic Resources (DAR) were used to analyze Kona crab commercial catch. In 2000, DAR began collecting sales data directly from commercial fish dealers, which became the sole data source for sold catch starting in 2002. Trip-level FRS reports include the fishing date, commercial marine license number, fishing area(s), species and pounds landed, pounds sold (until 2002), and number landed. Since 2002, the reports also include the gear type and number, hours fished per gear and area, the number of fish lost to predators, and the number of fish released, while the "pounds sold" column was removed. Such catch data are not available from fishers who do not have a commercial marine license.

The spatial distribution of catch in the main Hawaiian Islands was analyzed based on the area codes specified by Yau (2018). The nearshore (state waters) catch was defined as catch from inshore reporting areas surrounding the islands of Hawai'i, Maui, Moloka'i, Lana'i, Kaho'olawe, O'ahu, Kaua'i, Ni'ihau, and Ka'ula. These inshore areas extend to ~2 nautical miles from shore and include area codes 100–108 (Hawai'i county), 300–314 (Maui), 400–409 (O'ahu), and 500–508 (Kaua'i, Figure 1). The catch reported from areas beyond the inshore zones was classified as federal-waters catch, although a small portion of waters in the "federal" areas lie within 3 nautical miles and are technically state waters.

Catch rate and fishing effort were analyzed based on trip records where "hoop net" was deployed. From 1958–2016, 12,237 trips recorded Kona crab catch, including 11,305 records using hoop nets (Kapur et al., 2019). The catch rate was calculated as the catch per fishing day by a license holder (fisher). A "single-reporting day" was used in the most recent stock assessment as the effort unit for catch rate calculation. After 2002, when hours fished became available in FRS, Kapur et al. (2019) noted that there were no reported Kona crab fishing activities taking place longer than 24 hours. In this report, fishing days using hoop nets were used for fishing effort. Fishing days with zero Kona crab catch were included for catch rate and fishing effort summary. For comparison, catch rate and fishing effort in and after 2002 were also presented as catch per hoop net and number of hoop nets.

All analyses were conducted in R and most figures were also produced in R (see Appendix for the R script). The data analyses in some cases were conducted using SAS (statistical analysis system) for comparison and corroboration.

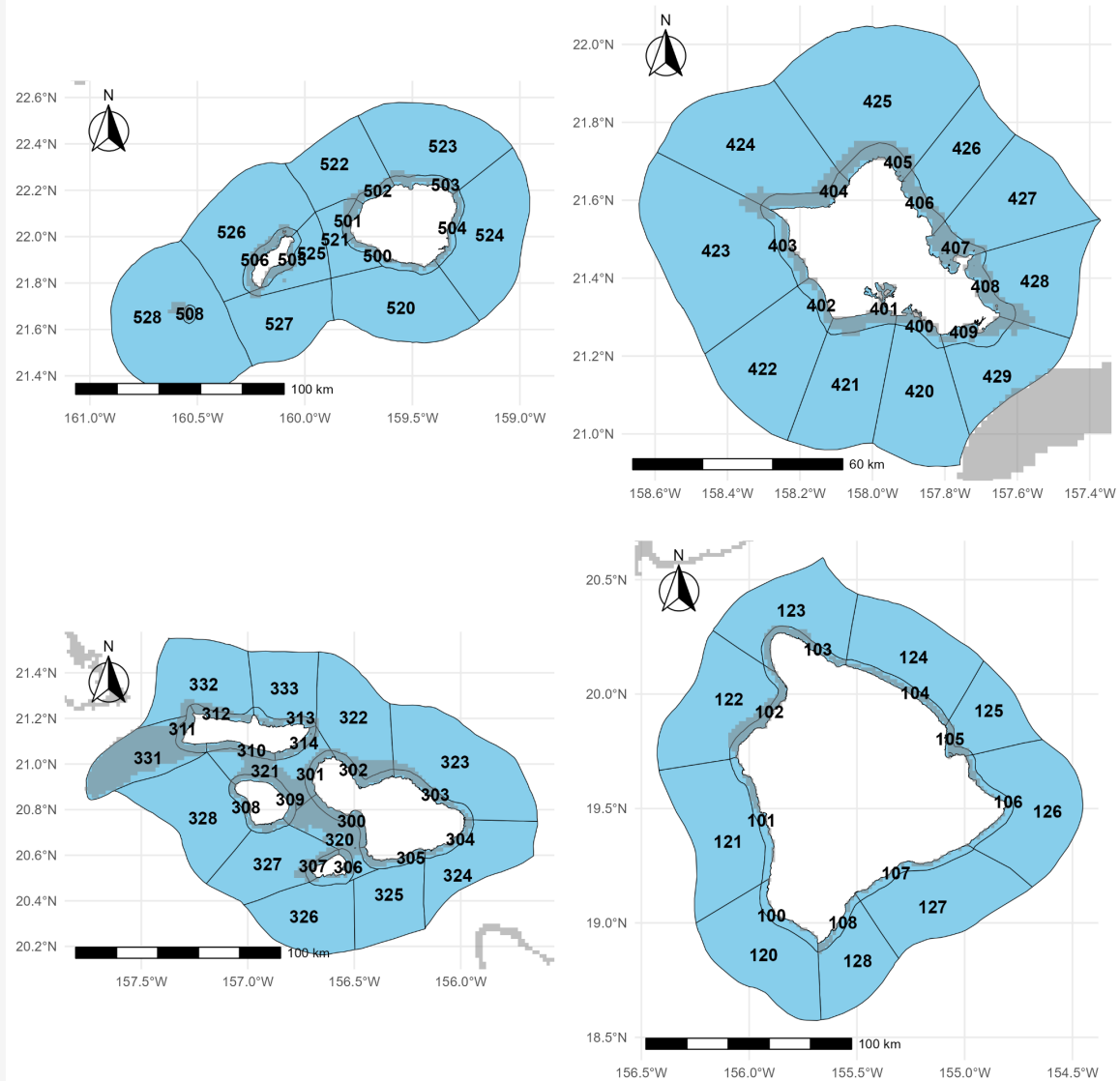


Figure 1. The inshore reporting areas (extending to 2 nautical miles from shore) and reporting areas immediately outside of the inshore areas in all main Hawaiian Islands. Kaua'i (including Ka'ula, Ni'ihau, and Kaua'i islands, top left), O'ahu (top right), Maui (including Moloka'i, Lana'i, Kaho'olawe, and Maui islands, bottom left) and Hawai'i (bottom right) counties are displayed separately. Penguin Bank is located in area 331. Shaded gray areas represent depths between 0 and 200 meters.

Results

Kona crab catch has been reported primarily from the main Hawaiian Islands since 1948 (Figure 2). There were moderate catches (~ 1,000 lb) from areas within the Northwestern Hawaiian Islands in 1956 and 2002. Since 2004, all reported catches have come exclusively from the main Hawaiian Islands.

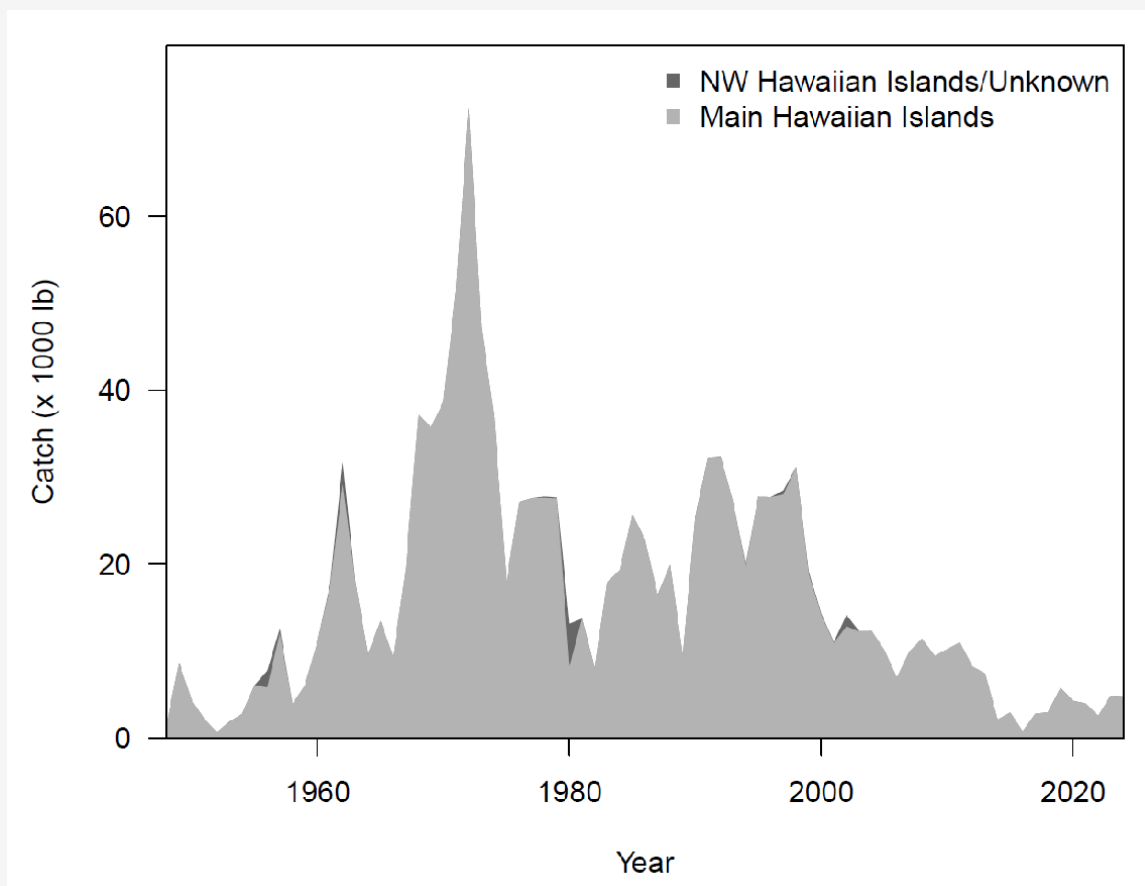


Figure 2. Commercial catch reported from the main Hawaiian Islands and the Northwestern Hawaiian Islands (NWHI). In 1962 and 1980, catch >2,000 lb each year was reported from unknown fishing areas.

Spatial distribution of catch

Catch from federal waters had a significant contribution to the total commercial landings in the main Hawaiian Islands from the 1960s to 2010s (Figure 3). The highest catch in 1972 was mostly from 4 highliners at Penguin Bank. However, catch from Penguin Bank and from federal waters has decreased in recent years. After the primary highliner

operating at Penguin Bank exited the fishery in 2014, federal-water catches have remained low (Figure 4).

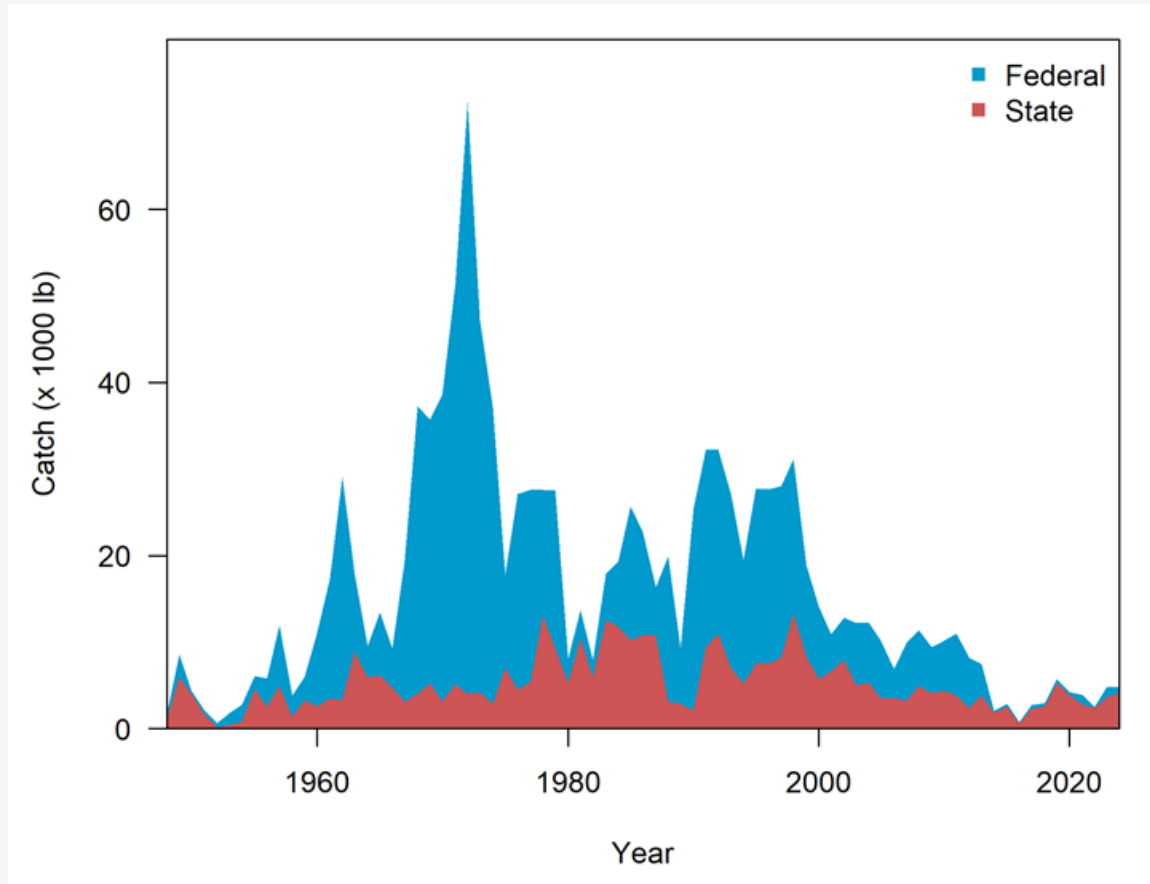


Figure 3. The main Hawaiian Islands commercial catch in state (red) and federal waters (including Penguin Bank, blue).

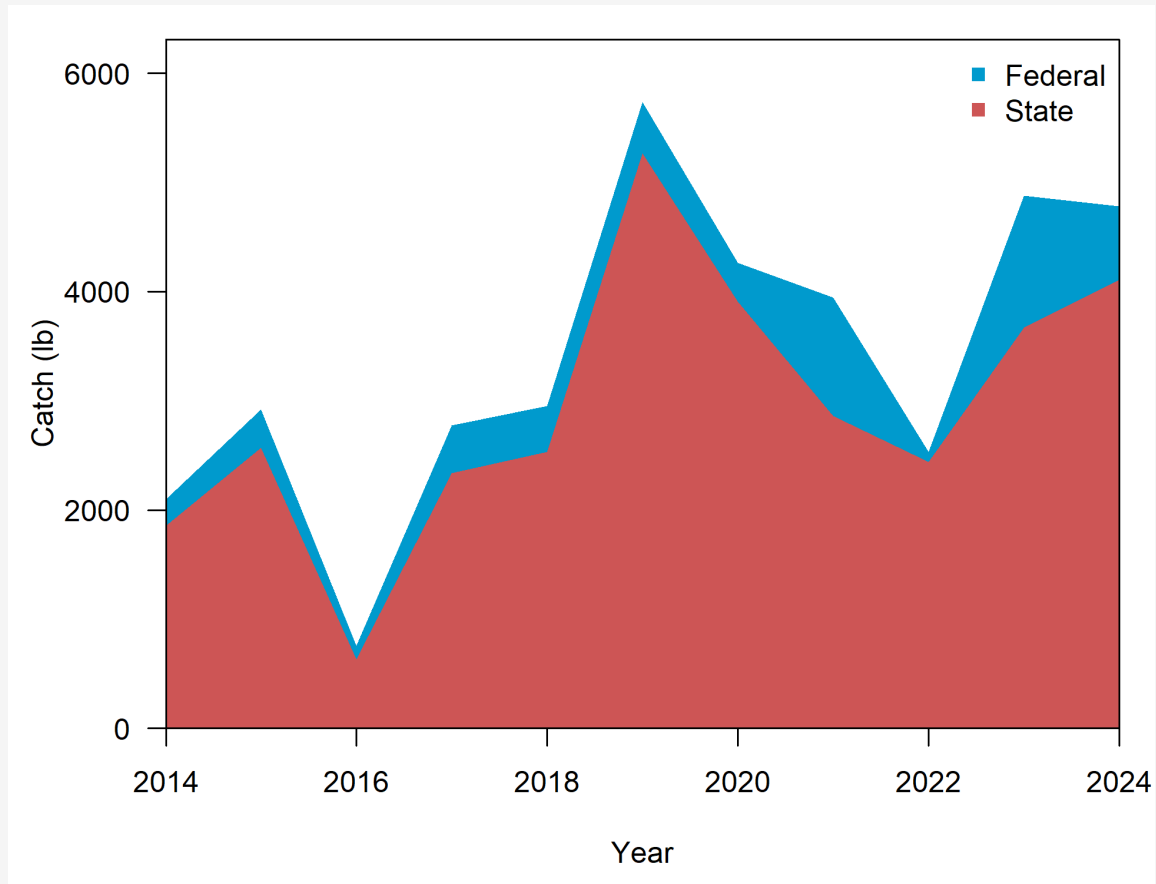


Figure 4. Commercial catch in the recent years (2014–2024) from state (red) and federal waters (including Penguin Bank, blue).

The reported main Hawaiian Islands commercial catch in 2014–2024 was less than 6,000 lb each year and mainly from the state waters (Table 1 and Figure 4). The average annual catch was 3,400 lb.

Table 1. Percent of catch in state waters, Penguin Bank (part of federal waters), and federal waters. ND = non-disclosure due to data confidentiality (<3 fishers reporting) in Penguin Bank. The percent of catch in federal waters includes catch in Penguin Bank when the percent of Penguin Bank catch is ND (*). When the percent of catch in Penguin Bank is available, the percent of catch in federal waters excludes Penguin Bank catch.

Year	Total (lb)	State%	Penguin%	Federal%
2000	14,144	41	54	5
2001	10,896	61	ND	39*
2002	12,830	62	ND	38*
2003	12,211	41	ND	59*
2004	12,297	43	ND	57*
2005	10,111	35	59	6
2006	6,921	52	ND	48*
2007	9,915	33	ND	67*
2008	11,396	44	54	2
2009	9,422	43	ND	57*
2010	10,195	43	44	13
2011	10,979	35	54	11
2012	8,212	30	ND	70*
2013	7,423	51	ND	49*
2014	2,101	88	ND	12*
2015	2,919	88	ND	12*
2016	758	84	0	16
2017	2,777	84	0	16
2018	2,953	86	0	14
2019	5,737	92	0	8
2020	4,265	92	0	8
2021	3,946	72	0	28
2022	2,533	96	0	4
2023	4,879	75	0	25
2024	4,783	86	ND	14*

Catch rate and fishing effort

After 2000, fewer than five fishers each year reported catch from Penguin Bank. One highliner took the majority of the trips in Penguin Bank. To avoid revealing confidential data (<3 fishers reporting), the number of trips were aggregated and displayed in three-year intervals. The number of trips increased until 2006–2008 and then began declining (Figure 5). While the number of trips declined, the catch rate displayed increasing trends during 2009–2014 (Figure 6). From 2000 to 2013, the highliner contributed the vast majority of both trips and landings from Penguin Bank. After this fisher exited in 2014, the commercial fishery at Penguin Bank effectively ceased.

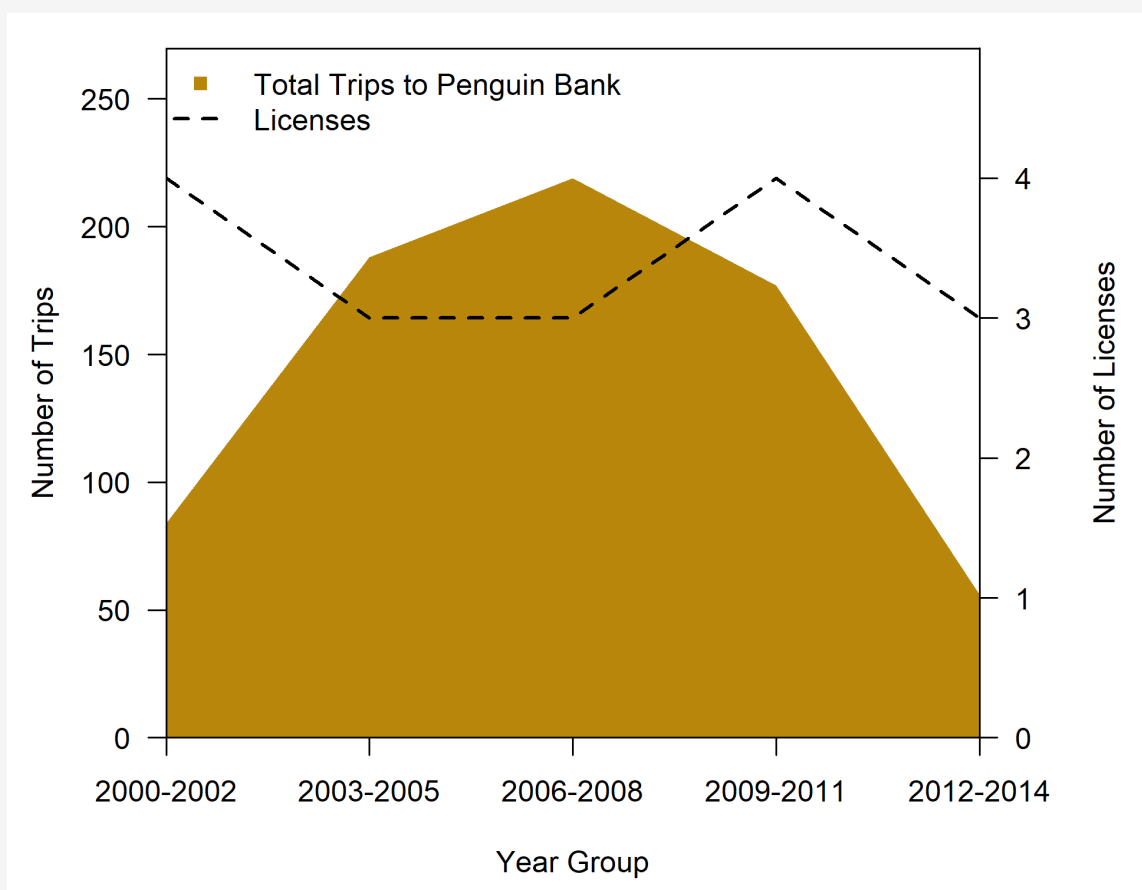


Figure 5. Number of trips and number of fishers (licenses) reporting catch in Penguin Bank.

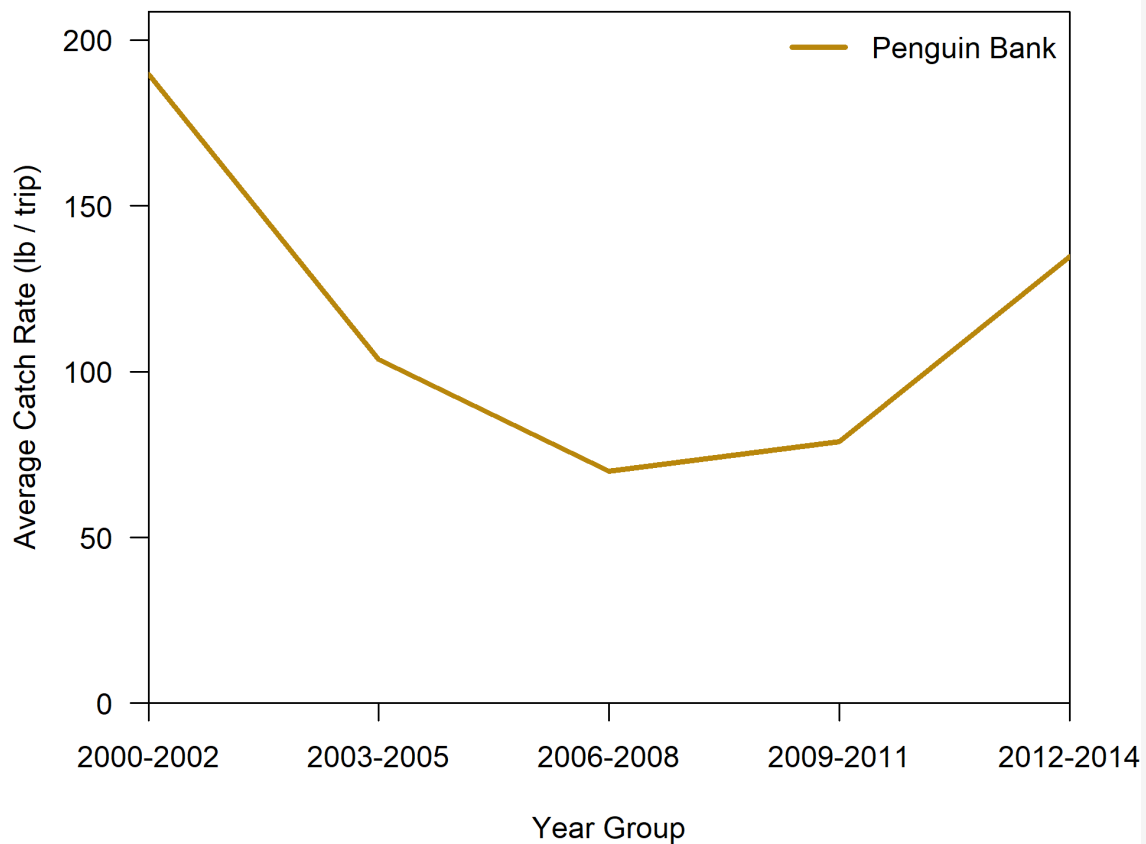


Figure 6. The catch rate from all fishers in Penguin Bank.

Excluding Penguin Bank, the majority of the fishing trips were taken in state waters and the annual number of trips steadily decreased from around 150 in 2000 to around 50 over the past 10 years (Figure 7). The catch rate since 2016 (the last year included in the last assessment) had increasing trends in state waters (Figure 8). The catch rate in federal waters appeared to be higher after 2016, but it was highly variable (Figure 8).

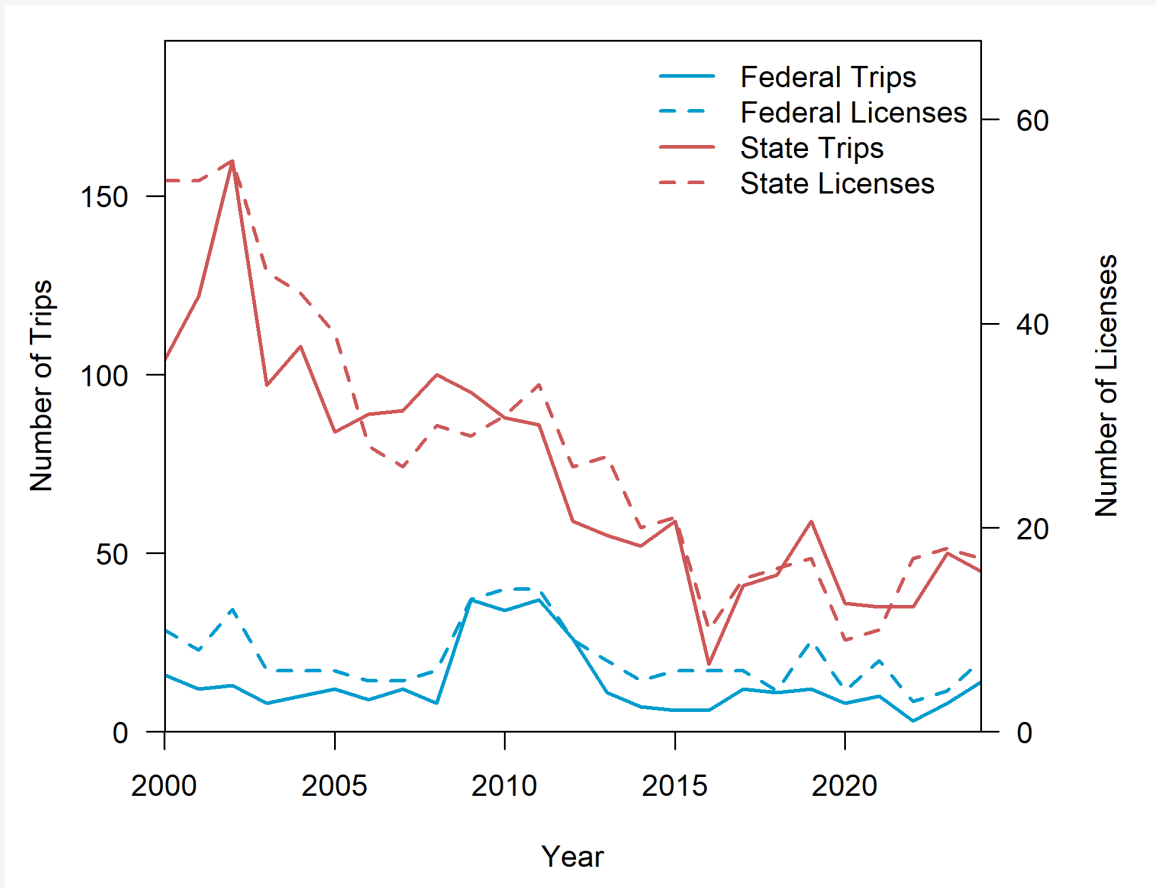


Figure 7. Number of fishing trips and number of fishers reporting fishing in federal waters (excluding Penguin Bank) and in state waters.



Figure 8. Catch rate (lb / trip) in state and federal waters (excluding Penguin Bank).

Since the early 2000s, the number of hoop nets deployed annually has shown greater variability, particularly in state waters (Figure 9), compared with the number of trips (Figure 7). Catch rate calculated by catch per hoop net in federal waters (excluding Penguin Bank) follows a similar fluctuation pattern as the catch rate measured by catch per trip. The increasing trend in catch rate (catch per trip) in state waters is not shown when the catch rate is presented as catch per hoop net (Figure 10).

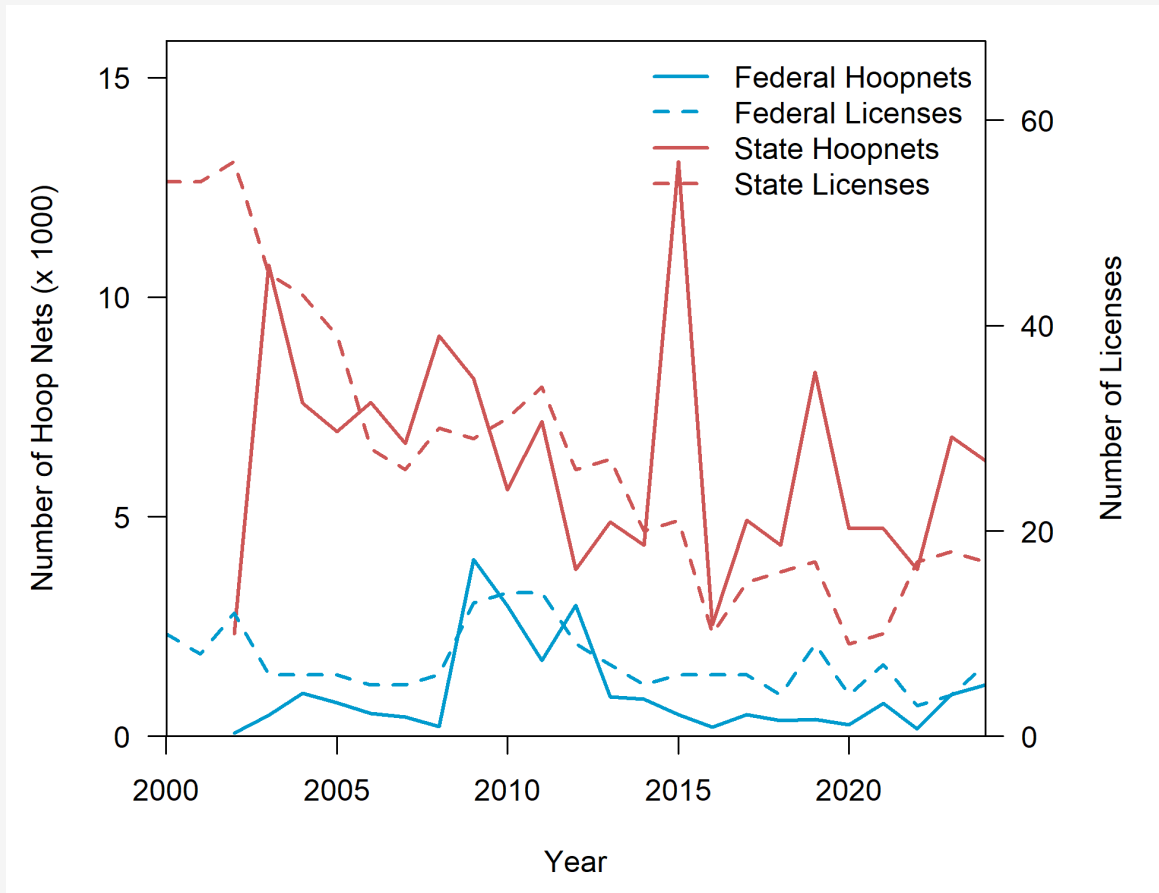


Figure 9. Number of hoop nets and number of fishers reporting fishing in federal waters (excluding Penguin Bank) and in state waters. The number of gears were not reported in the Fisher Reporting System (FRS) until 2002. The number of hoop nets in 2002 was incomplete.



Figure 10. Catch rate (lb / hoop net) in state and federal waters (excluding Penguin Bank). Catch rate was not available in 2000 and 2001.

Discussion and Summary

Non-commercial catch (unreported catch)

Unreported catch, which includes non-commercial catch (catch from fishers not having a commercial marine license) and under-reported commercial catch, remains largely unknown. Brown (1985) suggested that actual landings of Kona crab were probably at least twice the catch reported in the commercial fishing reports, implying an unreported : reported ratio of at least 1. The Hawai'i Marine Recreational Fishing Survey (HMRFS) only targets finfish (Ma and Ogawa, 2016), so the non-commercial catch for Kona crab cannot be estimated based on the HMRFS data.

In the most recent Kona crab stock assessment, an unreported : reported ratio of 1.54 was applied based on the unreported ratio of deep 7 bottomfish at that time (Langseth et al., 2018). The updated ratio for the deep 7 bottomfish in the most recent assessment was approximately 1:1 (Syslo et al., 2024).

In 2014–2024, the catch from the dealer reports accounted for 20–60% of the catch reported in the commercial fishing reports (Figure 11 and Figure A.1), implying that 40–80% of the reported catch (in commercial fishing reports) was not sold, assuming dealer reports captured all sold catch for Kona crab. Additional evaluation is needed to quantify catch from fishers who are not required to submit commercial fishing reports, i.e., fishers without a commercial marine license.

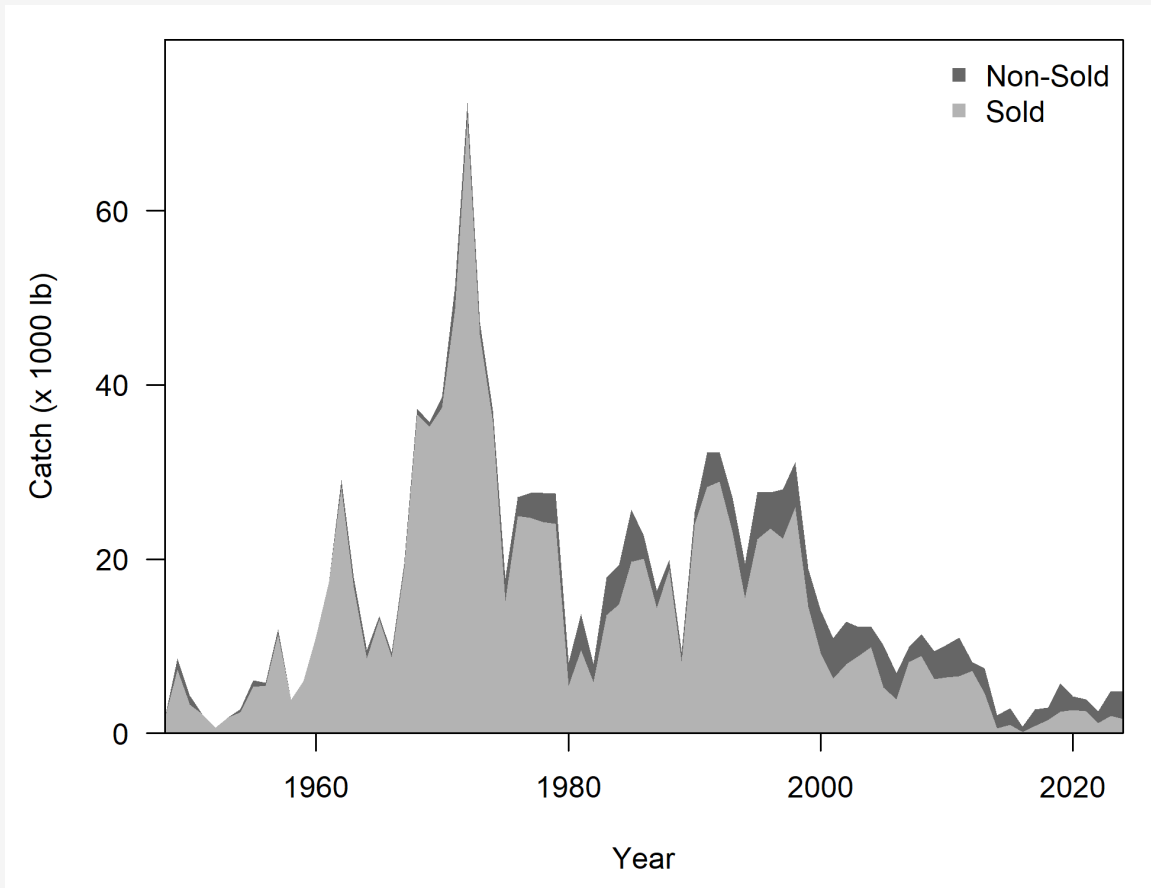


Figure 11. The sold and non-sold catch in the main Hawaiian Islands (reported in the commercial fishing reports). The sold catch was reported in the commercial fishing reports (prior to 2000) and captured in the dealer reports (since 2000). The non-sold catch is the difference between the total catch reported in the commercial fishing reports and the sold catch.

Highliners

From 2000 to 2013, catch from Penguin Bank accounted for the majority of the catch in federal waters (Figure 12). The Penguin Bank fishery during that period was dominated by one highliner (data not shown) and the catch from Penguin Bank accounted for 50% of the total catch (Figure 3). Beginning in 2014, the majority of the total catch was reported in state waters (Figure 4). A highliner fishing in Haleiwa and Kahuku (O‘ahu) had a significant contribution (~50%) to state water catch. Combined with catch from another fisher who fished in Kawaihae and Mākuona (on the Big Island), their catch accounted for two thirds of the state water catch since 2017 (data not shown due to data confidentiality).

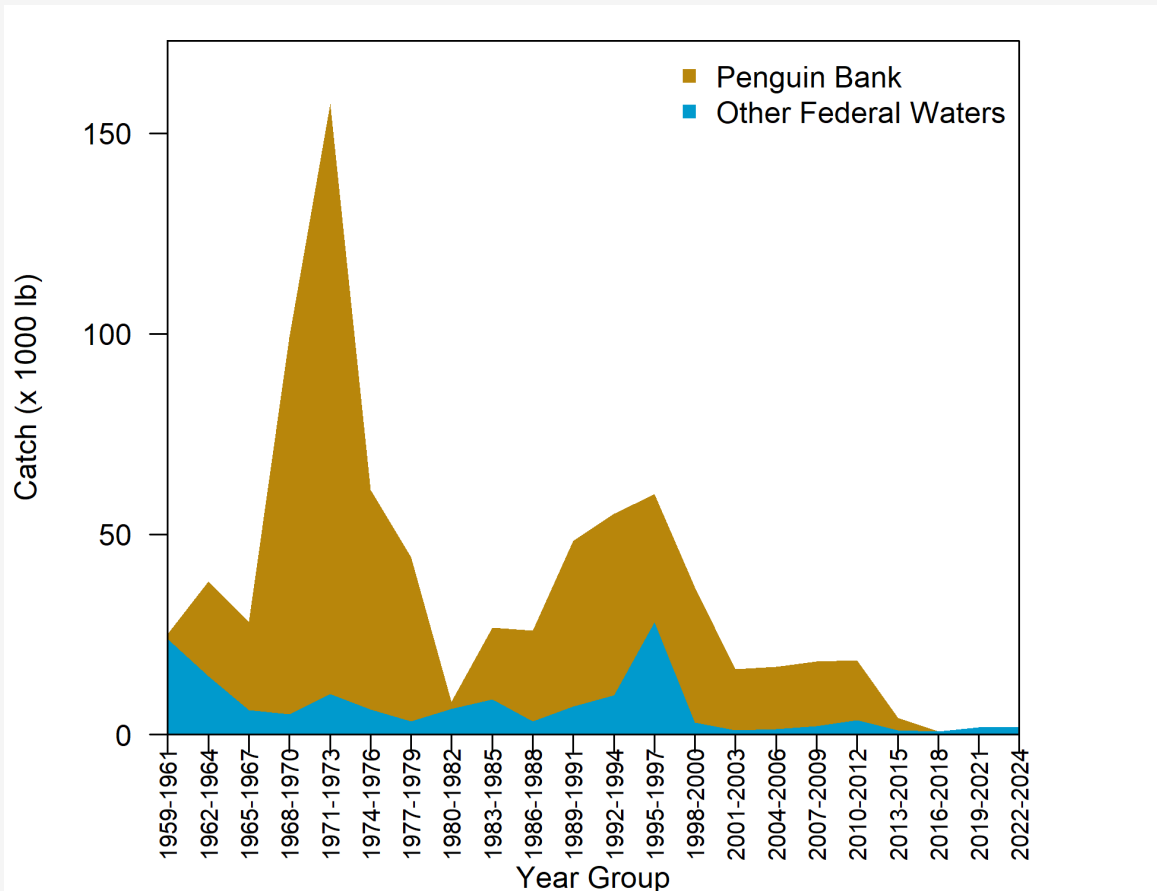


Figure 12. Kona crab catch from federal waters, including Penguin Bank and other areas in federal waters.

Caveats for catch from federal waters

The catch from areas beyond the inshore reporting areas was counted as catch in federal waters in the analyses. However, the inshore areas extend ~2 nautical miles from shore. The reporting areas immediately outside the inshore areas are not 100% in federal waters, which only includes areas >3 nautical miles from shore. Recent catch in Kaua'i and Ni'ihau accounted for the majority of the catch attributed to federal waters (Figure 13). Closer examination indicates that this catch was likely within state waters.

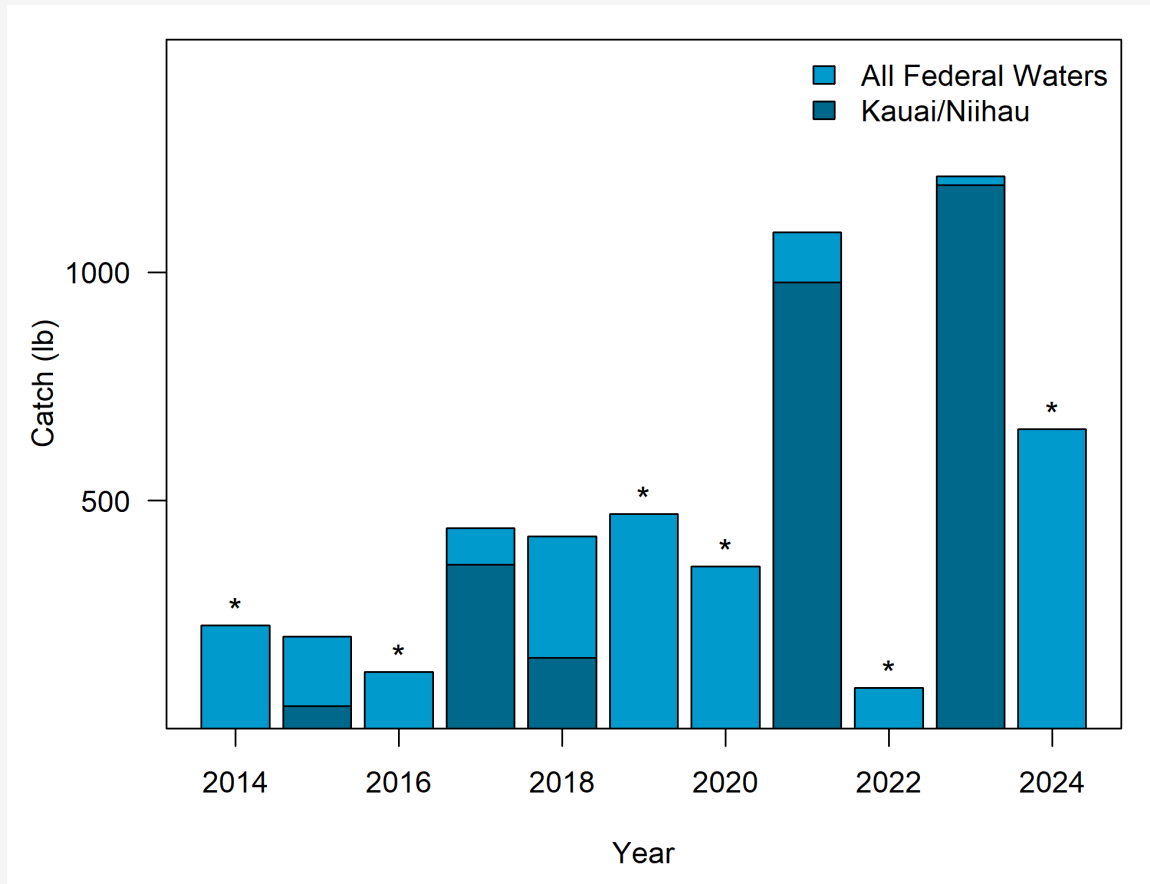


Figure 13. Federal-water catch from Kaua'i and Ni'ihau (dark blue, overlaid) versus from all federal waters. Catches from less than 3 fishers from Kaua'i and Ni'ihau are not shown (*).

In 2021 and 2023, the catch in federal waters accounted for >20% of the total catch (Table 1). Most of the federal-water catch in 2021 was reported from an area (reporting area 520) immediately outside the Southern inshore area in Kaua'i and an area (526) immediately beyond the Western inshore area in Ni'ihau (Figure 1 and Figure A.2). In 2023, the majority of the federal-water catch was reported from two areas (reporting areas 525 and 526) immediately outside two inshore reporting areas in Ni'ihau.

Based on a habitat depth of 2–200 m, the Kona crab habitat in these three areas (outside of inshore reporting areas in Kaua'i and Ni'ihau) would be still within 3 nautical miles from shore (Figure A.2 and Figure 2 in Nadon, 2024), i.e., in state waters. Similarly, the Kona crab habitat in the area (reporting area 524) immediately beyond the eastern inshore area of Kaua'i would be in state waters as well. If catches reported from these four areas were not counted toward federal-water catch, the percent of catch in federal waters would be no more than 12% each year since 2014 (Table 2). Kona crab habitat depth in all main Hawaiian Islands is also displayed for comparison (Figure 1).

Table 2. “Revised” percent of catch in state waters, Penguin Bank, and federal waters. The revised catch in state waters include catch from reporting areas 520 and 524–526 in Kaua’i and Ni’ihau. ND = non-disclosure due to data confidentiality in Penguin Bank. The percent of catch in federal waters includes catch in Penguin Bank when the percent of Penguin Bank catch is ND (*). When the percent of catch in Penguin Bank is available, the percent of catch in federal waters excludes Penguin Bank catch.

Year	Total (lb)	State%	Penguin%	Federal%
2000	14,144	42	54	3
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2005	10,111	35	59	6
2006	6,921	57	ND	43*
2007	9,915	34	ND	66*
2008	11,396	44	54	2
2009	9,422	51	ND	49*
2010	10,195	48	44	9
2011	10,979	37	54	9
2012	8,212	36	ND	64*
2013	7,423	57	ND	43*
2014	2,101	94	ND	6*
2015	2,919	93	ND	7*
2016	758	88	0	12
2017	2,777	94	0	6
2018	2,953	90	0	10
2019	5,737	95	0	5
2020	4,265	92	0	8
2021	3,946	93	0	7
2022	2,533	98	0	2
2023	4,879	99	0	1
2024	4,783	88	ND	12*

Catch rate

Since 2016 (the last year included for the last stock assessment), the catch rate calculated as catch per trip showed increasing trends (Figure 8). The increasing trend in federal waters was present with the catch rate calculated as catch per hoop net. The trend of catch rate in federal water is not statistically significant due to the fluctuations among years. The increasing trend in state waters is statistically significant with the catch rate measured as catch per trip (Figure 8). There is not a statistically significant linear trend in the catch rate by catch per hoop net (Figure 10).

The number of hoop nets reported since 2002 was variable. Usually, 10 or more hoop nets are deployed in one set attached to the mainline and there may be 10–20 deployments per trip (John Wiley, personal communication). Highliners may have over 100 hoop nets per set with multiple mainlines (John Wiley, personal communication). In some years (e.g., 2015), fishers reported using 1,000 gears per trip multiple times in a year. However, catch from these trips did not appear to be higher compared with the catch from trips with a few hundreds of hoop nets deployed (Figure A.3 & Figure A.4), resulting in lower catch per hoop net (find values for 2015 in Figure 9 & Figure 10).

There were two recent changes in the fishing regulations for Kona crab. The fishing season closure was extended to between May 1–September 30 in 2024. In the late 1970s, the closed season was initially established as June 1–August 31. The closure was extended to May 1–August 31 in 1993 (Figure A.5). The prohibition of harvesting female Kona crab was established in 2006 and it was lifted in 2024. The impacts of these recent changes could be assessed with new fishery data in 2025 and afterwards.

Summary

Since the last stock assessment, annual Kona crab catch was always less than 6,000 lb with an average of approximately 10% of the current ACL (also see Table 29 of WPRFMC, 2025). After the commercial fishery at Penguin Bank ended in 2014, catch in federal waters became minimal. Since then, inshore fishing areas extending 2 nautical miles from shore have accounted for about 80% of annual landings, and actual state-waters (to 3 nautical miles) catch is likely 90% or more each year. From 2014 to 2024, fewer than 60 commercial fishing trips occurred annually in state waters and fewer than 15 in federal waters.

Catch rates in both state and federal waters generally increased during this period, although the rising trend in state waters was less apparent when measured as catch per hoop net rather than catch per trip. Overall, these patterns suggest a stable or improving status for the Kona crab population and indicate that a full, rigorous stock assessment may not be necessary at this time.

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Appendix

Additional figures

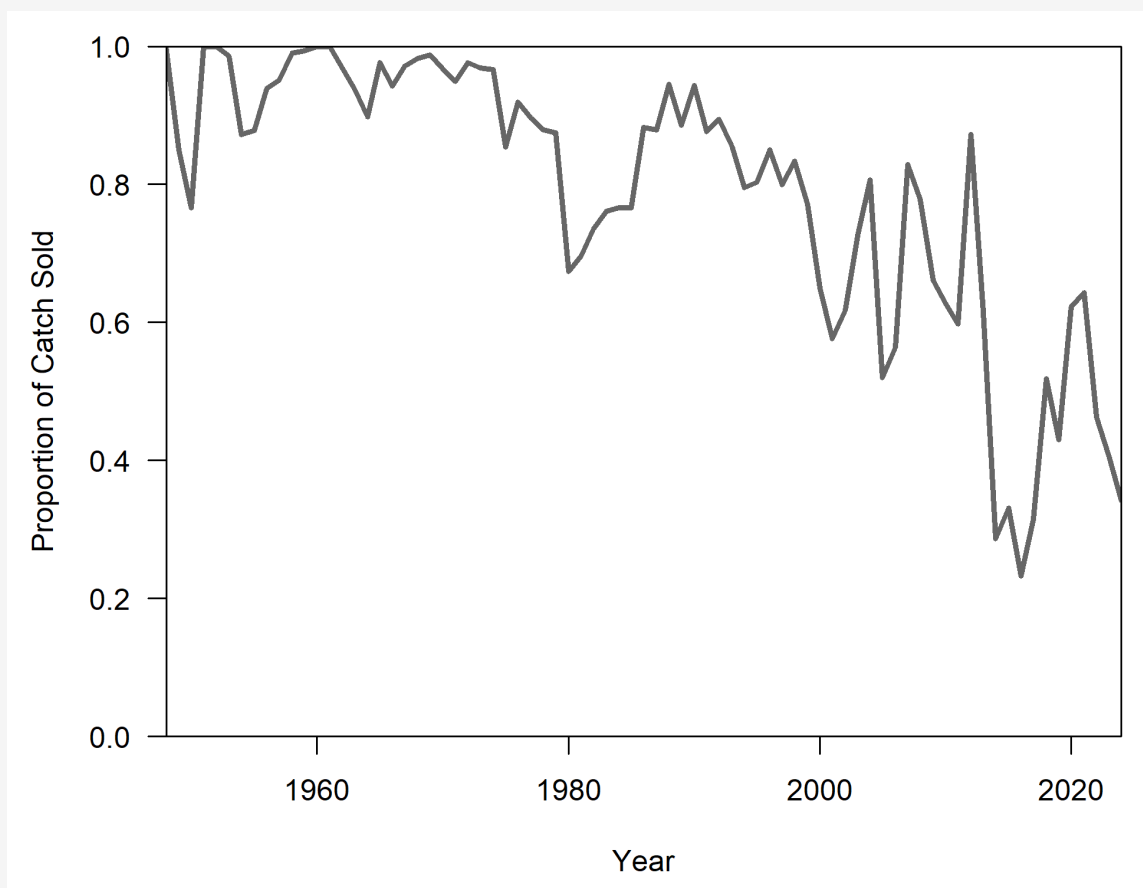


Figure A.1. Proportion of sold catch with respect to the landed catch in the commercial fishing reports.

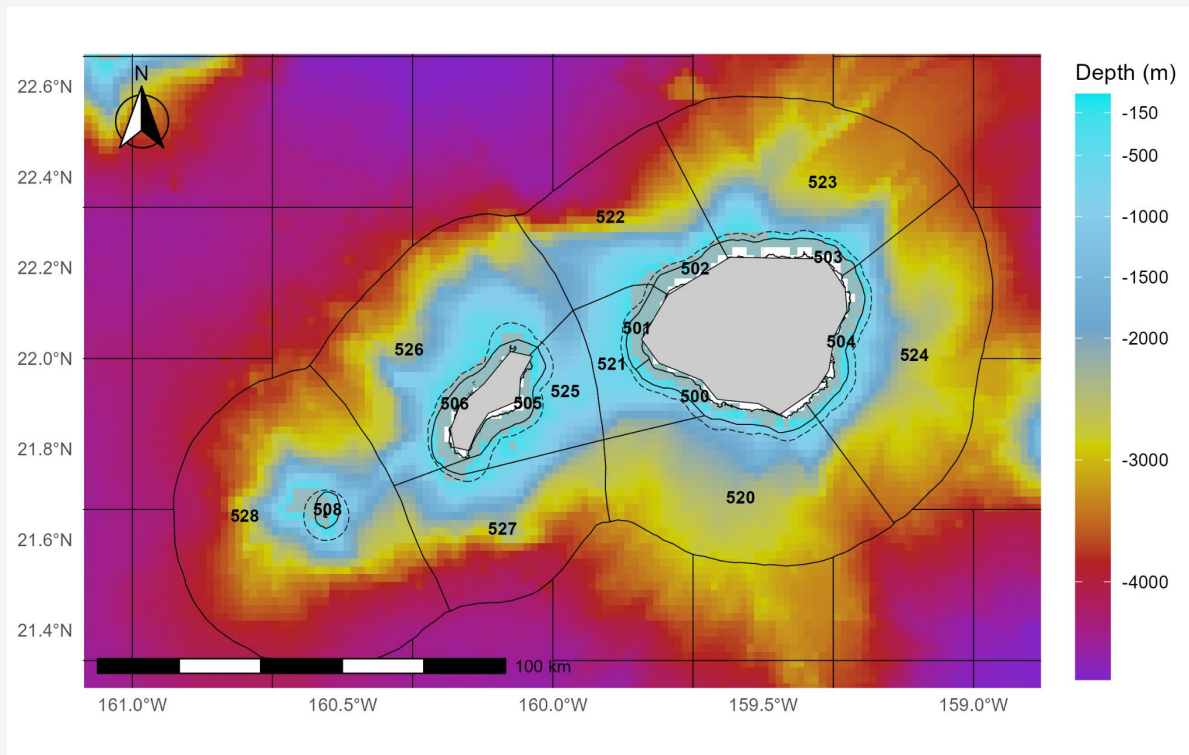


Figure A.2. The inshore reporting areas (500–506, extending to 2 nautical miles from shore) and reporting areas immediately outside of the inshore areas (520–526) in Kaua'i and Ni'ihau. Shaded gray areas represent depths between 0 and 200 meters. Dash lines indicate the boundaries 3 nautical miles from shore.

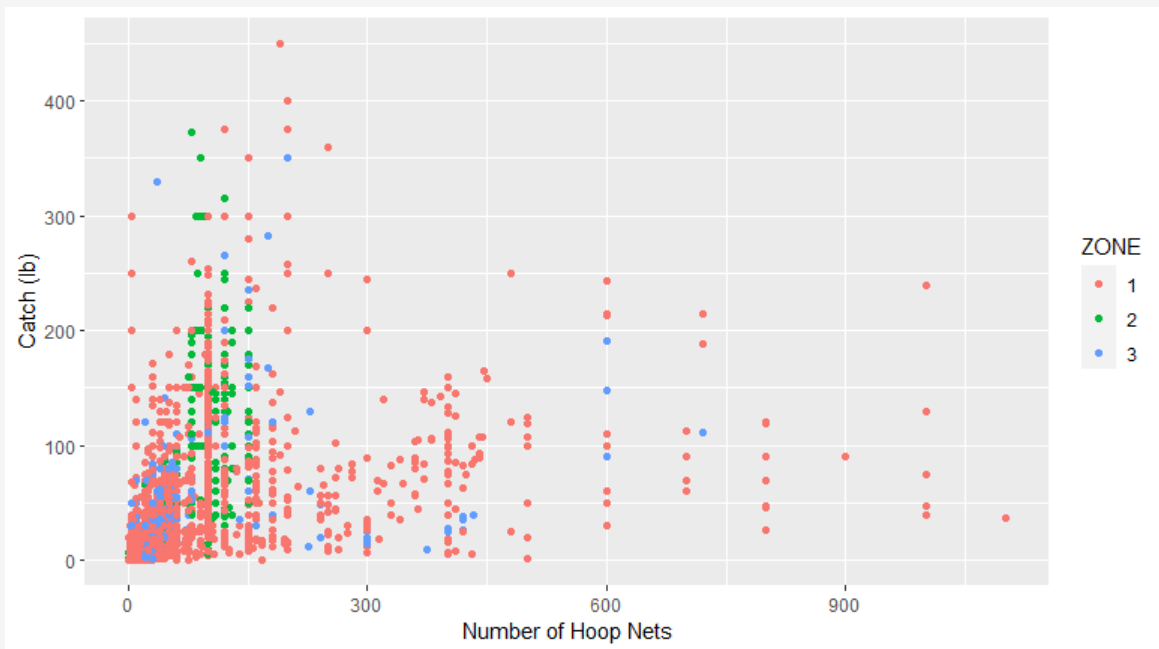


Figure A.3. The catch from trips with different numbers of hoop nets deployed. A wider range of hoop nets were used in state waters (red) and federal waters excluding Penguin Bank (blue) than in Penguin Bank (green). In state waters (ZONE = 1), the catch per trip did not show apparent increasing trends when the number of hoop nets per trip was higher.

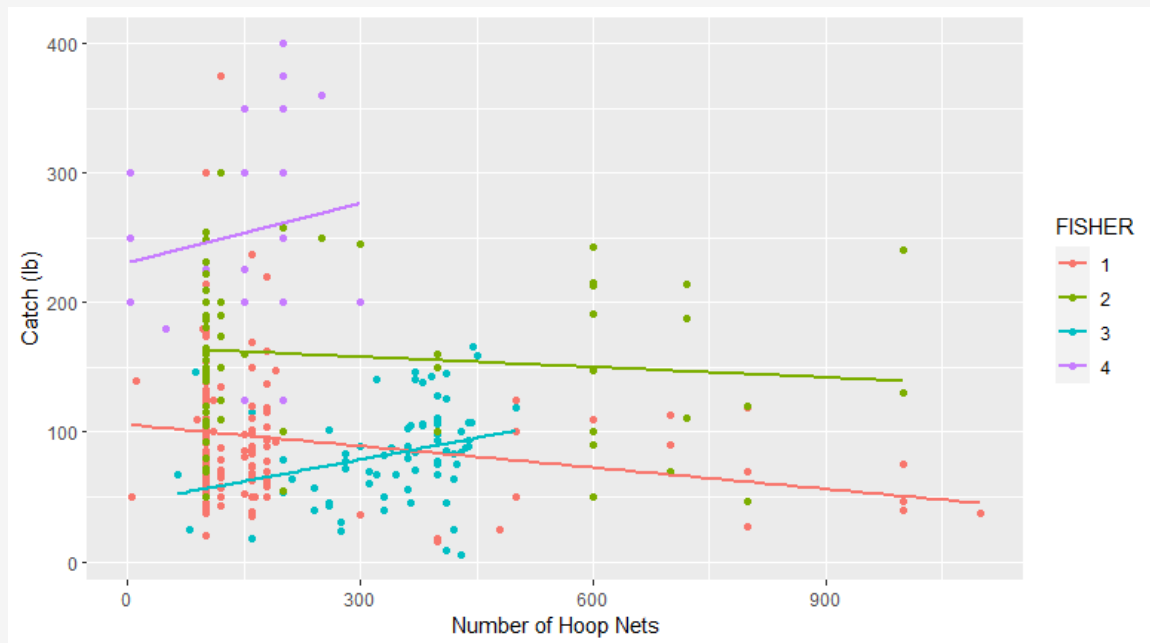


Figure A.4. The catch from trips with different numbers of hoop nets deployed from four highliners (Fisher 1–4). Three high liners (Fisher 1–3) accounted for the majority of the trips with a high number of gears (>300) deployed per trip and the linear regression did not show positive slopes for two highliners.

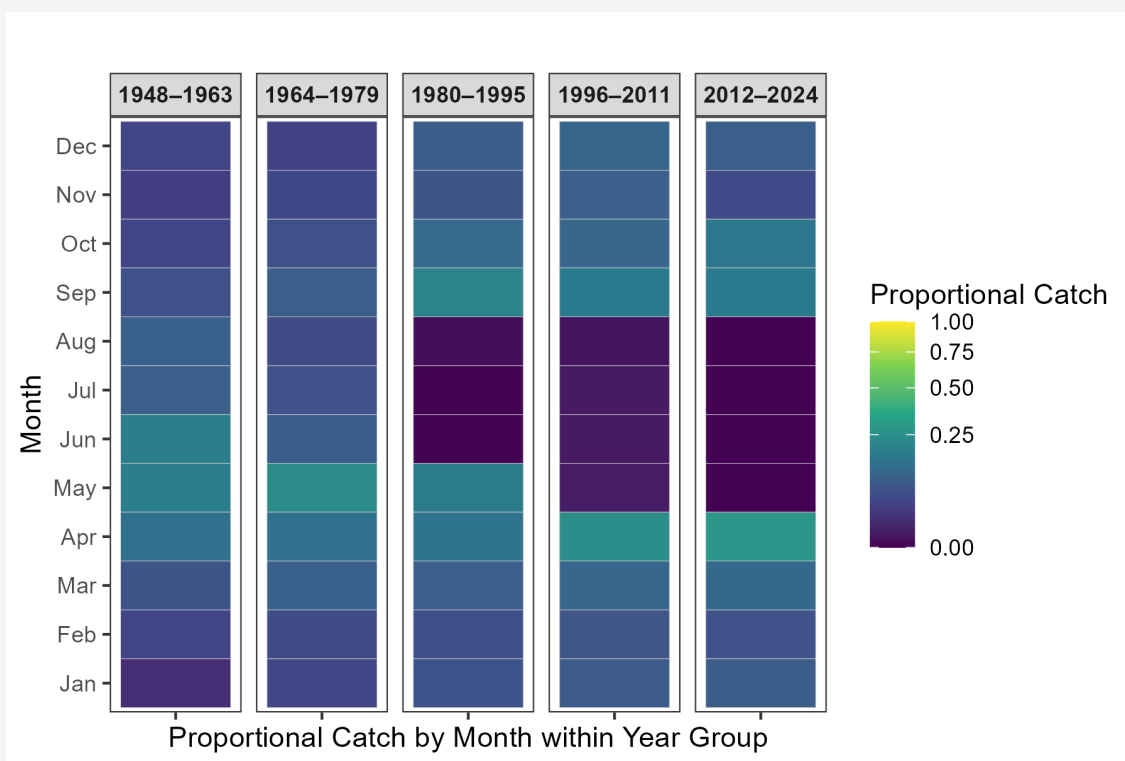


Figure A.5. Average proportional catch for each month over 16 years within the multi-year groups for all waters. Year groups were used to avoid revealing confidential data.

R script

[GitHub repository](#)

Full code:

```
#Loading libraries
```

```
rm(list=ls())
library(dplyr)
library(this.path)
library(tidyr)
library(tidyverse)
library(lubridate)
library(forcats)
```

```
root_dir <- this.path::here(..=1) #Root directory is one folder above where this script is
```

```
FRS = read.csv(file.path (root_dir, "01_Data/WH2024.csv")) # WH2024 based on warehouse data in
#picfinfish MYSQL database using query species_fk = 701 or gear_fk = 40 (13916 records)
MHI = read.csv(file.path (root_dir, "01_Data/MHI_Yau.csv"))
```

```
## Area code 16123 (instead of 16123I, 16123F, and 16123C) is included for MHI area code.
#Area codes 16123I, 16123F, and 16123C are not contained in FRS (up to 2024)
```

```
State = read.csv(file.path (root_dir, "01_Data/State.csv"))
Dealer = read.csv(file.path (root_dir, "01_Data/Dealer_WH2024.csv"))
```

```
Dealer$year2 = as.factor(substr(Dealer$REPORT_DATE, 1, 4))
FRS$water = ifelse(FRS$AREA_FK %in% State$code, 1, 2) # 1 = state waters, 2 = federal waters
FRS$zone = ifelse(FRS$AREA_FK %in% State$code, 1, ifelse(FRS$AREA_FK == 331, 2, 3))
```

```
# 1 = state waters, 2 = Penguin banks, 3 = federal waters
```

```
FRS$year = FRS$REPORT_YEAR
```

```
FRS$catch = FRS$LBS_KEPT
```

```
FRS$year2 = as.factor(FRS$year) # having year as a factor allows us to use .drop in group_by to avoid
#losing years with no data
```

```
years = sort(unique(FRS$year), decreasing = F)
```

```
year_groups <- c("2000–2002", "2003–2005", "2006–2008", "2009–2011", "2012-2014")
```

```
year_groups2 <- c("1959-1961", "1962-1964", "1965-1967", "1968-1970",
  "1971-1973", "1974-1976", "1977-1979", "1980-1982", "1983-1985", "1986-1988",
  "1989-1991", "1992-1994", "1995-1997", "1998-2000", "2001-2003", "2004-2006", "2007-2009",
  "2010-2012", "2013-2015",
  "2016-2018", "2019-2021", "2022-2024")
```

```
FRS_catch = FRS[FRS$AREA_FK %in% MHI$code & FRS$REPORT_YEAR < 2025 &
FRS$SPECIES_FK == 701,]
```

```
# used to compute catch -- MHI and kona crab only and remove incomplete data from 2025
```

```
FRS_catchrate = FRS[FRS$AREA_FK %in% MHI$code & FRS$REPORT_YEAR < 2025 &
FRS$GEAR_FK == 40,] # used to compute effort and catch rate -- MHI and dominant gear only and
```

```
#remove incomplete data from 2025
```

```
FRS_catchrate$kc_catch = ifelse(FRS_catchrate$SPECIES_FK == 701, FRS_catchrate$LBS_KEPT, 0)
```

```
pair_colors = c("gray40", "gray70")
```

```
state_colors = c("indianred3", "indianred4")
```

```
penguin_bank_colors = c("goldenrod1", "darkgoldenrod")
```

```

federal_colors = c("deepskyblue3", "deepskyblue4")
water_colors = c(federal_colors[1], state_colors[1])
zone_colors = c(federal_colors[1], penguin_bank_colors[1], state_colors[1])

#Plot function
plot_kc = function(file_name, plot_data, plot_years, ylab, plot_cols, filled, legend, legend_location =
"topright", set_y_max = NA) {
  x_min = min(years[plot_years])
  x_max = max(years[plot_years])
  y_min = 0
  y_max = NA
  if(is.na(set_y_max)) {
    if(filled) {
      y_max = max(apply(plot_data[, plot_years], c(2), sum), na.rm = T) * 1.1
    } else {
      y_max = max(plot_data[, plot_years], na.rm = T) * 1.1
    }
  } else {
    y_max = set_y_max
  }
  xs = pretty(c(x_min, x_max), n = 4)
  xs = xs[xs >= x_min & xs <= x_max]
  ys = pretty(c(y_min, y_max), n = 4)
  ys = ys[ys >= y_min & ys <= y_max]
  #pdf(paste0(root_dir, "/03_Outputs/", file_name, ".pdf"), width = 6.5, height = 5, pointsize = 12)
  png(paste0(root_dir, "/03_Outputs/", file_name, ".png"), width = 6.5, height = 5, units = "in", res = 300,
pointsize = 12)
  par(mar = c(4.5, 4.5, 1, 1))
  plot(NA, xlim = c(x_min, x_max), ylim = c(y_min, y_max), axes = F, xaxs = "i", yaxs = "i", xlab = "Year",
ylab = ylab)
  axis(side = 1, at = xs)
  axis(side = 2, at = ys, las = 1)
  n_row = dim(plot_data)[1]
  for(i in 1:n_row) {
    if(filled) {
      polygon(x = c(min(years[plot_years]), years[plot_years], max(years[plot_years])), y = c(0,
apply(plot_data[i:n_row, plot_years, drop = F], c(2), sum), 0), col = plot_cols[i], border = NA)
    } else {
      lines(x = years[plot_years], y = plot_data[i, plot_years], col = plot_cols[i], lwd = 3)
      n_col = dim(plot_data)[2]
      for(j in 1:n_col) {
        point_before = ifelse(j == 1, NA, plot_data[i, j - 1])
        point_after = ifelse(j == n_col, NA, plot_data[i, j + 1])

        if(is.na(point_before) & is.na(point_after)) {
          points(x = years[j], y = plot_data[i, j], col = plot_cols[i])
        }
      }
    }
  }
  box(which = "plot", lty = "solid")
  if(any(!is.na(legend))) {
    if(filled) {
      legend(x = legend_location, legend = legend, col = plot_cols, pch = 15, bty = "n")
    } else {

```

```

    legend(x = legend_location, legend = legend, col = plot_cols, lwd = 3, bty = "n")
  }
}
dev.off()
}

#Plot function for grouped years
plot_kc_grouped <- function(file_name, plot_data, year_groups, ylab, plot_cols, filled, legend,
legend_location = "topright", set_y_max = NA) {

  x_vals <- 1:length(year_groups) # Numeric x positions for year_groups
  y_min <- 0
  y_max <- if (is.na(set_y_max)) {
    if (filled) {
      max(apply(plot_data, 2, sum), na.rm = TRUE) * 1.1
    } else {
      max(plot_data, na.rm = TRUE) * 1.1
    }
  } else {
    set_y_max
  }

  #pdf(paste0(root_dir, "/03_Outputs/", file_name, ".pdf"), width = 6.5, height = 5, pointsize = 12)
  png(paste0(root_dir, "/03_Outputs/", file_name, ".png"), width = 6.5, height = 5, units = "in", res = 300,
pointsize = 12)
  par(mar = c(4.5, 4.6, 1, 4), # Increase bottom and left margins
      mgp = c(3.5, 1, 0), # Push axis titles further from tick labels
      las = 1 # Horizontal Y-axis tick labels (optional)
  )
  plot(NA, xlim = range(x_vals), ylim = c(y_min, y_max), axes = FALSE, xaxs = "i", yaxs = "i", xlab = "Year
Group", ylab = ylab)
  axis(side = 1, at = x_vals, labels = FALSE) # suppress default labels
  text(x = x_vals, y = par("usr")[3] - 0.02 * diff(par("usr")[3:4]),
      labels = year_groups, srt = 90, adj = 1, xpd = TRUE, cex = 0.8)
  axis(side = 2, las = 1)

  n_row <- nrow(plot_data)

  for (i in 1:n_row) {
    if (filled) {
      polygon(x = c(min(x_vals), x_vals, max(x_vals)),
              y = c(0, apply(plot_data[i:n_row, , drop = FALSE], 2, sum), 0),
              col = plot_cols[i], border = NA)
    } else {
      lines(x = x_vals, y = plot_data[i, ], col = plot_cols[i], lwd = 3)

      n_col <- ncol(plot_data)
      for (j in 1:n_col) {
        point_before <- ifelse(j == 1, NA, plot_data[i, j - 1])
        point_after <- ifelse(j == n_col, NA, plot_data[i, j + 1])

        if (is.na(point_before) & is.na(point_after)) {
          points(x = x_vals[j], y = plot_data[i, j], col = plot_cols[i])
        }
      }
    }
  }
}

```

```

}

box(which = "plot", lty = "solid")

if (any(!is.na(legend))) {
  if (filled) {
    legend(x = legend_location, legend = legend, col = plot_cols, pch = 15, bty = "n")
  } else {
    legend(x = legend_location, legend = legend, col = plot_cols, lwd = 3, bty = "n")
  }
}
dev.off()
}

# Plot function for line plot
plot_kc_line_grouped <- function(file_name, plot_data, group_labels, ylab, plot_cols, legend = NA) {
  y_min <- 0
  y_max <- max(plot_data, na.rm = TRUE) * 1.1

  #pdf(paste0(root_dir, "/03_Outputs/", file_name, ".pdf"), width = 6.5, height = 5, pointsize = 12)
  png(paste0(root_dir, "/03_Outputs/", file_name, ".png"), width = 6.5, height = 5, units = "in", res = 300,
  pointsize = 12)
  par(mar = c(4.5, 4.5, 1, 2))
  plot(NA, xlim = c(1, length(group_labels)), ylim = c(y_min, y_max), axes = FALSE, xaxs = "i", yaxs = "i",
    xlab = "Year Group", ylab = ylab)
  axis(1, at = 1:length(group_labels), labels = group_labels)
  axis(2, las = 1)
  box(which = "plot", lty = "solid")

  lines(1:length(group_labels), plot_data[1, ], col = plot_cols, lwd = 3)
  #points(1:length(group_labels), plot_data[1, ], col = plot_cols, pch = 16)

  # Add "Penguin Banks" label
  legend("topright", legend = "Penguin Bank", col = plot_cols, lty = 1, lwd = 3, bty = "n")

  dev.off()
}

#Modified plot function to receive long data format from dplyr
plot_kc_dplyr <- function(file_name, plot_data_list, ylab, plot_cols, filled = FALSE, legend = NULL,
legend_location = "topright", set_y_max = NA, year_range = NULL) {
  # Convert year2 to numeric inside each df and optionally filter by year_range
  plot_data_list <- lapply(plot_data_list, function(df) {
    df$year2 <- as.numeric(as.character(df$year2))
    if(!is.null(year_range)) {
      df <- df %>% filter(year2 >= year_range[1], year2 <= year_range[2])
    }
    df
  })

  # Combine all years from filtered data
  all_years <- sort(unique(unlist(lapply(plot_data_list, function(df) df$year2))))

  if(length(all_years) == 0) {

```

```

    stop("No data available in the specified year range.")
  }

  cpue_matrix <- sapply(plot_data_list, function(df) {
    cpue_vec <- rep(NA, length(all_years))
    match_years <- match(df$year2, all_years)
    cpue_vec[match_years] <- df$cpue
    return(cpue_vec)
  })
  cpue_matrix <- t(cpue_matrix)

  x_min <- if(!is.null(year_range)) year_range[1] else min(all_years)
  x_max <- if(!is.null(year_range)) year_range[2] else max(all_years)
  y_min <- 0
  y_max <- if (is.na(set_y_max)) {
    if (filled) {
      max(colSums(cpue_matrix, na.rm = TRUE)) * 1.1
    } else {
      max(cpue_matrix, na.rm = TRUE) * 1.1
    }
  } else {
    set_y_max
  }

  xs <- pretty(c(x_min, x_max), n = 4)
  xs <- xs[xs >= x_min & xs <= x_max]
  ys <- pretty(c(y_min, y_max), n = 4)
  ys <- ys[ys >= y_min & ys <= y_max]

  png(paste0(root_dir, "/03_Outputs/", file_name, ".png"), width = 6.5, height = 5, units = "in", res = 300,
    pointsize = 12)
  par(mar = c(4.5, 4.5, 1, 1))
  plot(NA, xlim = c(x_min, x_max), ylim = c(y_min, y_max), axes = FALSE, xaxs = "i", yaxs = "i", xlab =
    "Year", ylab = ylab)
  axis(side = 1, at = xs)
  axis(side = 2, at = ys, las = 1)

  n_row <- nrow(cpue_matrix)
  n_col <- ncol(cpue_matrix)

  for (i in 1:n_row) {
    if (filled) {
      polygon(x = c(x_min, all_years, x_max),
        y = c(0, colSums(cpue_matrix[i:n_row, , drop = FALSE], na.rm = TRUE), 0),
        col = plot_cols[i], border = NA)
    } else {
      lines(x = all_years, y = cpue_matrix[i, ], col = plot_cols[i], lwd = 3)
      for (j in 1:n_col) {
        point_before <- ifelse(j == 1, NA, cpue_matrix[i, j - 1])
        point_after <- ifelse(j == n_col, NA, cpue_matrix[i, j + 1])
        if (is.na(point_before) & is.na(point_after) & !is.na(cpue_matrix[i, j])) {
          points(x = all_years[j], y = cpue_matrix[i, j], col = plot_cols[i])
        }
      }
    }
  }
}

```

```

box(which = "plot", lty = "solid")
if (!is.null(legend)) {
  if (filled) {
    legend(x = legend_location, legend = legend, col = plot_cols, pch = 15, bty = "n")
  } else {
    legend(x = legend_location, legend = legend, col = plot_cols, lwd = 3, bty = "n")
  }
}
dev.off()
}

#-----#
# Fig.2: Catch vs Year, separately for MHI and entire archipelago
mhi = summarise(group_by(FRS[FRS$AREA_FK %in% MHI$code & FRS$SPECIES_FK == 701,],
REPORT_YEAR), n = sum(LBS_KEPT))$n
archipelago = summarise(group_by(FRS[FRS$SPECIES_FK == 701,], REPORT_YEAR), n =
sum(LBS_KEPT))$n
plot_years = years <= 2024
plot(x = years[plot_years], y = mhi[plot_years], type = 'l', col = "blue")
lines(x = years[plot_years], archipelago[plot_years], col = "orange")
plot_kc(file_name = "Fig.2", plot_data = matrix(c(archipelago - mhi, mhi) / 1000, nrow = 2, byrow = T),
plot_years, ylab = "Catch (x 1000 lb)", plot_cols = pair_colors, filled = T, legend = c("NW Hawaiian
Islands/Unknown", "Main Hawaiian Islands"))
#-----#

#-----#
# Fig.3: Catch vs year, stacked for state, and federal
#Create a zone for All federal together = 4
FRS_catch <- FRS_catch %>%
  mutate(zone_comb = case_when(zone == 3 | zone == 2 ~ 4,
TRUE ~ zone))
federal = summarise(group_by(FRS_catch[FRS_catch$zone_comb == 4,], year2, .drop = F), n =
sum(catch))$n
state = summarise(group_by(FRS_catch[FRS_catch$zone == 1,], year2, .drop = F), n = sum(catch))$n
plot_years = years <= 2024
plot(x = years[plot_years], y = federal[plot_years] + state[plot_years], type = 'l', col = "darkblue")
lines(x = years[plot_years], y = state[plot_years], col = "indianred4")
#lines(x = years[plot_years], y = state[plot_years], col = "lightblue")
plot_kc(file_name = "Fig.3", plot_data = matrix(c(federal, state) / 1000, nrow = 2, byrow = T), plot_years,
ylab = "Catch (x 1000 lb)", plot_cols = water_colors, filled = T, legend = c("Federal", "State"))
#-----#

#-----#
#Fig.4 but all federal waters combined
federal = summarise(group_by(FRS_catch[FRS_catch$zone_comb == 4,], year2, .drop = F), n =
sum(catch))$n
state = summarise(group_by(FRS_catch[FRS_catch$zone == 1,], year2, .drop = F), n = sum(catch))$n
plot_years = years >= 2014 & years <= 2024
plot(x = years[plot_years], y = federal[plot_years] + state[plot_years], type = 'l', col = "darkblue")
lines(x = years[plot_years], y = state[plot_years], col = "orange")
plot_kc(file_name = "Fig.4", plot_data = matrix(c(federal, state), nrow = 2, byrow = T), plot_years, ylab =
"Catch (lb)", plot_cols = water_colors, filled = T, legend = c("Federal", "State"))

```

```

#-----#

#-----#
# Fig.5 putting all federal catch together and combining years into 3 year groups:
#2000-2002; 2003-2005; 2006-2008; 2009-2011; 2012-2014
# 1. Create year groupings
group_breaks <- c(1999, 2002, 2005, 2008, 2011, 2014)
group_labels <- c("2000-2002", "2003-2005", "2006-2008", "2009-2011", "2012-2014")

# 2. Add year group column
FRS_catchrate$year_group <- cut(FRS_catchrate$year, breaks = group_breaks, labels = group_labels)

# 3. Aggregate total trips (distinct FISHER+DATE combos)
FRS_catchrate$trip_id <- paste(FRS_catchrate$FISHER_LIC_FK, FRS_catchrate$FISHED_DATE)
agg_trips <- aggregate(trip_id ~ year_group, data = FRS_catchrate[FRS_catchrate$zone == 2, ],
                      FUN = function(x) length(unique(x)))
names(agg_trips)[2] <- "all_trips"

# 4. Aggregate unique fishers per group
# Make sure year_group excludes NA and empty levels
FRS_filtered <- FRS_catchrate[FRS_catchrate$zone == 2 & !is.na(FRS_catchrate$year_group), ]
FRS_filtered$year_group <- droplevels(FRS_filtered$year_group)

agg_fishers <- aggregate(FISHER_LIC_FK ~ year_group, data = FRS_filtered,
                      FUN = function(x) length(unique(x)))
names(agg_fishers)[2] <- "licenses"

# 5. Merge both
agg <- merge(agg_trips, agg_fishers, by = "year_group")
group_labels <- as.character(agg$year_group)

# 6. Prepare data matrices
trips_data_grouped <- matrix(agg$all_trips, nrow = 1, byrow = TRUE)
licenses_data_grouped <- matrix(agg$licenses, nrow = 1, byrow = TRUE)

# 8. Plot individual PDFs
plot_kc_grouped("Fig.5.a", trips_data_grouped, group_labels, "Number of Trips", plot_cols =
"darkgoldenrod", filled = TRUE, legend = NA)
plot_kc_grouped("Fig.5.b", licenses_data_grouped, group_labels, "Number of Licenses", plot_cols =
"black", filled = FALSE, legend = NA)

# 9. Combined dual-axis plot (Grouped_E.pdf)
y_min <- 0
y_max_trips <- max(trips_data_grouped, na.rm = TRUE) * 1.1
y_max_licenses <- max(licenses_data_grouped, na.rm = TRUE) * 1.1
ys_trips <- pretty(c(y_min, y_max_trips), n = 4)
ys_licenses <- pretty(c(y_min, y_max_licenses), n = 4)

#pdf(paste0(root_dir, "/03_Outputs/Grouped_E.pdf"), width = 6.5, height = 5, pointsize = 12)
png(paste0(root_dir, "/03_Outputs/Fig.5.png"), width = 6.5, height = 5, units = "in", res = 300, pointsize =
12)
par(mar = c(4.5, 4.5, 1, 5))
plot(NA, xlim = c(1, length(group_labels)), ylim = c(0, 1.12), axes = FALSE, xaxs = "i", yaxs = "i", xlab =
"Year Group", ylab = "")
axis(1, at = 1:length(group_labels), labels = group_labels)

```

```

axis(2, at = ys_trips / y_max_trips, labels = ys_trips, las = 1)
axis(4, at = ys_licenses / y_max_licenses, labels = ys_licenses, las = 1)
mtext(side = 2, "Number of Trips", line = 3)
mtext(side = 4, "Number of Licenses", line = 3)

# Plot trips (as area)
polygon(x = c(1, 1:length(group_labels), length(group_labels)),
        y = c(0, trips_data_grouped[1, ] / y_max_trips,
        col = "darkgoldenrod", border = NA)

# Plot licenses
lines(1:length(group_labels), licenses_data_grouped[1, ] / y_max_licenses, col = "black", lty = "dashed",
lwd = 2)

box(which = "plot", lty = "solid")
legend("topleft", legend = c("Total Trips to Penguin Bank", "Licenses"),
      col = c("darkgoldenrod", "black"), lty = c(NA, "dashed"), lwd = c(NA, 2), pch = c(15, NA), bty = "n")
dev.off()
#-----#

#-----#
#Fig.6 for grouped years
# Filter zone 2 data
FRS_zone2 <- FRS_catchrate[FRS_catchrate$zone == 2 & !is.na(FRS_catchrate$year_group), ]
FRS_zone2$trip_id <- paste(FRS_zone2$FISHER_LIC_FK, FRS_zone2$FISHED_DATE)

# Calculate total catch and number of trips per group
agg <- FRS_zone2 %>%
  group_by(year_group) %>%
  summarize(
    total_catch = sum(kc_catch, na.rm = TRUE),
    total_trips = n_distinct(trip_id),
    avg_catch_rate = total_catch / total_trips,
    .groups = "drop"
  )

group_labels <- as.character(agg$year_group)
avg_catch_rate_data <- matrix(agg$avg_catch_rate, nrow = 1, byrow = TRUE)

plot_kc_line_grouped("Fig.6", avg_catch_rate_data, group_labels,
  ylab = "Average Catch Rate (lb / trip)", plot_cols = "darkgoldenrod")
#-----#

#-----#
# Fig.7: # Trips (federal and state) and licenses (federal and state) vs year
trips_federal = summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 3,], year2, .drop = F), n =
n_distinct(paste(FISHER_LIC_FK, FISHED_DATE)))$n # number of trips to federal waters by year
trips_state = summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 1,], year2, .drop = F), n =
n_distinct(paste(FISHER_LIC_FK, FISHED_DATE)))$n # number of trips to state waters by year
licenses_federal = summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 3,], year2, .drop = F), n
= n_distinct(FISHER_LIC_FK))$n # number of fishers making trips to federal waters by year
licenses_state = summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 1,], year2, .drop = F), n =
n_distinct(FISHER_LIC_FK))$n # number of fishers making trips to state waters by year
plot_years = years >= 2000 & years <= 2024

```

```

plot(x = years[plot_years], y = trips_state[plot_years], ylim = c(0, max(trips_state)), type = 'l', col =
"orange")
lines(x = years[plot_years], y = trips_federal[plot_years], col = "blue")
plot(x = years[plot_years], y = licenses_state[plot_years], ylim = c(0, max(licenses_state)), type = 'l', col =
"orange")
lines(x = years[plot_years], y = licenses_federal[plot_years], col = "blue")
plot_kc(file_name = "Fig.7.a", plot_data = matrix(c(trips_federal, trips_state), nrow = 2, byrow = T),
plot_years, ylab = "Number of Trips", plot_cols = water_colors, filled = F, legend = c("Federal", "State"))
plot_kc(file_name = "Fig.7.b", plot_data = matrix(c(licenses_federal, licenses_state), nrow = 2, byrow =
T), plot_years, ylab = "Number of Licenses", plot_cols = water_colors, filled = F, legend = c("Federal",
"State"))
trips_data = matrix(c(trips_federal, trips_state), nrow = 2, byrow = T)
licenses_data = matrix(c(licenses_federal, licenses_state), nrow = 2, byrow = T)

```

```

x_min = min(years[plot_years])
x_max = max(years[plot_years])
y_min = 0
y_max = 1.1
y_max_trips = max(trips_data[, plot_years], na.rm = T) * 1.1
y_max_licenses = max(licenses_data[, plot_years], na.rm = T) * 1.1
xs = pretty(c(x_min, x_max), n = 4)
xs = xs[xs >= x_min & xs <= x_max]
ys_trips = pretty(c(y_min, y_max_trips), n = 4)
ys_trips = ys_trips[ys_trips >= y_min & ys_trips <= y_max_trips]
ys_licenses = pretty(c(y_min, y_max_licenses), n = 4)
ys_licenses = ys_licenses[ys_licenses >= y_min & ys_licenses <= y_max_licenses]
#pdf(paste0(root_dir, "/03_Outputs/Fig.7.pdf"), width = 6.5, height = 5, pointsize = 12)
png(paste0(root_dir, "/03_Outputs/Fig.7.png"), width = 6.5, height = 5, units = "in", res = 300, pointsize =
12)

```

```

par(mar = c(4.5, 4.5, 1, 5))
plot(NA, xlim = c(x_min, x_max), ylim = c(y_min, y_max), axes = F, xaxs = "i", yaxs = "i", xlab = "Year",
ylab = "")
axis(side = 1, at = xs)
axis(side = 2, at = ys_trips / y_max_trips, labels = ys_trips, las = 1)
axis(side = 4, at = ys_licenses / y_max_licenses, labels = ys_licenses, las = 1)
mtext(side = 2, "Number of Trips", line = 3)
mtext(side = 4, "Number of Licenses", line = 3)
lines(x = years[plot_years], y = trips_data[1, plot_years] / y_max_trips, col = water_colors[1], lwd = 2)
lines(x = years[plot_years], y = trips_data[2, plot_years] / y_max_trips, col = water_colors[2], lwd = 2)
lines(x = years[plot_years], y = licenses_data[1, plot_years] / y_max_licenses, col = water_colors[1], lty =
"dashed", lwd = 2)
lines(x = years[plot_years], y = licenses_data[2, plot_years] / y_max_licenses, col = water_colors[2], lty =
"dashed", lwd = 2)
box(which = "plot", lty = "solid")
legend(x = "topright", legend = c("Federal Trips", "Federal Licenses", "State Trips", "State Licenses"), col
= c(rep(water_colors[1], 2), rep(water_colors[2], 2)), lty = c("solid", "dashed", "solid", "dashed"), lwd = 2,
bty = "n")
dev.off()
#-----#

```

```

#-----#
# Fig.8: Catch rate vs year, separately for federal and state
federal = summarise(group_by(summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 3,],

```

```

FISHER_LIC_FK, FISHED_DATE), n = sum(kc_catch), year2 = first(year2)), year2, .drop = F), n =
mean(n))$n # average catch rate across trips to federal waters by year; weighted by trip, not fisher
state = summarise(group_by(summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 1,],
FISHER_LIC_FK, FISHED_DATE), n = sum(kc_catch), year2 = first(year2)), year2, .drop = F), n =
mean(n))$n # average catch rate across trips to state waters by year; weighted by trip, not fisher
plot_years = years >= 2000 & years <= 2024
plot(x = years[plot_years], y = federal[plot_years], type = 'l', col = "blue")
lines(x = years[plot_years], y = state[plot_years], col = "orange")
plot_kc(file_name = "Fig.8", plot_data = matrix(c(federal, state), nrow = 2, byrow = T), plot_years, ylab =
"Catch Rate (lb / trip)", plot_cols = water_colors, filled = F, legend = c("Federal", "State"))
#-----#

```

```

#-----#
# Figure 9: # Trips (federal and state) and licenses (federal and state) vs year

```

```

# Calculating catch rate by hoopnet instead of by trip
FRS_catchrate_gear <- FRS_catchrate %>%
  filter(!(NUM_GEAR == 0)) %>% # Only reporting gear number after 2002
  group_by(FISHED_DATE, FISHER_LIC_FK) %>%
  arrange(desc(SPECIES_FK == 701)) %>% # puts 701 first if it exists
  slice(1) %>% # keep only the top-priority row
  ungroup() %>%
  mutate(kc_catch_gear = kc_catch / NUM_GEAR)

gear_federal = summarise(group_by(FRS_catchrate_gear[FRS_catchrate_gear$zone == 3,], year2, .drop
= F), n = sum(NUM_GEAR))$n # number of trips to federal waters by year
gear_state = summarise(group_by(FRS_catchrate_gear[FRS_catchrate_gear$zone == 1,], year2, .drop =
F), n = sum(NUM_GEAR))$n # number of trips to state waters by year
licenses_federal = summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 3,], year2, .drop = F), n
= n_distinct(FISHER_LIC_FK))$n # number of fishers making trips to federal waters by year
licenses_state = summarise(group_by(FRS_catchrate[FRS_catchrate$zone == 1,], year2, .drop = F), n =
n_distinct(FISHER_LIC_FK))$n # number of fishers making trips to state waters by year

plot_years = years >= 2000 & years <= 2024

# Plot individual lines (optional preview plots)
plot(x = years[plot_years], y = gear_state[plot_years], ylim = c(0, max(gear_state)), type = 'l', col =
"orange")
lines(x = years[plot_years], y = gear_federal[plot_years], col = "blue")
plot(x = years[plot_years], y = licenses_state[plot_years], ylim = c(0, max(licenses_state)), type = 'l', col =
"orange")
lines(x = years[plot_years], y = licenses_federal[plot_years], col = "blue")

# Create gear and license data matrices
gear_data = matrix(c(gear_federal, gear_state)/1000, nrow = 2, byrow = T)
licenses_data = matrix(c(licenses_federal, licenses_state), nrow = 2, byrow = T)

# Mask gear data before 2002
gear_data_masked <- gear_data
gear_data_masked[, years < 2002] <- NA

# Axes and scaling setup
x_min = min(years[plot_years])
x_max = max(years[plot_years])

```

```

y_min = 0
y_max = 1.1
y_max_gear = max(gear_data[, plot_years], na.rm = T) * 1.1
y_max_licenses = max(licenses_data[, plot_years], na.rm = T) * 1.1

xs = pretty(c(x_min, x_max), n = 4)
xs = xs[xs >= x_min & xs <= x_max]

ys_gear = pretty(c(y_min, y_max_gear), n = 4)
ys_gear_norm = ys_gear / y_max_gear

ys_licenses = pretty(c(y_min, y_max_licenses), n = 4)
ys_licenses = ys_licenses[ys_licenses >= y_min & ys_licenses <= y_max_licenses]

# Output to PNG
png(paste0(root_dir, "/03_Outputs/Fig.9.png"), width = 6.5, height = 5, units = "in", res = 300, fontsize = 12)

# Start plotting
par(mar = c(4.5, 4.5, 1, 5))
plot(NA, xlim = c(x_min, x_max), ylim = c(y_min, y_max), axes = F, xaxs = "i", yaxs = "i", xlab = "Year",
ylab = "")

# Axes
axis(side = 1, at = xs)
axis(side = 2, at = ys_gear / y_max_gear, labels = ys_gear, las = 1)
axis(side = 4, at = ys_licenses / y_max_licenses, labels = ys_licenses, las = 1)
mtext(side = 2, "Number of Hoop Nets (x 1000)", line = 3)
mtext(side = 4, "Number of Licenses", line = 3)

# Plot masked gear data (starts from 2002)
lines(x = years[plot_years], y = gear_data_masked[1, plot_years] / y_max_gear, col = water_colors[1],
lwd = 2)
lines(x = years[plot_years], y = gear_data_masked[2, plot_years] / y_max_gear, col = water_colors[2],
lwd = 2)

# Plot full license data
lines(x = years[plot_years], y = licenses_data[1, plot_years] / y_max_licenses, col = water_colors[1], lty =
"dashed", lwd = 2)
lines(x = years[plot_years], y = licenses_data[2, plot_years] / y_max_licenses, col = water_colors[2], lty =
"dashed", lwd = 2)

# Finalize
box(which = "plot", lty = "solid")
legend(x = "topright",
      legend = c("Federal Hoopnets", "Federal Licenses", "State Hoopnets", "State Licenses"),
      col = c(rep(water_colors[1], 2), rep(water_colors[2], 2)),
      lty = c("solid", "dashed", "solid", "dashed"),
      lwd = 2, bty = "n")

dev.off()
#-----#

#-----#
# Fig.10: Catch rate per gear vs year, separately for federal and state using ratio of means

```

```

# 1. Federal waters (zone 3): total CPUE per year = sum(catch) / sum(gear)
federal_df <- FRS_catchrate_gear %>%
  filter(zone == 3) %>%
  mutate(year2 = as.numeric(as.character(year2))) %>%
  group_by(year2) %>%
  summarise(
    cpue = sum(kc_catch, na.rm = TRUE) / sum(NUM_GEAR, na.rm = TRUE),
    .groups = "drop"
  )

# 2. State waters (zone 1): total CPUE per year = sum(catch) / sum(gear)
state_df <- FRS_catchrate_gear %>%
  filter(zone == 1) %>%
  mutate(year2 = as.numeric(as.character(year2))) %>%
  group_by(year2) %>%
  summarise(
    cpue = sum(kc_catch, na.rm = TRUE) / sum(NUM_GEAR, na.rm = TRUE),
    .groups = "drop"
  )

# 3. Plot using plot_kc_dplyr
plot_kc_dplyr(
  file_name = "Fig.10", # total CPUE, not average of trip CPUE
  plot_data_list = list(federal_df, state_df),
  ylab = "Catch Rate (lb / hoopnet)",
  plot_cols = water_colors, # e.g., c("blue", "orange")
  filled = FALSE,
  legend = c("Federal", "State"),
  year_range = c(2000, 2024),
  set_y_max = 2
)
#-----#

#-----#
# Fig.11: Catch vs year, separately for MHI FRS kept and sold
catch = summarise(group_by(FRS_catch, year2, .drop = F), n = sum(catch))$n
sold_frs = summarise(group_by(FRS_catch, year2, .drop = F), n = sum(LBS_SOLD))$n
sold_dealer = summarise(group_by(Dealer, year2, .drop = F), n = sum(LBS_SOLD))$n
sold = sold_frs
sold[years >= 2000 & years <= 2024] = sold_dealer
plot_years = years <= 2024
plot(x = years[plot_years], y = catch[plot_years], type = "l", col = "blue")
lines(x = years[plot_years], y = sold[plot_years], col = "orange")
plot_kc(file_name = "Fig.11", plot_data = matrix(c(catch - sold, sold) / 1000, nrow = 2, byrow = T),
  plot_years, ylab = "Catch (x 1000 lb)", plot_cols = pair_colors, filled = T, legend = c("Non-Sold", "Sold"))
#-----#

#-----#
# Figure 12: Penguin bank catches by year group due to confidentiality
group_breaks <- c(1958, 1961, 1964, 1967, 1970, 1973, 1976, 1979, 1982, 1985, 1988, 1991, 1994,
  1997, 2000, 2003, 2006, 2009, 2012, 2015, 2018, 2021, 2024)
group_labels <- year_groups2

# 2. Add year group column

```

```

FRS_catchrate$year_group2 <- cut(FRS_catchrate$year, breaks = group_breaks, labels = group_labels)

FRS_zone2 <- FRS_catchrate[FRS_catchrate$zone == 2 & !is.na(FRS_catchrate$year_group2), ]
FRS_zone2$trip_id <- paste(FRS_zone2$FISHER_LIC_FK, FRS_zone2$FISHED_DATE)

# Ensure year_group2 is a factor with all desired levels
FRS_zone2 <- FRS_zone2 %>%
  mutate(year_group2 = factor(year_group2, levels = year_groups2))

# Aggregate and include missing groups with 0 catch
agg <- FRS_zone2 %>%
  group_by(year_group2) %>%
  summarize(
    total_catch = sum(kc_catch, na.rm = TRUE),
    .groups = "drop"
  ) %>%
  complete(year_group2 = year_groups2, fill = list(total_catch = 0))

group_labels <- as.character(agg$year_group2)
sum_catch_data <- matrix(agg$total_catch, nrow = 1, byrow = TRUE)

FRS_zone3 <- FRS_catchrate %>%
  filter(zone == 3, !is.na(year_group2)) %>%
  mutate(
    trip_id = paste(FISHER_LIC_FK, FISHED_DATE),
    year_group2 = factor(year_group2, levels = year_groups2)
  )

# 5. Aggregate for Zone 3
agg_zone3 <- FRS_zone3 %>%
  group_by(year_group2) %>%
  summarize(total_catch = sum(kc_catch, na.rm = TRUE), .groups = "drop") %>%
  complete(year_group2 = year_groups2, fill = list(total_catch = 0))

# 6. Combine into matrix (Zone 2 on row 1, Zone 3 on row 2)
sum_catch_data2 <- rbind(agg$total_catch, agg_zone3$total_catch)

# 7. Call the plotting function
plot_kc_grouped(
  file_name = "Fig.12",
  plot_data = sum_catch_data2/1000,
  year_groups = year_groups2,
  ylab = "Catch (x 1000 lb)",
  plot_cols = c("darkgoldenrod", "deepskyblue3"),
  filled = TRUE,
  legend = c("Penguin Bank", "Other Federal Waters")
)
#-----#

#-----#
#Figure 13 - using stacked bar plot and excluding data we cannot show due to confidentiality when
#licenses N < 3
kauai_niihau = summarise(group_by(FRS_catch[FRS_catch$AREA_FK %in% c(520, 521, 525, 526)],

```

```

year2, .drop = F), n = sum(catch))$n
federal = summarise(group_by(FRS_catch[FRS_catch$zone == 3,], year2, .drop = F), n = sum(catch))$n
plot_years = years >= 2014 & years <= 2024
zero_years <- c(2014, 2016, 2019, 2020, 2022, 2024)
kauai_niihau = summarise(group_by(FRS_catch[FRS_catch$AREA_FK %in% c(520, 521, 525, 526),],
year2, .drop = F), n = sum(catch))$n
kauai_niihau2 <- kauai_niihau

# Loop through zero_years and set kauai_niihau to zero for those years
for (yr in zero_years) {
  idx <- which(years == yr)
  if(length(idx) == 1) {
    kauai_niihau2[idx] <- 0
  }
}

bar_data <- rbind(kauai_niihau2[plot_years], federal[plot_years]-kauai_niihau2[plot_years])

# Define years to mark with asterisk
asterisk_years <- c(2014, 2016, 2019, 2020, 2022, 2024)

# Calculate max Y value and add 400
y_max <- max(colSums(bar_data), na.rm = TRUE) + 300

png(paste0(root_dir, "/03_Outputs/Fig.13.png"), width = 6.5, height = 5, units = "in", res = 300, pointsize =
12)
par(mar = c(4.5, 4.5, 1, 1))

# Create the barplot with custom ylim
bar_positions <- barplot(bar_data,
  names.arg = rep("", ncol(bar_data)), # Must match number of bars
  col = c("deepskyblue4", "deepskyblue3"),
  xlab = "Year",
  ylab = "Catch (lb)",
  ylim = c(0, y_max),
  axes = FALSE,
  legend.text = c("Kauai/Niihau", "All Federal Waters"),
  args.legend = list(x = "topright", bty = "n"))

# Add custom y-axis
axis(side = 2, at = c(500, 1000), las = 1)

# Add custom x-axis: ticks only where labels exist
label_indices <- seq(1, ncol(bar_data), by = 2) # Change to desired spacing
axis(side = 1,
  at = bar_positions[label_indices],
  labels = years[plot_years][label_indices],
  tick = TRUE)

# Add asterisks to specific years
target_indices <- which(years[plot_years] %in% asterisk_years)
text(x = bar_positions[target_indices],
  y = colSums(bar_data)[target_indices] + 50, # Add a little vertical offset
  labels = "**",
  cex = 1.2)

```

```

# Box around plot
box(which = "plot", lty = "solid")

# Close PNG device
dev.off()
#-----#

#-----#
# Figure A1: % of sold catch vs year for FRS
catch = summarise(group_by(FRS_catch, year2, .drop = F), n = sum(catch))$n
sold_frs = summarise(group_by(FRS_catch, year2, .drop = F), n = sum(LBS_SOLD))$n
sold_dealer = summarise(group_by(Dealer, year2, .drop = F), n = sum(LBS_SOLD))$n
sold = sold_frs
sold[years >= 2000 & years <= 2024] = sold_dealer
plot_years = years <= 2024
plot(x = years[plot_years], y = sold[plot_years] / catch[plot_years], type = 'l', col = "black")
plot_kc(file_name = "Fig.A1", plot_data = matrix(sold / catch, nrow = 1, byrow = T), plot_years, ylab =
"Proportion of Catch Sold", plot_cols = "gray40", filled = F, legend = NA, set_y_max = 1)
dev.off()
#-----#

#-----#
#Figure A5: Large scale seasonal variability of catch
# Ensure FISHED_DATE is Date type
FRS$FISHED_DATE <- as.Date(FRS$FISHED_DATE)

# Extract year and month
FRS <- FRS %>%
  mutate(
    Year = year(FISHED_DATE),
    Month = month(FISHED_DATE, label = TRUE, abbr = TRUE), # abbreviated month labels
    Month_num = month(FISHED_DATE)
  )

# Calculate proportional catch by Month and Year
monthly_catch <- FRS %>%
  group_by(Year, Month, Month_num) %>%
  summarise(catch = sum(catch, na.rm = TRUE), .groups = "drop",
    licences = n_distinct(FISHER_LIC_FK)) %>%
  group_by(Year) %>%
  mutate(proportion = catch / sum(catch)) %>%
  ungroup()

# Create a consistent unordered factor for Month
# Create a common month level set
month_levels <- month.abb # "Jan", "Feb", ..., "Dec"

# Create full grid with correct Month factor (unordered)
full_grid <- expand_grid(
  Year = 1948:2024,
  Month_num = 1:12,
) %>%
  mutate(

```

```

Month = factor(month.abb[Month_num], levels = month_levels, ordered = FALSE),
Year_group_start = floor((Year - min(Year)) / 16) * 16 + min(Year),
Year_group_end = Year_group_start + 15,
Year_group = paste0(Year_group_start, "-", Year_group_end)
) %>%
mutate(Year_group = case_when(Year_group == "2012–2027" ~ "2012–2024",
                             TRUE ~ Year_group))

# Ensure monthly_catch uses the same factor type
monthly_catch <- monthly_catch %>%
  mutate(
    Month = as.character(Month), # strip ordering
    Month = factor(Month, levels = month_levels, ordered = FALSE)
  )

# Now safe to join
monthly_catch_full <- full_grid %>%
  left_join(monthly_catch, by = c("Year", "Month", "Month_num")) %>%
  replace_na(list(proportion = 0))

monthly_catch_full <- monthly_catch_full %>%
  mutate(
    Year = factor(Year, levels = 1948:2024),
    Month = factor(Month, levels = rev(month.abb)) # Reverse month order for y-axis
  )

# Several years put together due to confidentiality
# Aggregate by Year_group and Month
monthly_grouped <- monthly_catch_full %>%
  group_by(Year_group, Month) %>%
  summarise(proportion = mean(proportion, na.rm = TRUE), .groups = "drop")

# Plot using Year_group
ggplot(monthly_grouped, aes(x = Year_group, y = fct_rev(Month), fill = proportion)) +
  geom_tile(color = "grey80") +
  scale_fill_viridis_c(
    name = "Proportional Catch",
    trans = "sqrt",
    limits = c(0, 1)
  ) +
  facet_wrap(~ Year_group, scales = "free_x", nrow = 1) +
  theme_bw() +
  labs(
    title = "",
    x = "Proportional Catch by Month within Year Group",
    y = "Month"
  ) +
  theme(
    strip.text = element_text(face = "bold"),
    axis.text.x = element_blank(),
    panel.grid = element_blank()
  )

```

```
ggsave(paste0(root_dir, "/03_Outputs/Fig.A5.png"), width = 6, height = 4, units = "in", dpi = 300)
#-----#
```