TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Summary of objectives, methods and results...

RÉSUMÉ

Usually the french version of the abstract goes here, but it is included here to show how accents might be added to text and how non-numbered sections work.

1 INTRODUCTION

Hecate Strait and Queen Charlotte Sound contain some of the most productive fishing grounds in British Columbia (BC), providing key habitat for many commercially important groundfish species. This project will employ multivariate statistics and geostatistical approaches to analyse relationships between environmental factors and distribution and productivity of key groundfish populations in Hecate Strait and Queen Charlotte Sound. The project will improve advice for management of Pacific groundfish stocks by: (i) improving understanding of environmental drivers of groundfish distribution and productivity needed for ecosystem-based management; (ii) improved estimates of abundance for key species; (iii) identification of juvenile habitats; (iv) provision of a baseline for understanding impacts of environmental change on species distribution; and (v) identification of species that could indicate ecosystem change through shifts in distribution and productivity.

Distribution and abundance of groundfish species is associated with invariant (e.g., depth, bottom-type) and variable (e.g., temperature, salinity) environmental factors (Perry et al., 1994; Rooper et al., 2005; Rooper, 2008). Measuring relationships between these factors and distribution and abundance is the first step in understanding drivers of productivity (recruitment, growth, mortality), which is a critical component of ecosystem-based management. This project will employ statistical and hierarchical Bayesian geostatistical models (Rooper et al., 2005; Rooper, 2008; Lecomte et al., 2013*b*,*a*) to analyse relationships between environmental factors and distribution, abundance and size structure of a set of key, commercially harvested groundfish species in Hecate Strait and Queen Charlotte Sound. Models will utilize data from commercial trawl logbooks and fishery independent surveys. Temperature and salinity data from the Regional Oceanographic Model System (ROMS) (Masson and Fine, 2012) will provide key model inputs.

Results for each species will include maps of predicted distribution and abundance of adults and juveniles; Bayesian predictive probability distributions of the relationships between habitat and environmental factors and abundance; and plots of the distribution of adults and juveniles along environmental gradients. Species most likely to be impacted by large environmental changes (e.g., ocean temperature) will be identified. Working with our external collaborator, results for a subset of species will be compared to results from Alaska to test generality of results and identify key differences. The project will provide updated estimates of abundance for the species of interest and will identify locations that may represent critical juvenile habitat. Results will be published in the primary literature, and in a CSAS Research Document reviewed through the Centre for Science Advice Pacific.

In the long-term, the project will provide important baseline data for understanding potential future impacts of environmental change. Some species (e.g., Pacific Cod) are known to vary their habitat with depth to maintain a limited temperature range [1], indicating that their distribution could be strongly affected by long-term changes in ocean temperature. Published studies have shown that large-scale redistribution of north Pacific fish populations may occur under future climate scenarios, with the potential for large impacts on ecosystem structure and function [7][8]. Groundfish indicator species most likely to be affected by environmental change will be identified in this project. Finally, ecosystem-based fishery management is based on principles of understanding the structure and function of the living components of marine ecosystems. In the US, NOAA is mandated to identify habitats essential for every managed fish species and identify those habitats that contribute most to survival, growth and productivity [9]. The analyses in this project will form an important component of this understanding for central and northern BC waters. Through partnership with our external collaborator, comparative analyses will test generality of results and identify differences between BC and Alaska.

2 METHODS

2.1 GROUNDFISH BOTTOM TRAWL SURVEY

Groundfish bottom trawl survey data for our analyses were collected during the DFO's biennial Hecate Strait Synoptic Trawl Survey and the Queen Charlotte Sound Synoptic Trawl Survey between 1984 and 2015. Tows began at pre-determined locations as part of a random, stratified sampling design with strata based on (?????). Fish were identified to species, lengths measured, sexed (0 = unknown, 1 = male, 2 = female, 3 = ?), and characterised by maturity (categories 1 to 7) according to a prioritized sampling protocol. A sub-sample of each fish species from every tow were grouped by species and weighed to the nearest kilogram (kg). Tow length and travel speed were also recorded. The data used these analyses are therefore the biomass of each species in each tow, and in some cases, standardised as catch per unit of trawl effort (catch per square kilometre).

2.2 ENVIRONMENTAL DATA

During the groundfish bottom trawl survey average net depth (m) and ocean temperature (°C) data were also collected from sensors attached to the net. Highly spatially-resolved, commercial logbook data were available from BC's 100%-observed groundfish bottom trawl fishery. All these data are held in Oracle databases, co-managed by the Pacific Groundfish Statistics Program. Spatially-gridded predictions of temperature and salinity data for Hecate Strait and Queen Charlotte Sound, were output from the Regional Oceanographic Model System at the Institute of Ocean Sciences. Spatial bottom-type data at 100 m and 20 m resolution were available at the Pacific Biological Station. Scientists at NOAA's Alaska Fisheries Science Center are currently engaged in developing distribution maps for all commercially-fished species in Alaska. Some of these data were available, via our external collaborator Dr. Rooper at the Alaska Fisheries Science Center.

Substrate type (e.g. hard, sandy, muddy) and ocean depth for the study area was obtained from the BCMarine Conservation Analysis database.

Software: A version of the hierarchical Bayesian model has already been written using the OpenBUGS programming language. This code was customized and refined for this project. All other statistical models and graphic outputs were developed using the R-programming language. Species abundance and data distribution maps were made using ArcGIS or a similar (e.g., QGIS, PBSMapping).

2.3 DATA MANAGEMENT

Spatially-gridded Canadian datasets and gridded predictions of distribution and abundance were transferred to a database managed by the Pacific Groundfish Statistics program. They were available internally to Pacific stock assessment scientists, and by request externally. Maps were incorporated into an intranet-based tool, making them available to Pacific scientists and managers.

2.4 CUMULATIVE DISTRIBUTION FUNCTIONS

The purpose of this component of the study was to identify significant associations between environmental parameters and the distributions of 20 species of northeast Pacific Ocean groundfish. It was also meant to be a continuation of the analysis presented by Perry et al. (1994). We used cumulative distribution functions (cdf's) of fish catch (CPUE) and the environmental factors described above (substrate, salinity, temperature and depth) (Perry and Smith, 1994; Perry et al., 1994). This technique calculates the empirical cdf's for the environmental parameters alone and the environmental parameters weighted by the CPUE of a particular species (Perry and Smith, 1994; Perry et al., 1994).

The probability associated with each observation in a cdf is 1/*n*. Therefore the cdf for a given habitat variable (x_i) is of the form (Chambers and Dunstan, 1986):

$$f(t) = \sum_h \sum_i \frac{W_h}{n_h} \, I(x_{hi}) \tag{1}$$

with the indicator function

$$I\ (x_{hi}) = \begin{cases} 1, & \text{if } x_h i \leq t; \\ 0, & \text{otherwise.} \end{cases}$$

Where *t* represents an index, ranging from the lowest to the highest values of the habitat parameter at a step appropriate for the desired resolution. Equation 1 is calculated over all values of *t* for each habitat measurement (x_i) available.

The cdf's derived from Equation 1 can be used to determine the proportion of the environmental-weighted catch within any range of the environmental variable during the survey.

Copied directly from Perry and Smith 1994. Including the survey stratification scheme via the W_h/n_h terms ensures that we have an unbiased estimate of the frequency distribution for the habitat measurement. Ignoring the stratification by replacing W_h/n_h with 1/*n* would result in either under- or overestimating the area associated with any particular value of the habitat measurement. However, he term W_h/n_h does simplify to 1/*n* when the number of sets allocated to each stratum is proportional to the size of the stratum (i.e., n_h = nW_h). That is stratification can be ignored when the allocation of sets is strictly proportional to the stratum size. Next, we associate the catch of fish (in weight) of a particular species in each tow with the habitat parameters during that tow as weight in the form:

$$g(t) = \sum_h \sum_i \frac{W_h}{n_h} \frac{y_{hi}}{y_{st}} I(x_{hi}). \tag{2}$$

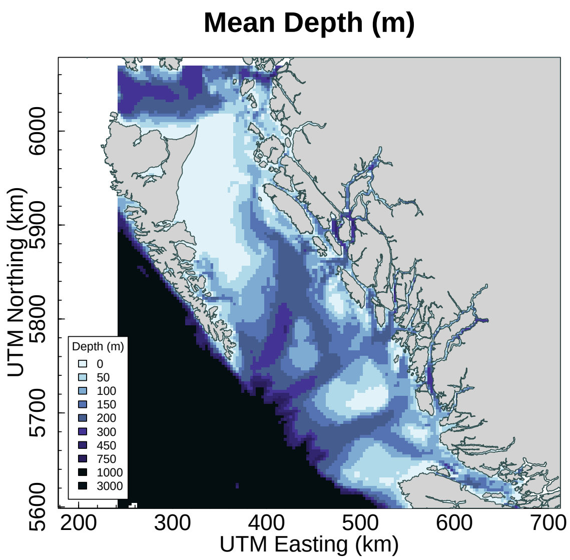
2.5 MODELS

The project will apply a mix of established and recently-published statistical approaches to achieve the deliverables of the project. An earlier study [1] applied a set of multivariate statistical models to classify groundfish species in Hecate Strait according to their relationships with invariant and variable environmental factors. Recent studies have further developed these types of approaches for Alaskan groundfish species (e.g., [2][3]). A problem with spatial datasets for many marine species is the high proportion of zero observations, which can bias results. One approach to solving this problem is to use a two-stage model to first predict presence and absence, then analyse relationships between environmental variables and abundance [10]. More recently, the problem has been addressed using new Bayesian hierarchical models which estimates both the probability of zero observations and abundance in a hierarchical framework [4][5]. Within this framework, a geostatistical approximation, consisting of a linear model with spatially-correlated errors, is used to efficiently predict spatial abundance as a function of environmental factors [5]. The model outputs spatial predictions of abundance, and predictive probability distributions of the effects of each environmental factor on abundance for each species. Models are calibrated with spatial abundance observations. Analyses can be done on different size-classes of the population to better understand differences in adult and juvenile distribution and improve understanding of productivity.

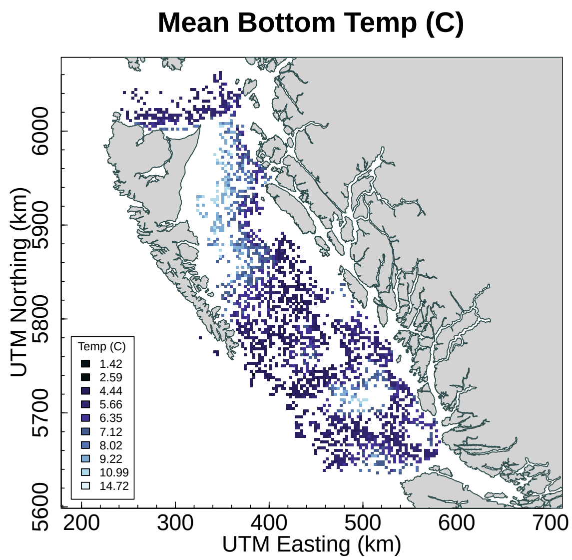
3 RESULTS

4 ENVIRONMENTAL COVARIATES

Environmental covariates considered during this analysis included average trawl net depth, and bottom temperature and salinity. Trawl net depth was recorded during each tow. Temperature and salinity data were collected during the groundfish trawl surveys and were also available from the Regional Oceanographic Model System (ROMS).

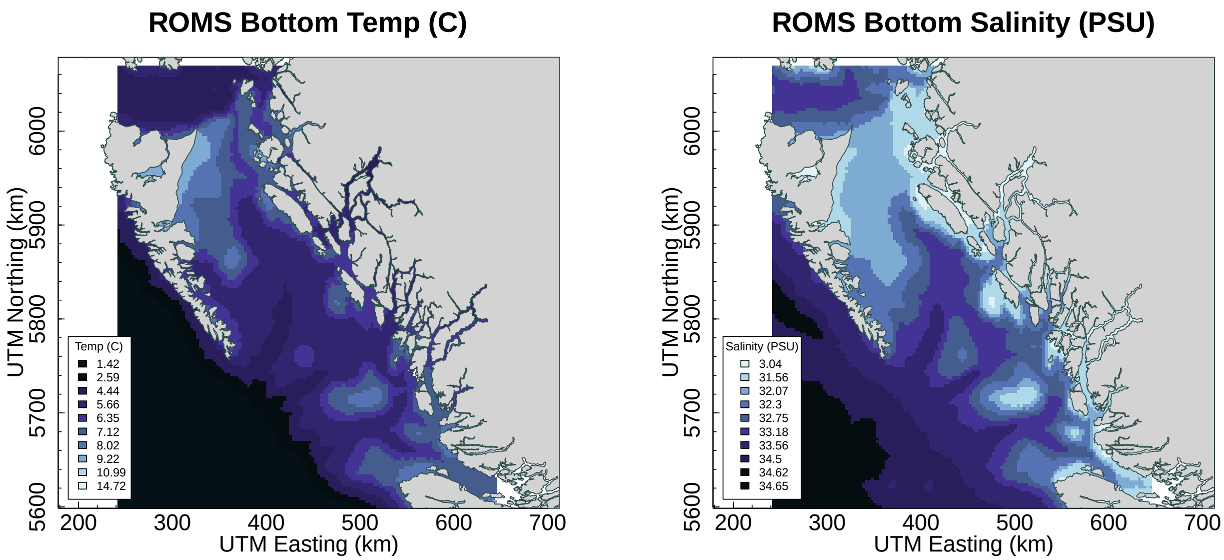


(a) Mean ocean depth (m) in grid cells of 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean bottom temperature (°C) in grid cells of 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure 1. Summary of environmental covariate data. See Table XX for a list of surveys.



(a) Ocean floor temperature (°C) from ROMS in grid cells of 3 km x 3 km for XX years.

(b) Mean bottom salinity (PSU) from ROMS in grid cells of 3 km x 3 km for XX years.

Figure 2. Regional Oceanographic Model System (ROMS) ocean floor temperature (°C) and salinity (PSU) data from XX years.

5 HOW REFERENCES WORK

5.1 HOW THE FIGURE AND TABLE REFERENCES WORK

See Figures 3, 4, 5, and 6. Note that these numbers are clickable and you can go directly to the figure. These are referenced figures.

A figure/table reference works by adding a reference name to a figure/table, then remembering what is was and using a `\ref` command to reference the figure/table. For example in Figure 3, the figure reference code has a label tag like this `\label{fig:example-random-stuff}`. The figure can be referenced anywhere in the latex document by using this syntax: `\ref{fig:example-random-stuff}`. The numbering is taken care of for you and is separate for each type of reference. Here is a list of suggested prefixes to use for different reference types:

1. **sec**: - section
2. **subsec**: - subsection
3. **fig**: - figure
4. **tab**: - table
5. **eq**: - equation
6. **lst**: - code listing
7. **itm**: - enumerated list item (like this list)
8. **chap**: - appendix

5.2 HOW APPENDIX REFERENCES WORK

Appendix references are much like chapters of a book. They can be added or commented out easily at the bottom of *example.Rnw*. This helps with the incremental form of development where you make sure the main document is compiling and then when ready, uncomment the appendix inclusion code and the appendix will be included in the document. Once included, any appendix references will be resolved.

The code which adds an appendix is *knitr* code because you want the appendix added before the knitting process so that any figures or R expressions are resolved, just like in the main document. This is an example of how appendix code is added:

```
\rfoot{Appendix A -- Species Summaries}

<<appendix-A, child='appendix-A/appendix-A.Rnw'>>=
@
```

To reference this appendix, use this syntax: `\ref{chap:example.1}` which resolves to appendix A. This is also clickable and will take you directly to the appendix. The reference must be defined at the beginning of *appendix-A.Rnw* like this: `\label{chap:example.1}`. This method is repeated for all appendices. They will be lettered in the order in which they appear in example.Rnw, so it is very easy to change the order of appendices and rebuild the document.

6 SUMMARY

Here's a reference to an appendix:

REFERENCES

Abookire, A. 2006. Reproductive biology, spawning season, and growth of female rex sole (*Glyptocephalus zachirus*) in the Gulf of Alaska. Fish. Bull. **104**: 350–359.

Allen, M.J. and Smith, G.B. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. U.S. Department of Commerce, NOAA Tech. Rep. NMFS. **66**: 151 p.

Alverson, D. 1960. A study of annual and seasonal bathymetric catch patterns for commercially important groundfishes of the Pacific northwest coast of North America. Pac. Mar. Fish. Comm. Bull. **4**: 66 p.

Alverson, D., Pruter, A. and Ronholt, L. 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. *In* MacMillan Lectures in Fisheries. Institute of Fisheries, University of British Columbia 190 p.

Andrews, A., Burton, E., Kerr, L., Cailliet, G., Coale, K., Lundstrom, C. and Brown, T. 2005. Bomb radiocarbon and lead-radium disequilibria in otoliths of bocaccio rockfish (*Sebastes* *paucispinis*): a determination of age and longevity for a difficult-to-age fish. Mar. Freshwat. Res. **56**: 517–528.

Armstrong, R. 1996. Alaska's fish. A guide to select species. Alaska Northwest Books.

Barnett, L., Earley, R., Ebert, D., and Cailliet, G. 2009*a*. Maturity,fecundity and reproductive cycle of the spotted ratfish, *Hydrolagus colliei*. Mar. Biol. **156**: 301–316.

Barnett, L., Ebert, D. and Cailliet, G. 2009*b*. Assessment of thedorsal fin spine for chimaeroid(Holocephali:Chimaeriformes) age estimation. J. Fish Biol. **75**: 1258–1270.

Bars, W. and Echeverria, T.W. 1987. Maturity of Widow Rockfish *Sebastes entomelas* from the Northeastern Pacific, 1977-82. 13–18. Alaska Sea Grant College Program, Fairbanks, Alaska.

Blood, D., Matarese, A. and Busby, M. 2007. Spawning, egg development, and early life history dynamics of arrowtooth flounder (*Atheresthes stomias*) in the Gulf of Alaska. U.S. Department of Commerce, NOAA Tech. Rep. NMFS. **7**: 28 p.

Bourne, N. and Pope, M. 1969. Deep-sea line fishing off British Columbia. J. Fish. Res. Board Can. **26**: 2527–2531.

Brodeur, R. and Livingston, P. 1988. Food habits and diet overlap of various eastern Bering Sea fishes. NOAA Tech. Memo NMFS F/NWC **127**: 76 p.

Browne, P., Laake, J. and DeLong, R. 2002. Improving pinniped diet analyses through identification of multiple skeletal structures in fecal samples. Fish. Bull. **100**: 423–433.

Buckley, T., Tyler, G.E., Smith, D.M. and Livingston, P.A. 1999. Food habits of some commercially important groundfish off the coasts of California, Oregon, Washington, and British Columbia. NOAA Technical Memorandum. NFMS-AFSC-102 173 p.

Cailliet, G., Andrews, A., Burton, E., Watters, D., Kline, D. and Ferry-Graham, L. 2001. Age determination and validation studies of marine fishes: do deep-dwellers live longer? Exp. Geront. **36**: 739–764.

Carlson, H.R. and Straty, R.R. 1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes spp.*, in rocky coastal areas of southeastern Alaska. Mar. Fish. Rev. **43**: 13–19.

Carlson, H. and Haight, R. 1976. Juvenile life of Pacific Ocean perch, <>Sebastes alutus, in coastal fjords of southeastern Alaska: their environment, growth, food habits, and schooling behavior. Trans. Am. Fish. Soc. **105**: 191–201.

Casillas, E., Crockett, L., deReynier, Y., Glock, J., Helvey, M., B. Meyer, C.S., Yoklavich, M., Bailey, A., Chao, B., Johnson, B. and Pepperell, T. 1998. Essential Fish Habitat, West Coast Groundfish. Appendix to Amendment 11 of the Pacific Coast Groundfish Plan. In Fishery Management Plan Environmental Impact Statement for the California, Oregon, Washington Groundfish Fishery. National Marine Fisheries Service, Seattle.

Castillo, G., Golden, J. and Li, H. 1995. Variations in relative abundance and year-class strength of petrale sole off Oregon and Washington. In Proceedings of the International Symposium on North Pacific Flatfish, 321–341. Alaska Sea Grant College Program, Fairbanks, Alaska.

Chambers, R. and Dunstan, R. 1986. Estimating Distribution Fucntions from Survey Data. Biometrika **73**: 597–604.

Chilton, D. and Beamish, R. 2000. Age determination methods for fish studies by the groundfish program at the Pacific Biological Station. Can. Spec. Pub. Fish. Aquat. Sci. **60**: 102 p.

Clemens, W. and Wilby, G. 1961. Flatfish Stock Assessments for the west coast of Canada for 1997 and recommended yield options for 1998. Fish. Res. Bd. Canada Bull. 2nd ed. **68**: 443 p.

la Cruz Agüero, J.D., Martínez, M.A., Gómez, V.C. and de la Cruz-Agüero, G. 1997. Catalogo de los peces marinos de Baja California Sur. IPN-CICIMAR 346 p.

Dean, B. 1906. Chimaeroid Fishes and their Development. Carnegie Institute Publication Washington, D.C.

DeLacy, A. and Dryfoos, R. 1962. Maturation and the young of rockfishes (Sebastodes). Res. Fish. 1962. Coll. Fish. Univ. Wash. 22–23.

DeMott, G. 1983. Movement of tagged lingcod and rockfishes off Depoe Bay, Oregon. Master's thesis, Oregon State University, Corvalis, OR.

DFO. 1999. Dover sole west coast Vancouver Island (Areas 3C, D) to Queen Charlotte Islands (Areas 5A-E). DFO Science Stock Status Report **A6-04**: 3 p.

DFO. 2009. Recovery assessment of canary rockfish in British Columbia waters. DFO Can. Sci. Advis. Sec. Advis. Rep. **2009/041**: 32 p.

DFO. 2010. Assessment of Spiny Dogfish (*Squalus acanthias*) in British Columbia in 2010. DFO Can. Sci. Advis. Sec. Advis. Rep. **2010/057**: 11 p.

DFO. 2011. Management Procedures for the Multi-Gear Sablefish (*Anoplopoma fimbria*) Fishery in British Columbia, Canada. DFO Can. Sci. Advis. Sec. Advis. Rep. **2011/025**: 10 p.

DFO. 2013. A Review of Sablefish Population Structure in the Northeast Pacific Ocean and Implications for Canadian Seamount Fisheries. DFO Can. Sci. Advis. Sec. Resp. **2013/017**: 21 p.

DFO. 2015. Arrowtooth Flounder (*Atheresthes stomias* stock assessment for the west coast of British Columbia. DFO Can. Sci. Advis. Sec. Advis. Rep. **2015/055**: 10 p.

Ebert, D. 2003. Sharks, rays and chimaeras of California. California Natural History Guides No. 71. University of California Press, Berkeley, California.

Ebert, D., White, W., Goldman, K., Compagno, L., Daly-Engel, T. and Ward, R. 2010. Resurrection and redescription of *Squalus suckleyi* (Girard, 1854) from the North Pacific, with comments on the *Squalus acanthias* subgroup (Squaliformes: Squalidae). Zootaxa **2612**: 22–40.

Edwards, A.M., Haigh, R. and Starr, P.J. 2012*a*. Stock assessment and recovery potential assessment for Yellowmouth Rockfish (*Sebastes reedi*) along the Pacific coast of Canada. DFO Can. Sci. Advis. Sec. Res. Doc. **2012/095**: iv + 188 p.

Edwards, A.M., Starr, P.J. and Haigh, R. 2012*b*. Stock assessment for Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. **2011/111**: viii + 172 p.

Edwards, A., Haigh, R. and Starr, P. 2013. Pacific Ocean Perch (*Sebastes alutus*) stock assessment for the west coast of Vancouver Island, Britsh Columbia. DFO Can. Sci. Advis.

Sec. Res. Doc. **2013/093**: vi + 135 p.

Enticknap, B. and Sheard, W. 2005. Conservation and management of North Pacific rockfishes. Alaska Marine Conservation Council, Anchorage, AK.

Eschmeyer, W., Herald, E. and Hammann, H. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Company, Boston, U.S.A.

Fargo, J. 1998. Flatfish Stock Assessments for the west coast of Canada for 1997 and recommended yield options for 1998. Canadian Stock Assessment Secretariat Research Document **1997/36**: 55 p.

Fargo, J., Kronlund, A., Schnute, J. and Haigh, R. 2000. Stock assessment of rock sole and English sole in Hecate Strait for 2000/2001. DFO Can. Sci. Advis. Sec. Advis. Rep. **2000/166**: 83 p.

Fort, K., Amey, K. and Dunn, M. 2006. Scott Islands Marine Wildlife Area Study Area: an ecosystems overview report. Canadian Wildlife Service, Pacific Yukon Region, Technical Report Series No. 427 .

Fournier, D. 1983. An analysis of the Hecate Strait Pacific cod fishery using an age-structured model incorporating density-dependent effects. Can. J. Fish. Aquat. Sci. **40**: 1233–1243.

Gaichas, S. and Ianelli, J. 2005. Gulf of Alaska Thornyheads. *In* 2005 North Pacific Groundfish Stock Assessments and Fishery Evaluation Reports for 2006. U.S. Department of Commerce, NOAA Technical Report NMFS 826–860.

Grinols, R. 1965. Check-List of the Offshore Marine Fishes Occurring in the Northeast Pacific Ocean, Principally off the Coasts of British Columbia, Washington, and Oregon. Master's thesis, University of Washington, Seattle, WA.

Gunderson, D. 1997. Trade-off between reproductive effort and adult survival in oviparous and viviparous fishes. Can. J. Fish. Aquat. Sci. **54**: 990–998.

Haigh, R. and Starr, P.J. 2008. A review of yellowmouth rockfish *Sebastes reedi* along the Pacific coast of Canada: biology, distribution, and abundance trends. Canadian Science Advisory Secretariat Research Document **2008/055**: vi + 97. Available from http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2008/2008_055_e.htm.

Hart, J.L. 1973. Pacific fishes of Canada. Bulletin of the Fisheries Research Board of Canada **80**: 740.

Harvey, C., Gross, K., Simon, V. and Hastie, J. 2008. Trophic and fishery interactions between Pacific hake and rockfish: effect on rockfish population rebuilding times. Mar. Ecol. Prog. Ser. **365**: 165–176.

Harvey, J. 1989. Food habits, seasonal abundance, size, and sex of the blue shark, *Prionace gluaca*, in Monterey Bay, California. Cali. Fish Game **75**: 33–44.

Hitz, C. 1962. Seasons of birth of rockfish (*Sebastodes spp.*) in Oregon coastal waters. Trans. Am. Fish. Soc. **91**: 231–233.

Holt, K., Starr, P., Haigh, R. and Krishka, B. 2014. Stock Assessment and Harvest Advice for Rock Sole (*Lepidopsetta Spp.*) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. **2013/nnn**: v + 161 p.

Hosie, M. and Horton, H. 1977. Biology of the rex sole, *Glyptocephalus zachirus* in waters off Oregon. Fish. Bull. **75**: 51–60.

Ianelli, J., Lauth, R. and Jacobson, L. 1994. Status of the thornyhead (Sebastolobus sp.) resource in 1994 (Appendix D). In Appendices to the Status of the Pacific Coast Groundfish Fishery Through 1994 and Recommended Accepted Biological Catches for 1995. Appendix Vol. 1: Stock Assessment and Fishery Evaluation. Pacific Fishery Management Council, Portland, Oregon.

Jacobson, L. and Vetter, R. 1996. Bathymetric demography and niche separation of thornyhead rockfishes: *Sebastolobus alascanus* and *Sebastolobus altivelis*. Can. J. Fish. Aquat. Sci. **53**: 600–609.

Kendall Jr., A.W. and Lenarz, W.H. 1986. Status of early life history studies of northeast Pacific rockfishes. In Proceedings of the International Rockfish Symposium, 99–128. University of Alaska, Alaska Sea Grant College Program Report AK-SG-87-2, Anchorage, Alaska.

King, J. and McPhie, R. 2015. Preliminary age, growth and maturity estimates of spotted ratfish (*Hydrolagus colliei*) in British Columbia. Deep-Sea Res. Pt. II **115**: 55–63.

Kramer, D. and O'Connell, V. 1995. Guide to Northeast Pacific rockfishes. Genera *Sebastes* and *Sebastolobus*. Alaska Sea Grant, Marine Advisory Bulletin **No. 25**.

Lamb, A. and Edgell, P. 1986. Coastal fishes of the the Pacific northwest. Harbour Publishing Co. Ltd., B.C., Canada.

Lecomte, J., Benoît, H., Ancelet, S., Etienne, M., Bel, L. and Parent, E. 2013*a*. Compound Poisson-Gamma versus Delta-Gamma to handle zero-inflated continuous data under a variable sampling volume. Methods Ecol. Evol. **4**: 1159–1166.

Lecomte, J., Benoît, H., Etienne, M. and Parent, E. 2013*b*. Modeling the habitat associations and spatial distribution of benthic macroinvertebrates: A hierarchical Bayesian model for zero-inflated biomass data. Ecol. Model. **265**: 74–84.

Livingston, P. 1993. Importance of predation by groundfish, marine mammals and birds on walleye pollock *Theragra chalcogramma* and Pacific herring *Clupea pallasi* in the eastern Bering Sea. Mar. Ecol. Prog. Ser. **102**: 205–215.

Love, M.S., Yoklavich, M. and Thorsteinson, L. 2002. The Rockfishes of the Northeast Pacific. University of California Press, Berkeley and Los Angeles, California.

Love, M., P. Morris, M.M. and Collins, R. 1990. Life History Aspects of 19 Rockfish Species (Scorpaenidae: *Sebastes*) from the Southern California Bight. NOAA Tech. Rep. NMFS **87**: 38 p.

Lowe, S., Gaichas, S. and Ianelli, J. 2007. Gulf of Alaska Thornyheads. *In* 2007 North Pacific Groundfish Stock Assessments and Fishery Evaluation Reports for 2008. U.S. Department of Commerce, NOAA Technical Report NMFS 889–928.

Lowry, M., Oliver, C., Macky, C. and Wexler, J. 1990. Food habits of California sea lions Zalophus californianus at San Clemente Island, California, 1981-86. Fish. Bull. **88**: 509–521.

Major, R. and Shippen, H. 1970. Synopsis of biological data on Pacific Ocean perch *Sebastodes alutus*. FAO Spec. Synops. (79) and NOAA Circ. **347**: 38 p.

Masson, D. and Fine, I. 2012. Modeling seasonal to interannual ocean variability of coastal

British Columbia. Journal of Geophysical Research **117**.

McAllister, D. and Westrheim, S. 1965. Widow rockfish, *Sebastodes entomelas*, new to British Columbia waters. J. Fish. Res. Board Can. **22**: 1559–1564.

Mecklenburg, C., Mecklenburg, T.A. and Thorstein, L.K. 2002. Fishes of Alaska. Am. Fish. Soc. 848 p.

Mills, K., Laidig, T., Ralston, S. and Sydeman, W. 2007. Bomb radiocarbon and lead-radium disequilibria in otoliths of bocaccio rockfish (*Sebastes paucispinis*): a determination of age and longevity for a difficult-to-age fish. Fish. Oceanogr. **16**: 273–283.

Moser, H. 1967. Reproduction and development of *Sebastodes paucispinis* and comparison with other rockfishes off southern California. Copeia 773–797.

N., C., Boldt, J.L. and Zimmermann, M. 2007. An assessment of juvenile Pacific ocean perch (*Sebastes alutus*) habitat use in a deepwater nursery. Estuar. Coast. Shelf Sci. **75**: 371–380.

Orlov, A. 1997. The qualitative characteristic of feeding of the sablefish *Anoplopoma fimbria* with notes on its frequency in the Pacific waters of the North Kuril Islands and southeastern Kamchatka. J. Ichthyol. **37**: 33–40.

Orlov, A. 2001. Fish predation on the rockfish young. Vestnik DVO RAN **4**: 64–68.

Pearcy, W. and Hancock, D. 1978. Feeding habits of dover sole, *Microstomus stenolepis*; rex sole, *Glyptocephalus zachirus*; slender sole, *Lyopsetta exilis*; and pacific sanddab, *Citharichthys sordidus*, in a region of diverse sediments and bathymetry off Oregon. Fish. Bull. **76**: 641–651.

Pearsall, I. and Fargo, J. 2007. Diet composition and habitat fidelity for groundfish assemblages in Hecate Strait, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. **2692**: 141 p.

Perry, R.I. and Smith, S. 1994. Identifying Habitat Associations of Marine Fishes Using Survey Data: An Application to the Northwest Atlantic. Can. J. Fish. Aquat. Sci. **51**: 589–602.

Perry, R., Stocker, M. and Fargo, J. 1994. Environmental effects on the distributions of groundfish in Hecate Strait, British Columbia. Can. J. Fish. Aquat. Sci. **51**: 1401–1409.

Peyrera, W., Pearcy, W. and Carvey Jr., F. 1983. *Sebastodes flavidus*, a shelf rockfish feeding on mesopelagic fauna, with consideration of the ecological implications. J. Fish. Res. Board Can. **26**: 2211–2215.

PFMC and NMFS. 2006. Proposed Acceptable Biological Catch and Optimum Yield Specifications and Management Measures for the 2007-2008 Pacific Coast Groundfish Fishery, and Amendment 16-4: Rebuilding Plans For Seven Depleted Pacific Coast Groundfish Species; Final Environmental Impact Statement Including Regulatory Impact Review and Initial Regulatory Flexibility Analysis. Pacific Fishery Management Council, Portland, OR. October 2006.

Phillips, J. 1964. Life history studies of ten species of rockfish (genus *Sebastodes*). Calif. Dept. Fish Game Fish. Bull. **126**: 70 p.

Rickey, M.H. 1995. Maturity, Spawning, and Seasonal Movement of Arrowtooth Flounder, Atheresthes Stomias, off Washington. Fishery Bulletin **93:1**: 127–138.

Rooper, C. 2008. An ecological analysis of rockfish (*Sebastes* spp.) assemblages in the North Pacific Ocean along broad-scale environmental gradients. Fish. Bull. **106**: 1–11.

Rooper, C., Zimmermann, M. and Spencer, P. 2005. Using ecologically based relationships to predict distribution of flathead sole *Hippoglossoides elassodon* in the eastern Bering Sea. Mar. Ecol. Prog. Ser. **290**: 251–262.

Rosenthal, R., O'Connell, V. and Murphy, M. 1988. Feeding ecology of ten species of rockfishes (Scorpaenidae) from the Gulf of Alaska. Calif. Fish and Game **74**: 16–37.

Shanks, A. and Eckert, G. 2005. Population persistence of California current fishes and benthic crustaceans: a marine drift paradox. Ecol. Monogr. **74**: 505–524.

Sinclair, A. and Crawford, W. 2005. Incorporating an environmental stock recruitment relationship in the assessment of Pacific cod (*Gadus macrocephalus*). Fish. Oceanogr. **14**: 138–150.

Sinclair, A., Martell, S. and Boutillier, J. 2001. Assessment of Pacific Cod off the West Coast of Vancouver Island and in Hecate Strait, Nov. 2001. DFO Can. Sci. Advis. Sec. Advis. Rep. **2001/159**: 61 p.

Sinclair, A.F. and Starr, P.J. 2005. Assessment of Pacific Cod in Hecate Strait (5CD) and Queen Charlotte Sound (5AB), January, 2005. Canadian Science Advisory Secretariat, Research Document **2005/026**: 97. Available from http://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2005/2005_026-eng.htm.

Somerton, D., Funk, F., Mesmer, K., Bledsoe, L. and Thornburgh, K. 1978. A comparative study of the diets of Pacific ocean perch (*Sebastes alutus*) and walleye pollock (*Theragra chalcogramma*) in the Gulf of Alaska. NORFISH NPB8. Washington Sea Grant Communications Program, Univ. of Washington, Division of Marine Resources.

Stanley, R.D. and Kronlund, A.R. 2000. Silvergray rockfish (*Sebastes brevispinis*) assessment for 2000 and recommended yield options for 2001/2002. DFO Can. Sci. Advis. Sec. Res. Doc. **2000/173**: 116 p.

Starr, P. 2009. English sole (*Parophrys vetulus*) in British Columbia, Canada: Stock Assessment for 2006/07 and Advice to Managers for 2007/08. DFO Can. Sci. Advis. Sec. Advis. Rep. **2009/069**: 149 p.

Starr, P. and Fargo, J. 1976. Petral sole stock assessment for 2003 and recommendations for management in 2004. DFO Can. Sci. Advis. Sec. Advis. Rep. **2004/036**: 86 p.

Stockhausen, W., Wilkins, M. and Martin, M. 2011. Assessment of the Rex Sole Stock in the Gulf of Alaska. *In* 2011 North Pacific Groundfish Stock Assessments and Fishery Evaluation Reports for 2012. U.S. Department of Commerce, NOAA Technical Report NMFS. 629–690.

Strachan, A. 1965. New southern record for the silvergray rockfish, *Sebastes brevispinis* (Bean). Calif. Fish and Game **51**: 220–221.

Taylor, F.H.C. 1967. Midwater trawl catches from Queen Charlotte Sound and the open ocean adjacent to the Queen Charlotte Islands. J. Fish. Res. Board Can. Tech. Rep. **11**: 1–44.

Tyler, A. and Crawford, W. 1991. Modeling of recruitment patterns in Pacific cod (*Gadus macrocephalus*) in Hecate Strait, British Columbia. Can. J. Fish. Aquat. Sci. **48**: 2240–2249.

Tyler, A. and Westrheim, S. 1986. Effects of transport, temperature and stock size on recruitment of Pacific cod. Int. N. Pac. Fish. Comm. Bull. **47**: 175–189.

Wakefield, W. 1990. Patterns in the distribution of demersal fishes on the upper continental shelf off central California with studies of ontogenetic vertical migration in particle flux. Ph.D. thesis, University of California, San Diego.

Walters, C., Stocker, M., Tyler, A. and Westrheim, S. 1986. Interaction between Pacific Cod (*Gadus macrocephalus*) and Herring (*Clupea harengus pallasi*) in the Hecate Strait, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. **43**: 830–837.

Ware, D. and McFarlane, G. 1986. Relative impact of Pacific hake, sablefish and Pacific cod on west coast of Vancouver Island herring stocks. Int. N. Pac. Fish. Comm. Bull. **47**: 67–78.

Westrheim, S. 1975. Reproduction, Maturation, and Identification of Larvae of some *Sebastes* (Scorpaenidae) Species in the Northeast Pacific Ocean. J. Fish. Res. Board Can. **32**: 2399–2411.

Westrheim, S. 1996. On the Pacific Cod (*Gadus macrocephalus* in British Columbia Waters, and a Comparison with Pacific Cod Elsewhere, and Atlantic Cod (*G. morhua*). Can. Tech. Rep. Fish. Aquat. Sci. **2092**: 390 p.

Wilimovsky, N. 1954. List of fishes of Alaska. Stan. Ichthyol. Bull. **4**: 279–294.

Wourms, J. 1991. Reproduction and development of Sebastes in the context of the evolution of piscine viviparity. Environ. Biol. Fish. **30**: 111–126.

Yamanaka, K. and Lacko, L. 2001. Inshore rockfish (*Sebastes ruberrimus*, |emphS. maliger, *S. caurinus*, *S. melanops*, *S. nigrocinctus*, and *S. nebulosus*) stock assessment for the west coast of Canada and recommendations for management. DFO Can. Sci. Advis. Sec. Res. Doc. **2001**/**139**: 102 p.

Yang, M. and Nelson, M. 1999. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. NOAA Tech. Memo. NMFS-AFSC **112**: 174 p.

Yang, M. and Page, B. 1999. Diet of Pacific sleeper shark, Somniosus pacificus, in the Gulf of Alaska. Fish. Bull. **97**: 406–409.

Zimmerman, M. and Goddard, P. 1996. Biology and distribution of arrowtooth flounder, *Atheresthes stomias*, and Kamchatka flounders (*A. evermanni*) in Alaskan waters. Fishery Bulletin **94**: 358–370.

7 TABLES

Table 1. Estimated and fixed parameters and prior probablilty distributions used in the Reference Case.

Parameter	Number estimated	Bounds [low,high]	Prior (Mean, SD) (single value=fixed)
Log recruitment ($\ln(R_0)$)	1	[-2,6]	Uniform
Steepness (h)	1	[0.2,1]	Beta($\alpha = 13.4$,$\beta = 2.40$)
Log natural mortality ($\ln(M)$)	1	[-5,0]	Normal($\ln(0.2)$,0.2)
Log mean recruitment ($\ln(\overline{R})$)	1	[-2,6]	Uniform
Log initial recruitment ($\ln(\overline{R}_{init})$)	1	[-2,6]	Uniform
Variance ratio (ρ)	0	Fixed	0.059
Inverse total variance (ϑ^2)	0	Fixed	1.471
Survey age at 50% selectivity ($\hat{a}_k$)	3	[0,1]	None
Fishery age at 50% selectivity ($\hat{a}_k$)	1	[0,1]	None
Survey SD of logistic selectivity ($\hat{\gamma}_k$)	3	[0,Inf)	None
Fishery SD of logistic selectivity ($\hat{\gamma}_k$)	1	[0,Inf)	None
Survey catchability (q_k)	4	None	Normal(0.5,1.0)
Log fishing mortality values ($\Gamma_{k,t}$)	19	[-30,3]	[-30,3]
Log recruitment deviations (ω_t)	19	None	Normal(0,τ)
Initial log recruitment deviations ($\omega_{init,t}$)	19	None	Normal(0,τ)

Table 2. Example using xtable with some pseudo-random seeded numbers. The function get.align makes the left column justified left and the rest justified right which is how most tables giving values are shown.

ID	$R_{s=1}$	$R_{s=2}$	$R_{s=3}$	$R_{s=4}$	$\overline{R}$	σ
1	1.52	11.57	12.54	16.04	10.42	6.23
2	5.19	12.18	5.18	6.16	7.18	3.37
3	11.12	16.99	11.56	19.04	14.68	3.94
4	5.87	7.55	1.58	19.49	8.62	7.67
5	14.75	8.27	15.46	5.33	10.95	4.96
6	1.58	6.21	2.02	15.79	6.40	6.60
7	15.16	3.91	3.79	8.43	7.82	5.35
8	13.65	6.07	5.13	1.70	6.64	5.04
9	19.58	14.46	10.44	13.04	14.38	3.85
10	16.18	3.30	15.46	4.54	9.87	6.89
11	12.75	8.52	8.08	18.19	11.88	4.70
12	10.49	7.17	16.04	5.64	9.83	4.60
13	5.80	17.18	11.04	13.30	11.83	4.75
14	4.09	13.79	16.24	2.37	9.12	6.91
15	6.30	9.46	4.25	17.04	9.26	5.61
16	17.23	3.48	12.21	12.05	11.24	5.71
17	3.71	1.65	2.14	9.24	4.18	3.48
18	4.15	4.07	16.51	1.54	6.57	6.74
19	19.46	16.45	18.98	5.80	15.17	6.39
20	18.94	3.53	19.74	19.90	15.53	8.01

Table 3. *Arrowtooth Flounder mean lengths (mm), maturity, sex and total sample weight (kg) $\pm$ standard deviation (SD) from 1984 to 2015.*

Survey Year	$\overline{L}$	SD	$\overline{S}$	SD	$\overline{M}$	SD	$\overline{TotWt_s}$	SD
1984	a	See Table 3						
1987	a	$\vartheta^2 = 1.538$; $\rho = 0.015$						
1989	a	ϑ^2 estimated; $\rho = 0.059$						
1991	a	$\vartheta^2 = 0.962$; $\rho = 0.038$						
1993	a	$\vartheta^2 = 2.500$; $\rho = 0.100$						
1998	a	h = Beta($\alpha = 12.7$, $\beta = 5.0$)						
2000	a	$\ln(M)$ = Normal($\ln(0.2)$, 0.05)						
2002	a	$\ln(M)$ = Normal($\ln(0.2)$, 0.25)						
2003	a	$\ln(M)$ = Normal($\ln(0.3)$, 0.20)						
2004	a	$\ln(q_k)$ = Normal($\ln(1.0)$, 1.0)						
2005	a	$\ln(q_k)$ = Normal($\ln(0.5)$, 1.5)						
2007	a	$\hat{a}$ = 4.99 yrs; $\hat{\gamma}$ = 1.27 yrs						
2009	a	$\hat{a}$ = 6.00 yrs; $\hat{\gamma}$ = 1.00 yrs						
2011	Aa	$\hat{a}$ = 6.00 yrs; $\hat{\gamma}$ = 1.00 yrs						
2013	a	$\hat{a}$ = 6.00 yrs; $\hat{\gamma}$ = 1.00 yrs						
2015	a	$\hat{a}$ = 6.00 yrs; $\hat{\gamma}$ = 1.00 yrs						

Table 4. *Sensitivity cases for q_k; posterior quantiles.*

Index	Sensitivity 10			Sensitivity 11		
$\mathbf{q_k}$	**2.5%**	**50%**	**97.5%**	**2.5%**	**50%**	**97.5%**
QCSSS	0.081	0.158	0.508	0.029	0.083	0.226
HSMAS	0.079	0.121	0.155	0.035	0.081	0.136
HSSS	0.070	0.118	0.200	0.027	0.067	0.136
WCVISS	0.061	0.104	0.172	0.022	0.059	0.118

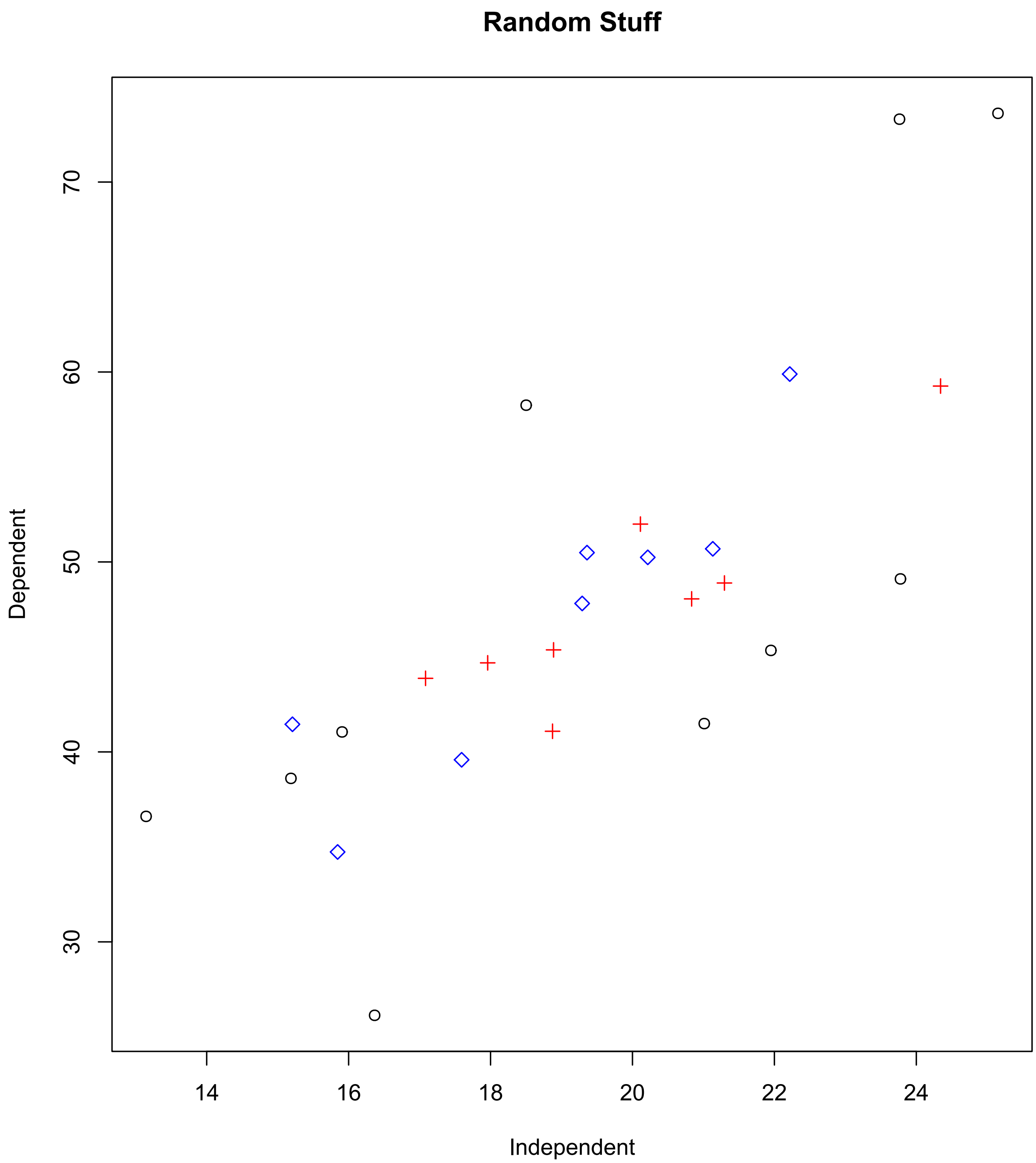


Figure 3. Random points example... Degrees are represented in LaTeX like this 0.1° and superscript like this km^2)

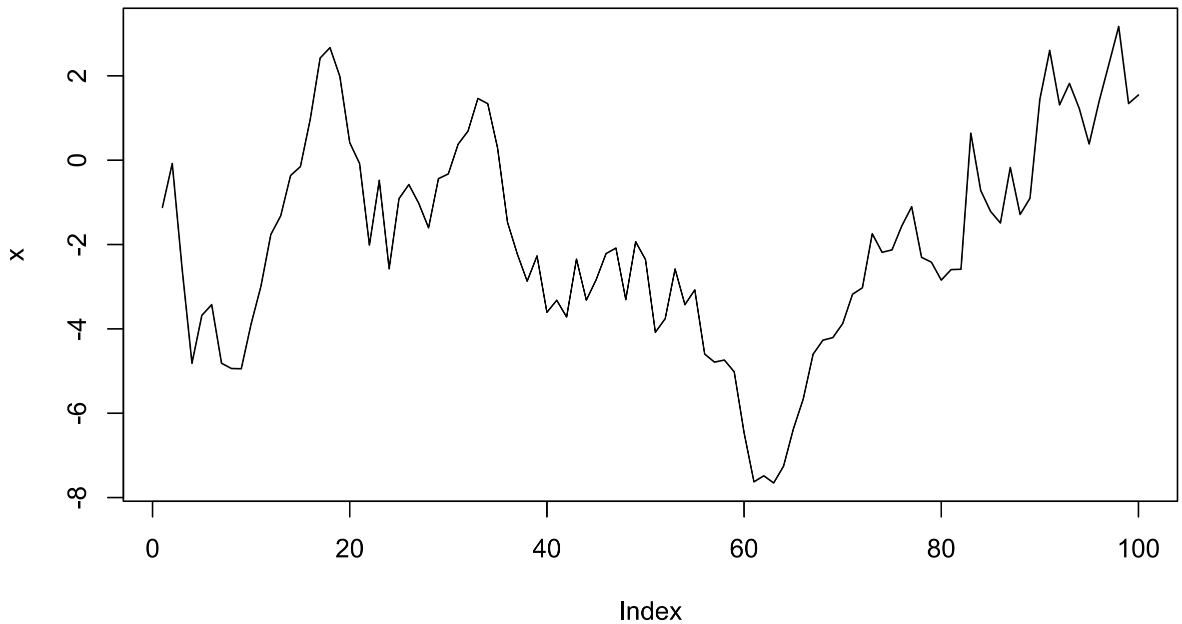


Figure 4. Brownian motion example..

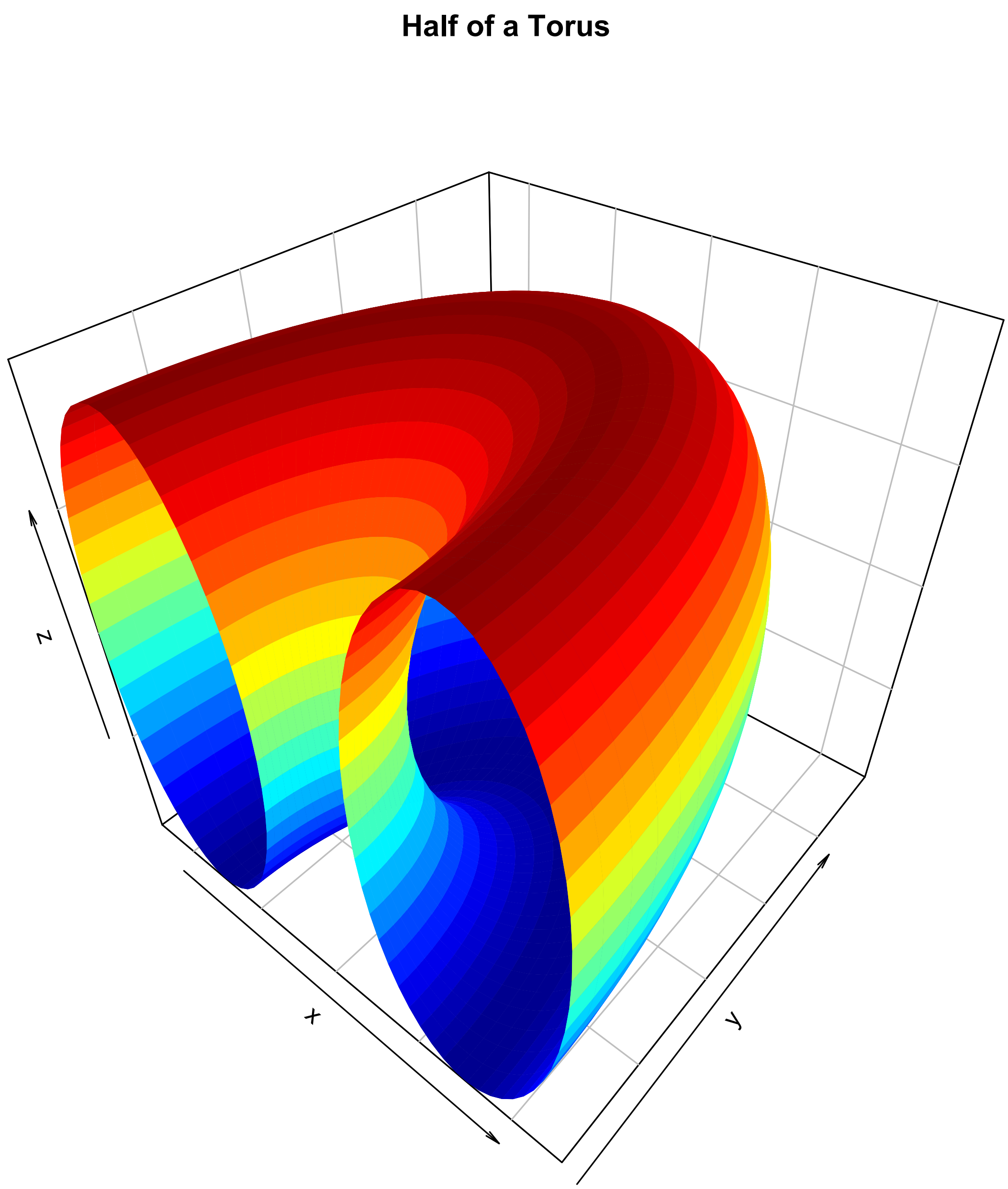


Figure 5. Half torus example..

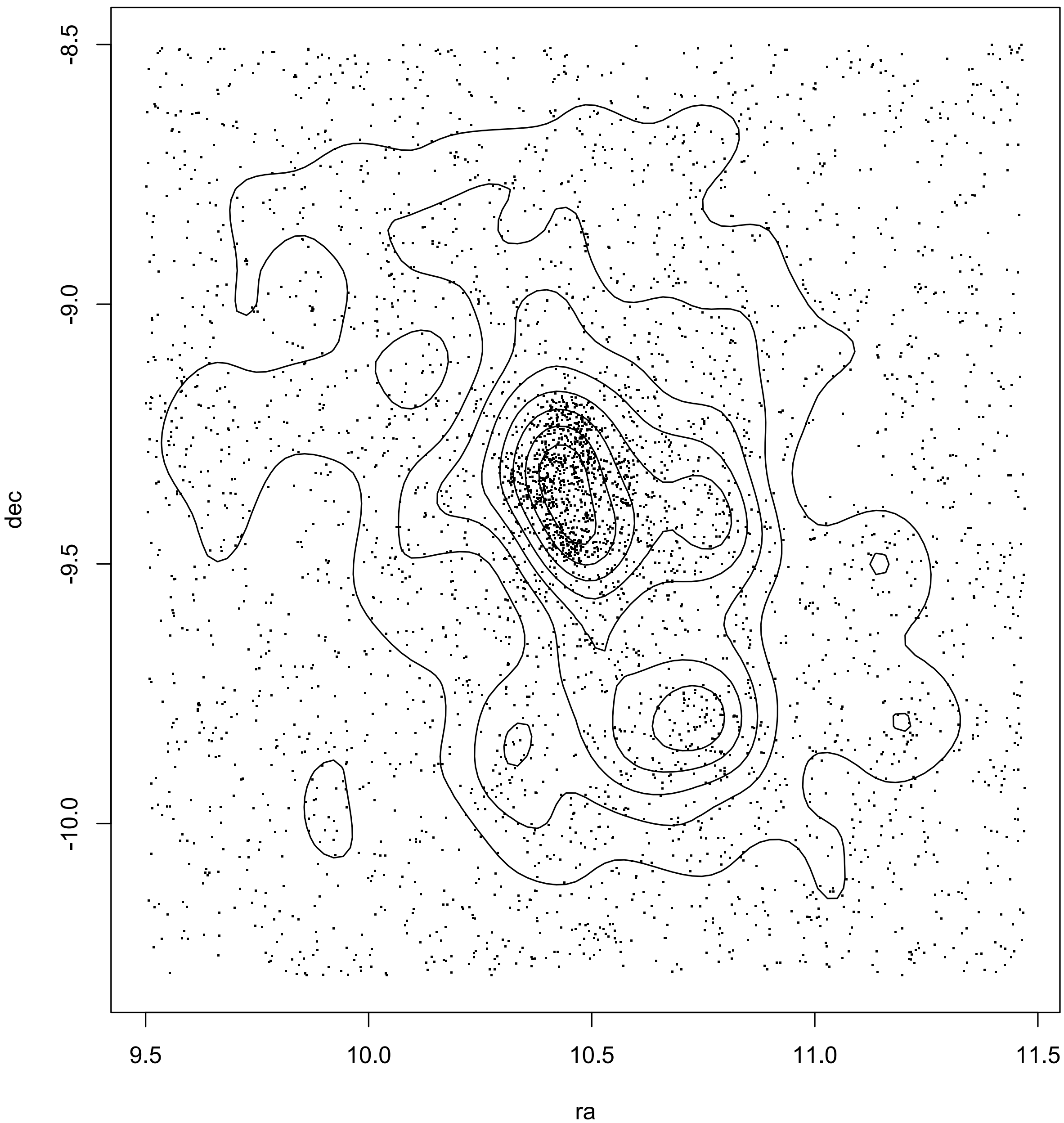


Figure 6. Galaxy example

A SPECIES SUMMARIES

A.1 ARROWTOOTH FLOUNDER

A.1.1 LIFE HISTORY

They are mainly found on soft bottoms from Central California to the eastern Bering Sea (Hart, 1973). They occur from the surface to 900 m depth but are common up to 400 m deep (Allen and Smith, 1988). Larvae have been sampled between the surface and 200 m depth off northern BC in June (Taylor, 1967; Hart, 1973).

The maximum recorded length is 84 cm (Eschmeyer et al., 1983).

A.1.2 PREDATORS AND PREY

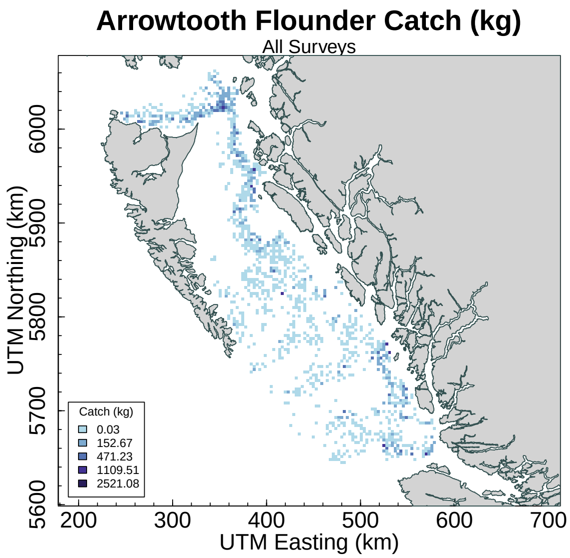
Predators include the bony fishes Sablefish (*Anoplopoma fimbria*), Pacific Cod (*Gadus macrocephalus*), Alaska Pollock (*Gadus chalcogrammus*) and Arrowtooth Flounder (*Reinhardtius stomias*). Steller Sea Lions (*Eumetopias jubatus*) and the Pacific Sleeper Shark (*Somniosus pacificus*) are also known predators. Arrowtooth Flounder larvae off the coast of BC are known to eat juvenile and adult copepods and eggs. Adults feed on crustaceans and fishes that include shrimp species, Pacific Herring (Hart, 1973; Eschmeyer et al., 1983) and Walleye Pollock *Gadus chalcogrammus* (Livingston, 1993). Migration patterns are not well understood but it is believed that Arrowtooth Flounder move into deeper waters as they grow, similar to other flatfish species (Zimmerman and Goddard, 1996). They spawn in deep water (> 400 m) from fall to winter along the continental shelf break in winter and move to shallower water during the summer (Rickey, 1995; Blood et al., 2007).

A.1.3 ENVIRONMENT

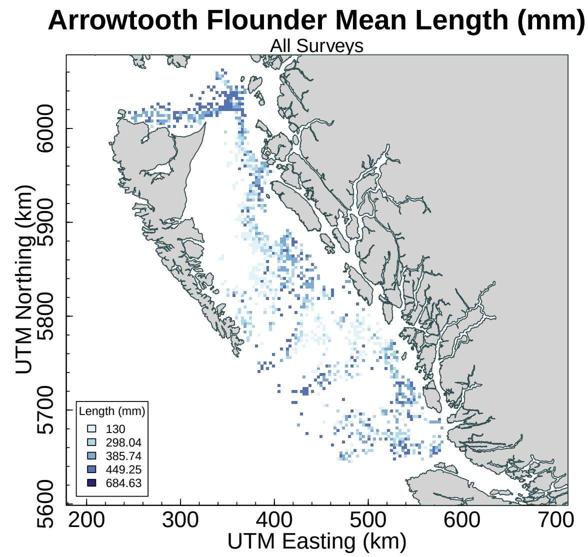
A.1.4 OTHER SPECIES

Arrowtooth Flounder is primarily taken by the groundfish bottom trawl fishery but is also caught in small quantities by hook and line fisheries, particularly those that are targeting Pacific Halibut (*Hippoglossus stenolepis*) (DFO, 2015).

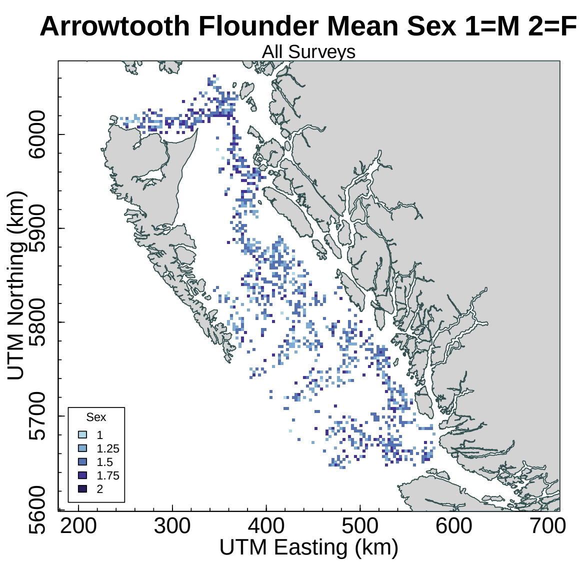
A.1.5 FIGURES



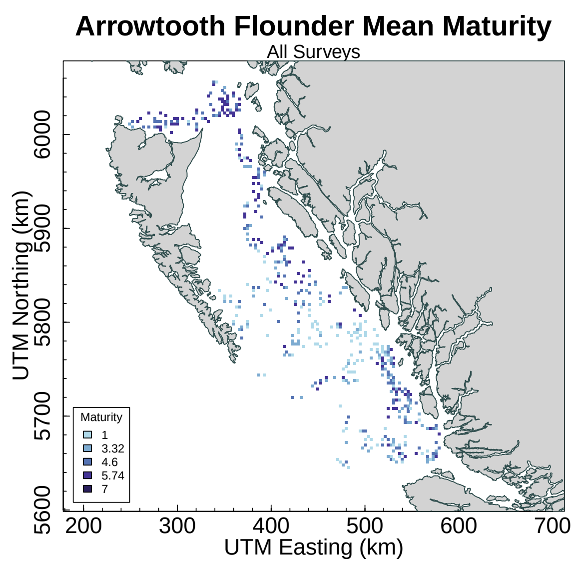
(a) Mean survey catch (kg) of Arrowtooth Flounder in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Arrowtooth Flounder in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

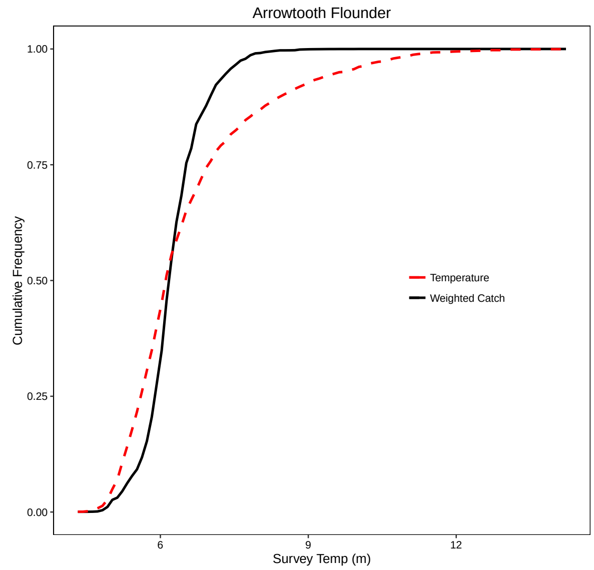


(c) Mean survey fish sex of Arrowtooth Flounder in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Arrowtooth Flounder in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.1. Summary of Arrowtooth Flounder data. The shaded cells give an approximation of the area where Arrowtooth Flounder was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.2. Cumulative frequency distributions of habitat variables and Arrowtooth Flounder catch-weighted data for all groundfish trawls surveys for all years.

A.2 BOCACCIO

A.2.1 LIFE HISTORY

Bocaccio are distributed from Baja California to the Alaska Peninsula. A few sites within BC northern Washington, along the California coast and Baja California may be the last areas within significant abundance (Love et al., 2002). Adults have been observed between 12 and 478 m but are most abundant between 50 to 250 m depth (Love et al., 2002). Adults utilise rocky reefs, but are also common on open bottoms (Eschmeyer et al 1983). Juveniles are found in shallow water and move to deeper water with age (Love et al., 2002).

Larvae are most commonly found between December and April, and have been found as far as 480 km offshore (Love et al., 2002). Young Bocaccio may stay in the upper water column for up to 5.5 months, most settle by 3.5 months (Love et al., 2002). In California, juveniles recruit to nearshore waters between February and August with a peak between May and July (Love et al., 2002). Juveniles will often recruit to rocky areas covered with algae or sand habitat with eelgrass and drift algae (Love et al., 2002). Adults are usually associated with high relief boulder fields and rocks while the largest individuals remain sedentary in caves and crevices (Love et al., 2002). Young Bocaccio form schools (Eschmeyer et al., 1983). Bocaccio are difficult to age but the oldest known individual is 50 years (Andrews et al., 2005).

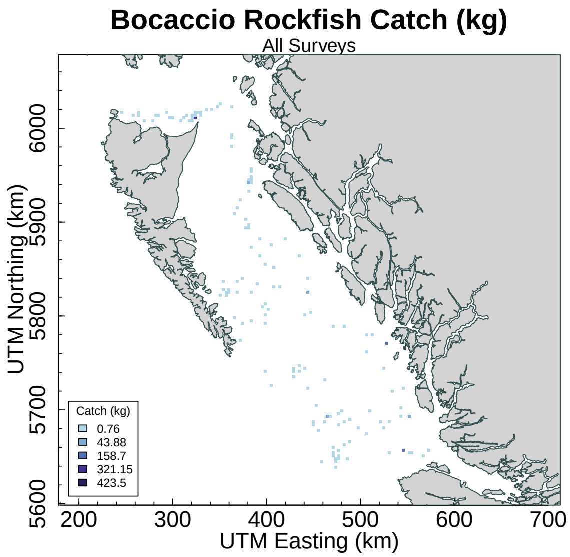
A.2.2 PREDATORS AND PREY

Bocaccio are predated on by Chinook salmon (*Oncorhynchus tshawytscha*), Least Terns (*Sternula antillarum*, Rhinoceros Auklet (*Cerorhinca monocerata*), Blue Shark (*Prionace glauca*) and Harbour Seal (*Phoca vitulina*) (Harvey, 1989; Love et al., 2002; Mills et al., 2007). Larval Bocaccio feed on larval krill, diatoms and dinoflagellates. Pelagic juveniles feed on fish larvae, copepods and krill. Larger juveniles and adults feed on other rockfish, Pacific Hake, Northern Anchovy (*Engraulis mordax*), Lanternfishes and squid (Love et al., 2002).

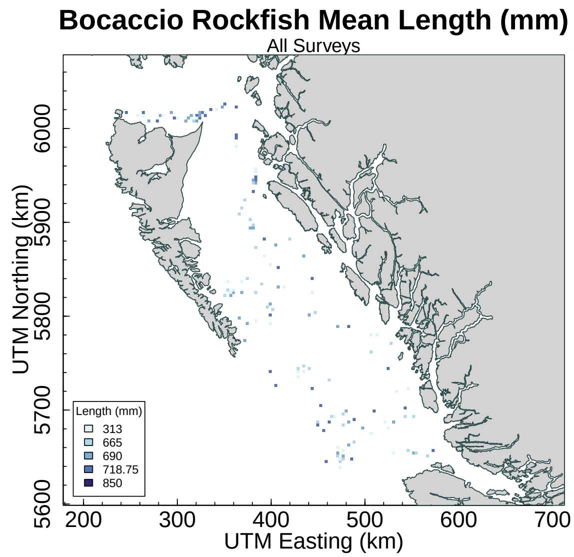
A.2.3 ENVIRONMENT

A.2.4 OTHER SPECIES

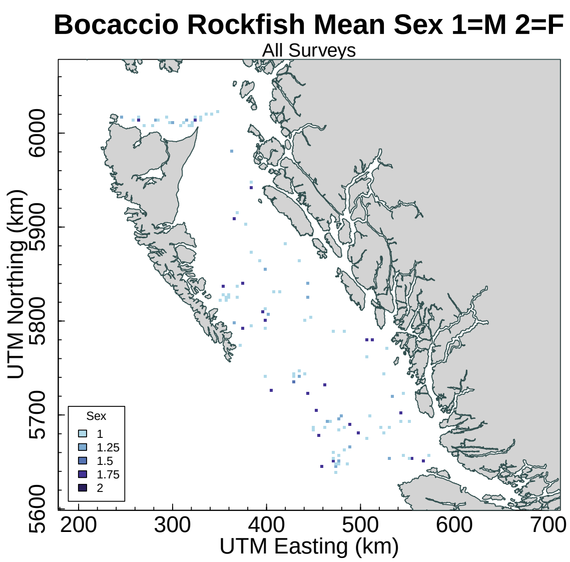
Adults school with Widow Rockfish Yellowtail Rockfish (*Sebastes flavidus*), Vermilion Rockfish (*Sebastes miniatus*) and Speckled Rockfish (*Sebastes ovalis*) (Love et al., 2002).



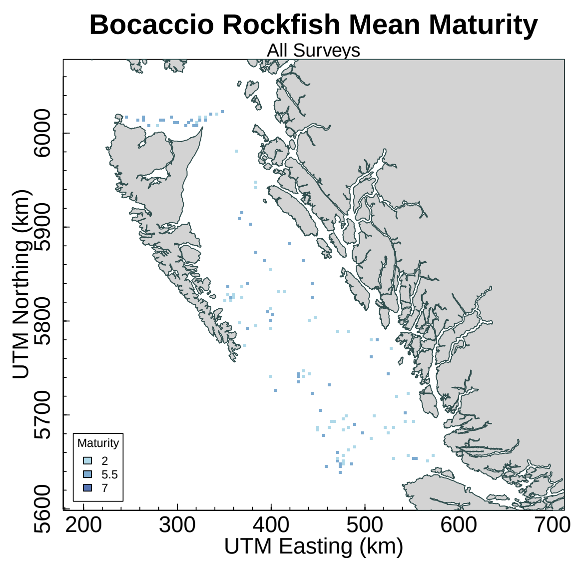
(a) Mean survey catch (kg) of Bocaccio in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Bocaccio in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

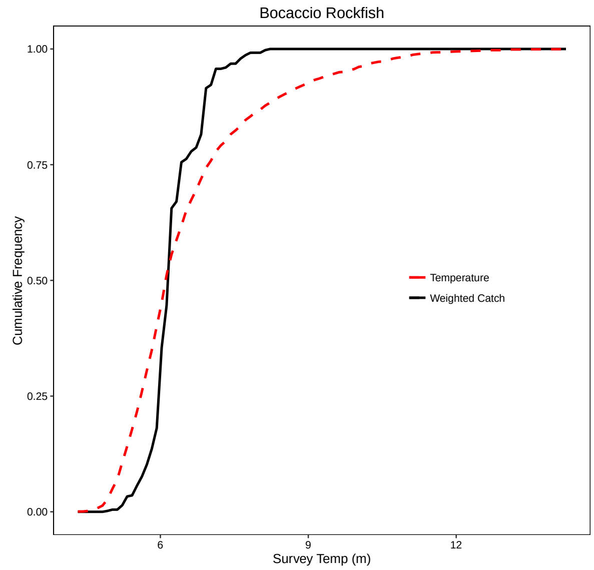


(c) Mean survey fish sex of Bocaccio in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Bocaccio in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.3. Summary of Bocaccio data. The shaded cells give an approximation of the area where Bocaccio was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) (b)

Figure A.4. Cumulative frequency distributions of habitat variables and Bocaccio catch-weighted data for all groundfish trawls surveys for all years.

A.3 CANARY ROCKFISH

A.3.1 LIFE HISTORY

Canary Rockfish (*Sebastes pinniger*) is one of over 102 rockfish species of the genus Sebastes, 96 of which are found in the North Pacific. There are over 39 species present in BC waters (DFO, 2009).

Canary Rockfish are found from northern Baja California to the western Gulf of Alaska (Love et al., 2002), but populations are most abundant between northern California and BC(DFO, 2009). Little is known about the distribution of young Canary Rockfish in BC waters although they have been captured by gillnets in nearshore sub-tidal depths. They appear to move deeper as they become older and larger. Most of the late stage juveniles and adults are caught over depths of 100 m to 225 m on the continental shelf. Most Canary Rockfish will probably die if released after capture (DFO, 2009). Adults congregate in loose groups above hard bottoms (Lamb and Edgell, 1986)

Mean size or age in the Canary Rockfish samples tends to increase with depth but other than the assumption that juveniles aggregate over hard bottom, there are no known nursery areas (DFO, 2009).

Canary Rockfish give birth to live young (ovoviviparous) in January or later in BC (Hart, 1973). In California studies, larvae and pelagic juvenile Canary Rockfish are reported to occupy the top 100 m for up to 3-4 months after parturition, and then settle to benthic habitats gradually moving deeper as they grow and age (Love et al., 2002). However, little is actually known about the spatial distribution of larval and juvenile stages in BC waters (DFO, 2009). Later stage juveniles and adults are typically captured in BC by hook-and-line (HL) or trawl gear over rocky, gravel, or sandy bottom on the continental shelf. Canary Rockfish are a marine and sub-tidal species; thus all Canadian habitat is within Federal waters.

Work in Oregon has shown that movements by adults can migrate further than 100 km (DeMott, 1983).

A.3.2 PREDATORS AND PREY

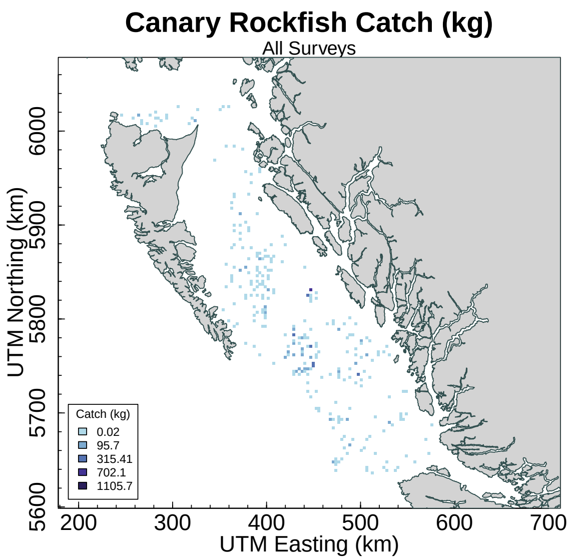
Pelagic juveniles feed on an array of planktonic items. Adults and subadults primarily eat krill and small fishes (Eschmeyer et al., 1983). Significant predators probably include lingcod (DFO, 2009).

A.3.3 ENVIRONMENT

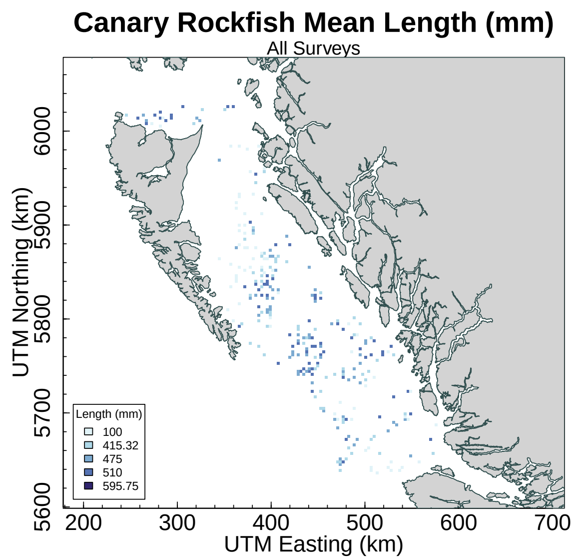
Unpublished information (presented as pers. comm. within DFO (2009)) suggests observed declines in dissolved oxygen, which appear to be correlated with apparent shifts in distribution of many groundfish species to shallower depths, may be a source of concern. These observations are preliminary and their longterm significance is unknown and it is not known if these shifts are outside expected long term variation. This observation could act to reduce both the quality and quantity of available habitat for Canary Rockfish (DFO, 2009).

A.3.4 OTHER SPECIES

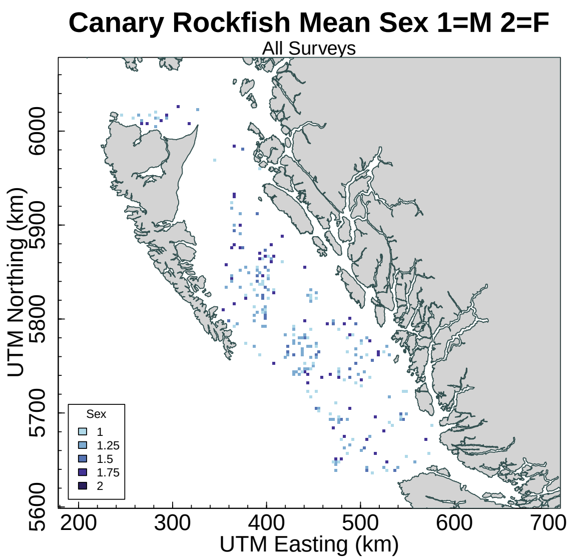
A.3.5 FIGURES



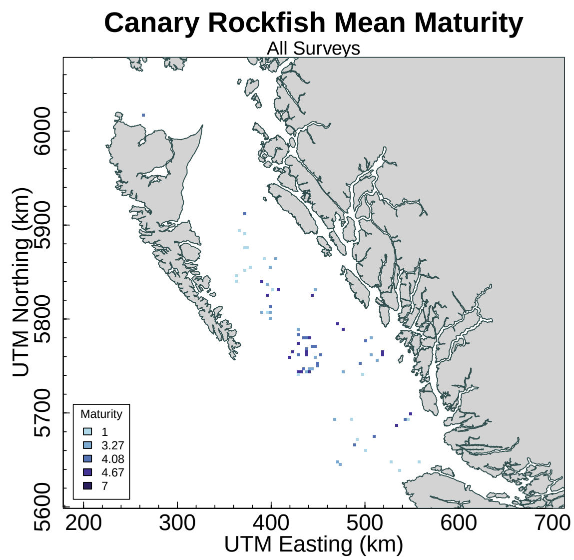
(a) Mean survey catch (kg) of Canary Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Canary Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

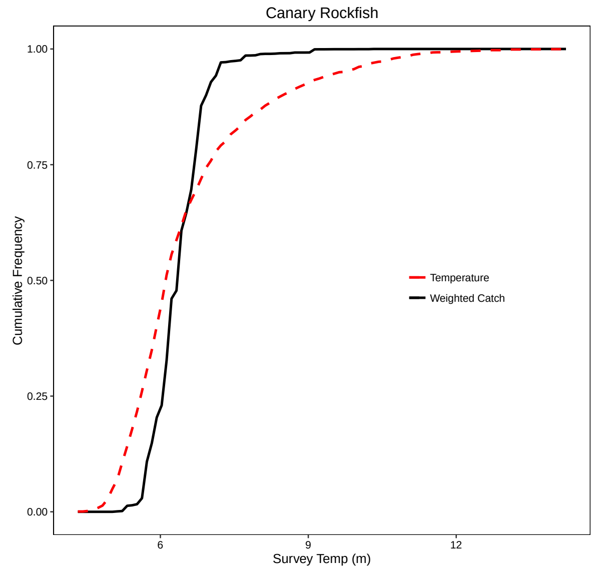


(c) Mean survey fish sex of Arrowtooth Flounder in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Canary Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.5. Summary of Canary Rockfish data. The shaded cells give an approximation of the area where Canary Rockfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.6. Cumulative frequency distributions of habitat variables and Canary Rockfish catch-weighted data for all groundfish trawls surveys for all years.

A.4 SPINY DOGFISH

A.4.1 LIFE HISTORY

In British Columbia, there are two discrete stocks of Spiny Dogfish an outside stock that extends from Baja California to Alaska and an inside stock, in the Strait of Georgia. Spiny Dogfish like most shark species grow slowly, mature late (35-36 years for females) and produce between 2 and 17 offspring (pups) per year resulting in very low intrinsic rates of population increase (DFO, 2010).

In Hecate Strait and Dixon Entrance, Spiny Dogfish are available only during summer but it is unclear whether their movements are mainly horizontal or with depth (Hart, 1973). Spiny Dogfish occur in brackish to marine waters from the surface to depths of 730 m (Hart, 1973; Ebert et al., 2010). The Spiny Dogfish is a small, gregarious shark belonging to the order Squaliformes and inhabiting temperate waters off the east and west coasts of North America. Recent reexamination of differences in natural history and demography between Pacific and Atlantic populations has resulted in a recommendation that these two populations should be reseparated into two different species, *S. suckleyi* in the Pacific and *S. acanthias* in the Atlantic (DFO, 2010).

Reproduction in the Spiny Dogfish is carried out through internal fertilization. Breeding occurs during the late fall and early spring. Large eggs, approximately 35 mm in diameter and numbering 2 to 17, are released from the ovaries of the females, where they then pass through the shell gland for simultaneous fertilization and encapsulation in thick, rubbery "shells" before proceeding into the oviducts. Development is ovoviviparous (internal). Encapsulated eggs remain in the oviducts for nearly 2 years (18-22 months), a gestation period almost unmatched by any other species. During gestation, the shells dissolve and the free embryos are nourished by yolk material which they gradually deplete until they reach a full-term size averaging between 26 and 27 cm. In British Columbia waters, average fecundity in the Spiny Dogfish is between six and seven (range from 2 to 16 pups) (DFO, 2010). Young Spiny Dogfish born as miniature replicas of their parents, are released in midwater layers overlying depths of 165 - 350 m.

As a result of their low metabolic rate, Spiny Dogfish in the Northeast Pacific exhibit exceptionally slow growth. Age-at-maturity in females is approximately 35-36 years (Strait of Georgia) corresponding to approximately 94 cm total length. The maximum recorded age in females is 80 years old, and the recorded maximum size is approximately 130 cm total length, which corresponds to an estimated age of 90 years, based on growth (DFO, 2010).

A.4.2 PREDATORS AND PREY

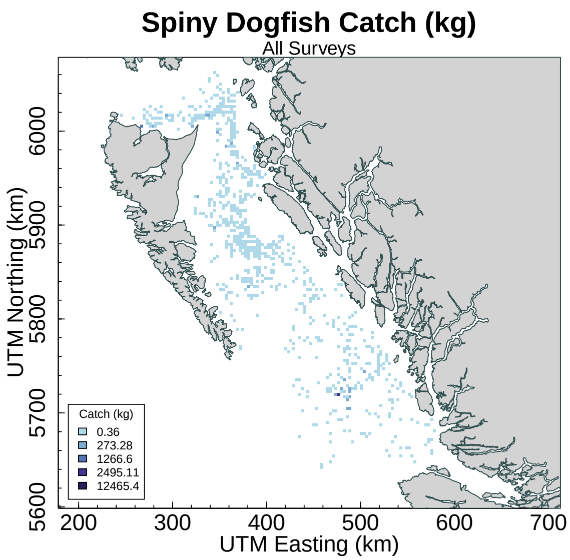
After birth, juveniles immediately begin feeding on a variety of small invertebrates. As growth progresses and juveniles begin to assume a more bottomdwelling existence, their diet gradually shifts to fish (DFO, 2010). As opportunistic feeders, adult spiny dogfish prey on a number of species of fish including herring, capelin and eulachon, rising only occasionally in the water column to feed on surface swarms of euphasiids (Hart 1988). They are also known to feed on commercial crab species, shrimps and octopus (Hart, 1973). Digestion is a slow process in spiny dogfish, with an observed time between feeding events of 16 days in BC waters. The relationship between Spiny Dogfish and higher trophic level predators such as lingcod, sablefish, other shark species, and northern sea lions is not well understood (DFO, 2010).

A.4.3 ENVIRONMENT

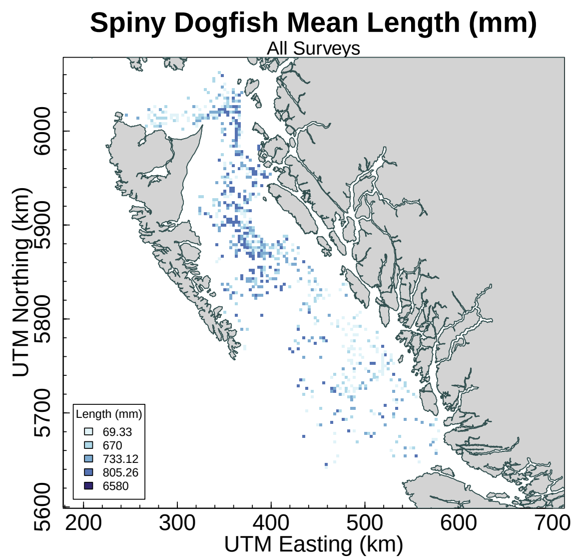
They prefer 7 °C to 15 °C water and it is believed that they will migrate to follow this temperature preference (Ebert, 2003).

A.4.4 OTHER SPECIES

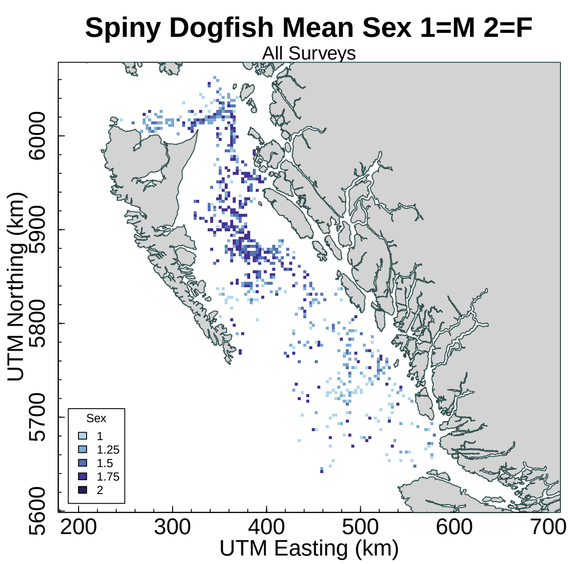
A.4.5 FIGURES



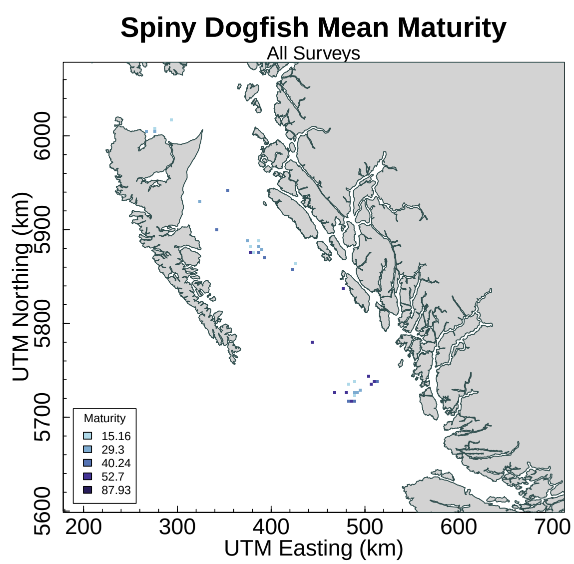
(a) Mean survey catch (kg) of Spiny Dogfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Spiny Dogfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

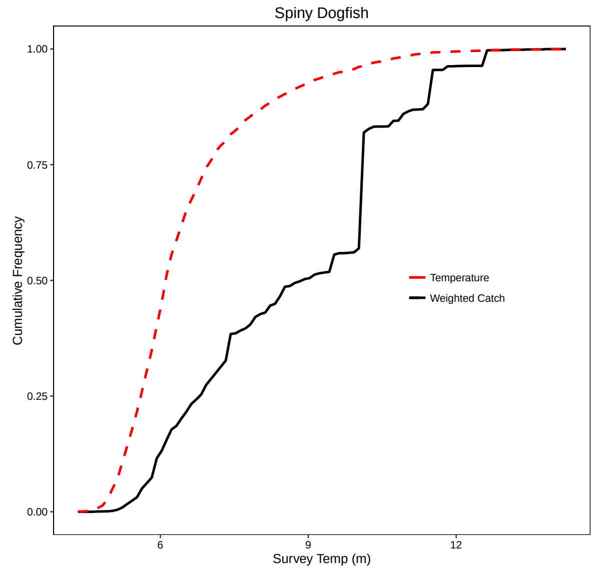


(c) Mean survey fish sex of Spiny Dogfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Spiny Dogfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.7. Summary of Spiny Dogfish data. The shaded cells give an approximation of the area where Spiny Dogfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.8. Cumulative frequency distributions of habitat variables and Spiny Dogfish catch-weighted data for all groundfish trawls surveys for all years.

A.5 DOVER SOLE

A.5.1 LIFE HISTORY

Dover Sole are distributed from the northern Baja California to the Bering Sea and are found at the surface to depths of 1,100 m (Hart 1973). Two discrete populations have been identified in BC waters with the southern population occurring off the west coast of Vancouver Island while the northern populations occurs in Queen Charlotte Sound, Hecate Strait and the west coast of Haida Gwaii (Fargo 1999). Adults occur on mud bottoms (Eschmeyer et al., 1983). Dover Sole can live for 45 years. They spawn annually in deepwater during the winter at depths between 800 and 1,000 m. Females beging to spawn at age 5 while males begin to spawn at 4 year of age (DFO, 1999). Spawning in California occurs between November and February. Their eggs range in diameter between 2.05 and 2.57 mm with an average of 2.33 mm. The pelagic life of larvae is prolonged over several months and is longer in duration than other flatfish species (Hart, 1973). Males are mature at 39 cm while females are mature at 45 cm in length. Off the coast of Oregon 50 percent of females are mature at 38 to 40 cm in length (Hart, 1973). Their reach a maximum length of 76.0 cm (Eschmeyer et al., 1983). This species does not appear to migrate along the coast; however, in Washington they have been observed to 200 km northward and 680 km southward.

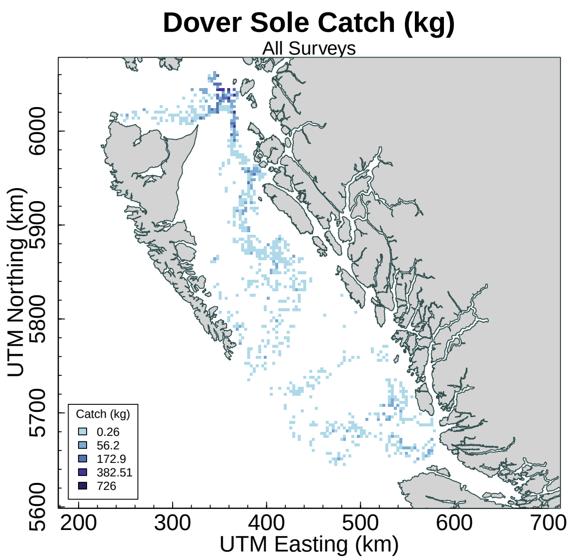
A.5.2 PREDATORS AND PREY

Potential predators include the Pacific Sleeper Shark (*Somniosus pacificus*), California Sea Lion (*Zalophus californiaus*), Harbour Seal and Pacific halibut (*Hippoglossus stenolepis*). Dover Sole mainly prey upon zoobenthos which include worms, crustaceans, echinoderms and mollusks (Pearcy and Hancock, 1978).

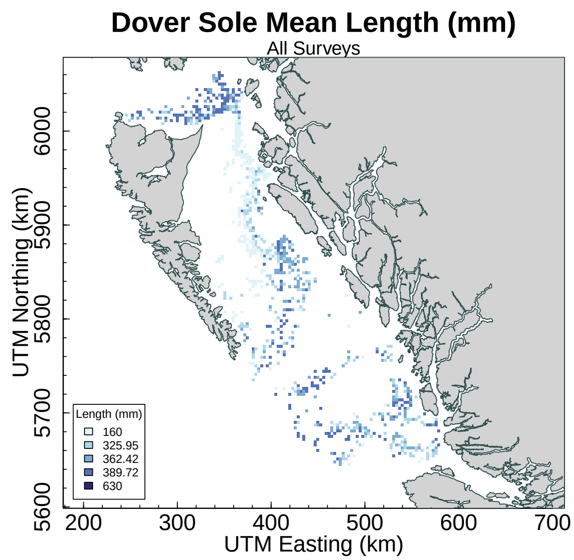
A.5.3 ENVIRONMENT

A.5.4 OTHER SPECIES

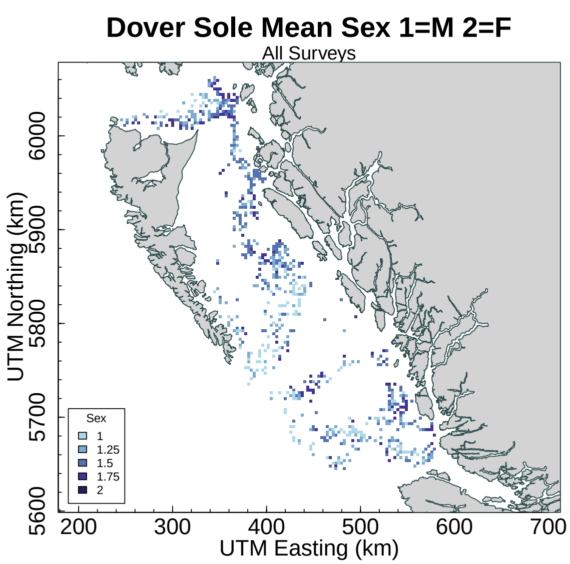
A.5.5 FIGURES



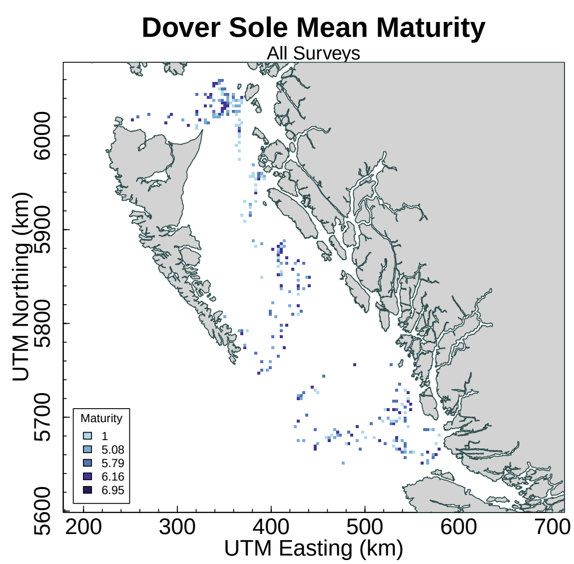
(a) Mean survey catch (kg) of Dover Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Dover Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



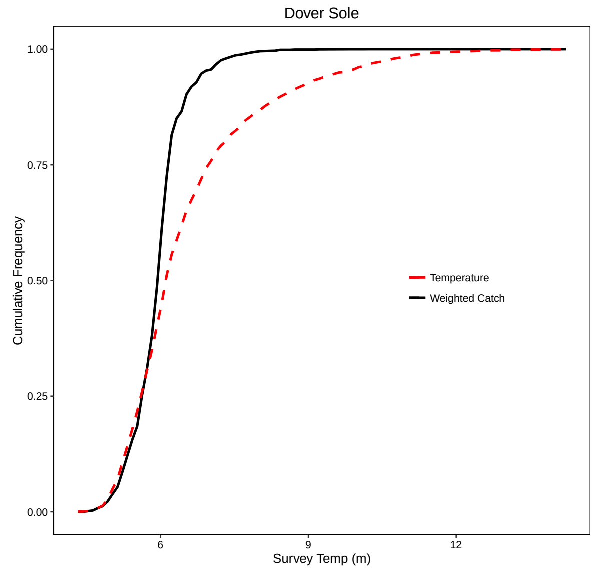
(c) Mean survey fish sex of Dover Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Dover Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.9. Summary of Dover Sole data. The shaded cells give an approximation of the area where Dover Sole was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.

(a)



(b)

Figure A.10. Cumulative frequency distributions of habitat variables and Dover Sole catch-weighted data for all groundfish trawls surveys for all years.

A.6 ENGLISH SOLE

A.6.1 LIFE HISTORY

English Sole are distributed from California to south east Alaska, but abundance declines with increasing latitude and Hecate Strait is near the northern limit for this species (Fargo et al., 2000). Their preferred depth range is between 5 and 150 m, with mature fish at deeper depths and the shallow depths being used by pre-recruits (Fargo, 1998). Adults inhabit sand and mud bottoms (Clemens and Wilby, 1961). Females attain larger sizes than males and they reach sexual maturity around 300 mm (Fargo et al., 2000). After that age males stop growing and put their energy into reproduction. Females grow to a maximum length of approximately 500 mm. English Sole are believed to live up to 22 years of age (Chilton and Beamish, 2000; Starr, 2009). Spawning occurs in BC from January to March (Hart, 1973; Starr, 2009). Fifty percent maturity occurs at 29.5 cm for females and at 26.0 cm for males. English Sole larvae are pelagic 6 to 10 weeks after they are laid as eggs (Hart, 1973). Early on, juveniles occur in the intertidal zone and the shallow subtidal zone and move deeper as they age. In general, adults move into relatively shallow waters during the spring and deep water during the winter. English Sole can travel 7 km during a single day and are known to migrate as far as 960 km from BC waters to northern California (Hart, 1973).

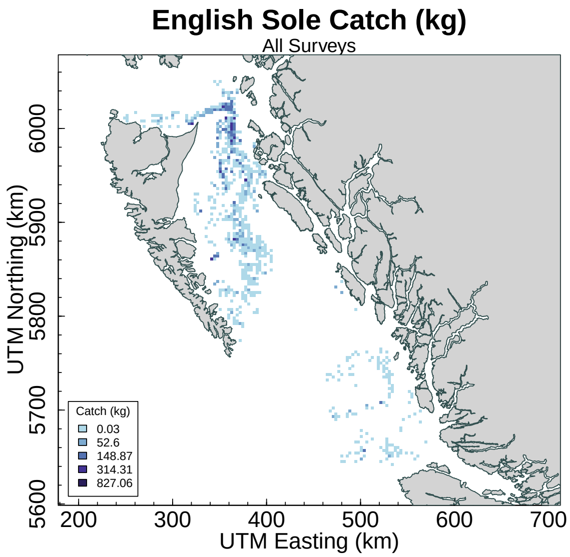
A.6.2 PREDATORS AND PREY

English Sole predators include the Pacific staghorn sculpin (*Leptocottus armatus*), California sea lions and harbour seals. The crystal jelly (*Aequorea victoria*) feeds on English Sole larval stages. English Sole feed on a variety of benthic crustaceans including ostracods, amphipods, shrimps, prawns, crabs and copepods. They also prey on worms, echinoderms, bivalves and gastropods.

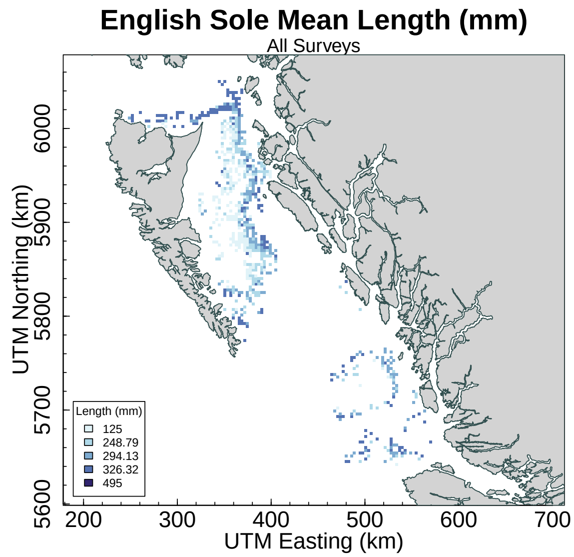
A.6.3 ENVIRONMENT

A.6.4 OTHER SPECIES

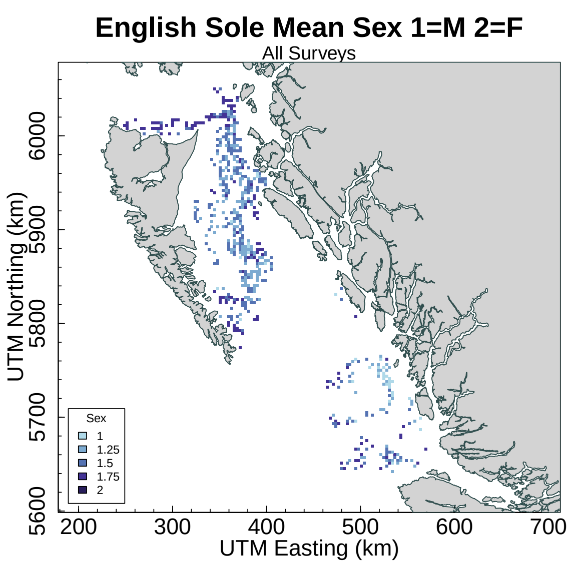
A.6.5 FIGURES



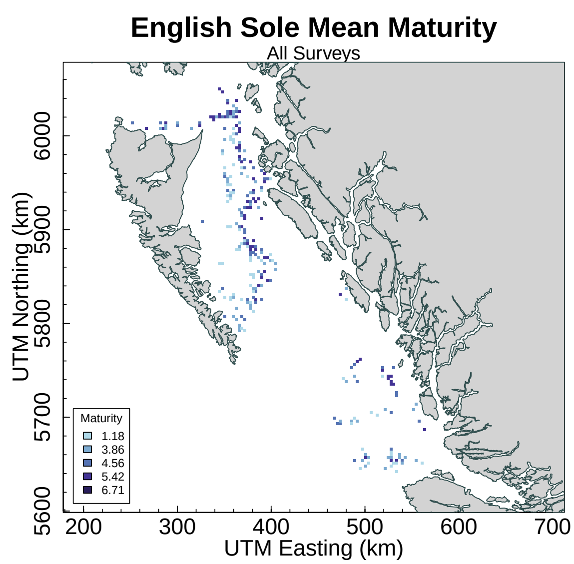
(a) Mean survey catch (kg) of English Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of English Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

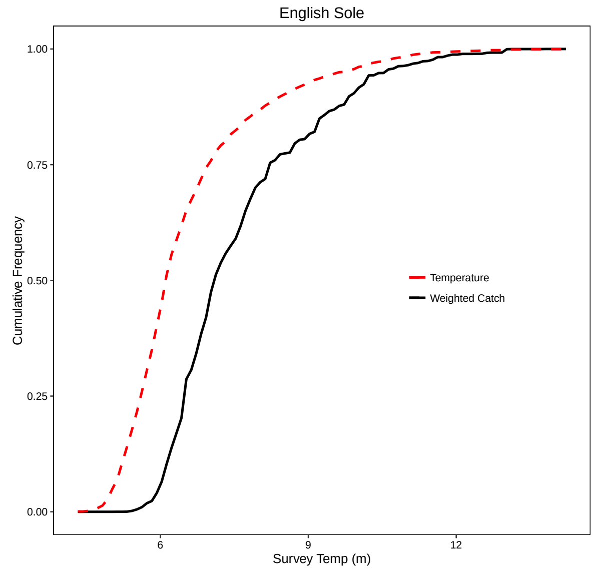


(c) Mean survey fish sex of English Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of English Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.11. Summary of English Sole data. The shaded cells give an approximation of the area where English Sole was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.12. Cumulative frequency distributions of habitat variables and English Sole catch-weighted data for all groundfish trawls surveys for all years.

A.7 GREENSTRIPE ROCKFISH

A.7.1 LIFE HISTORY

Greenstripe Rockfish inhabit inshore and offshore areas from the Baja California to the Gulf of Alaska (Hart, 1973). They commonly occur at depths between 90 and 365 m and unlike other rockfish species they prefer mud or sand bottoms (Love et al., 2002). Both sexes mature between 18 and 24 cm but females grow larger than males (Love et al., 2002). Mating occurs in December through February, fertilization occurs in early spring, with birth occurring in late spring (Shaw and Gunderson 2006). From BC to Oregon young Greenstripe Rockfish are likely born in late spring or early summer. Larvae are approximately 5 mm when they are released (Hart, 1973).

A.7.2 PREDATORS AND PREY

Predators of Greenstripe Rockfish include Chinook salmon (Mills et al., 2007).

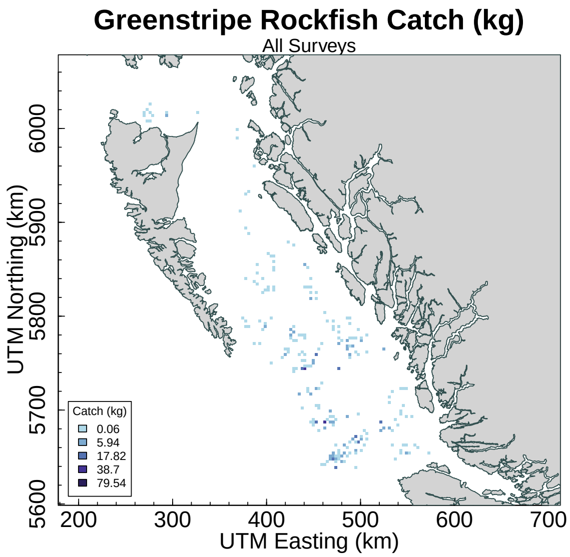
Greenstripe Rockfish feed on calenoid copepods, amphipods, krill, shrimps, squids and fishes (Love et al., 2002).

A.7.3 ENVIRONMENT

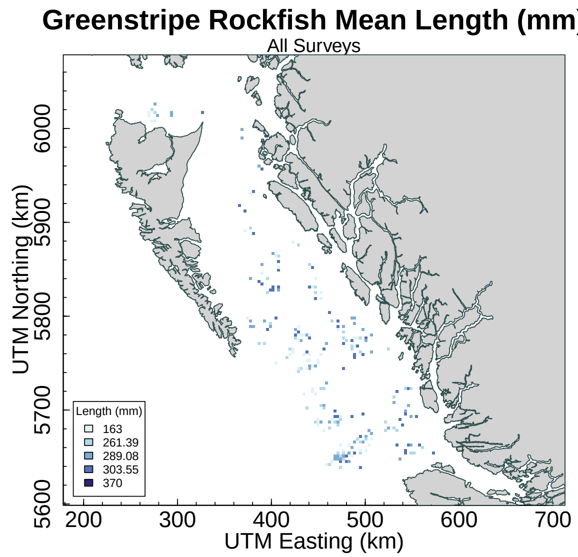
A.7.4 OTHER SPECIES

Studies have found a higher abundance of Greenstripe Rockfish at reefs with small numbers of piscivorous rockfish relative to reefs with higher numbers of piscivorous rockfish (PFMC and NMFS, 2006).

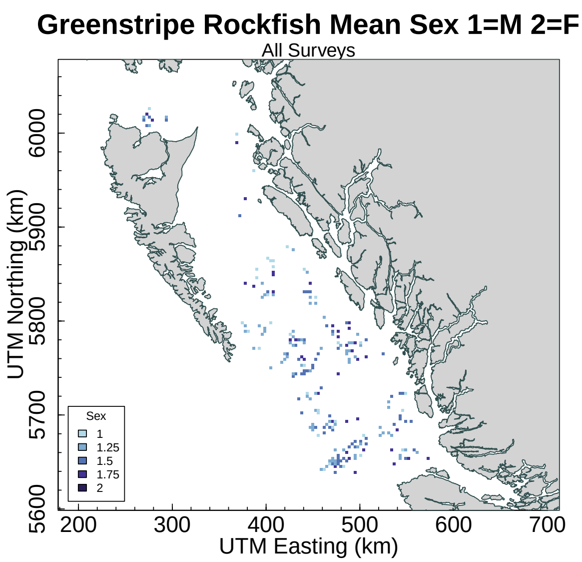
A.7.5 FIGURES



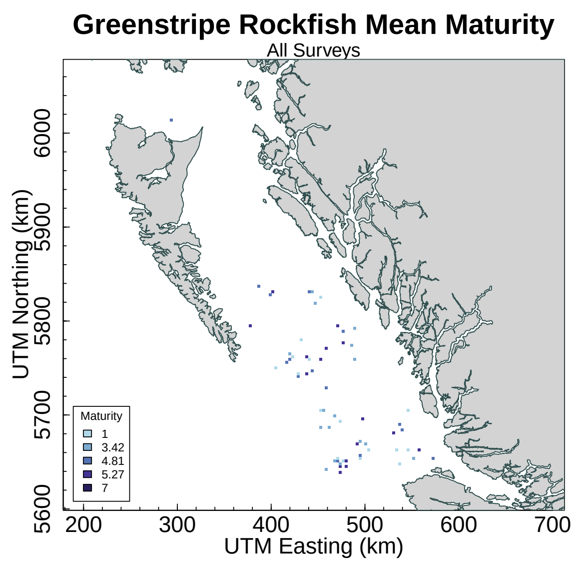
(a) Mean survey catch (kg) of Greenstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Greenstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

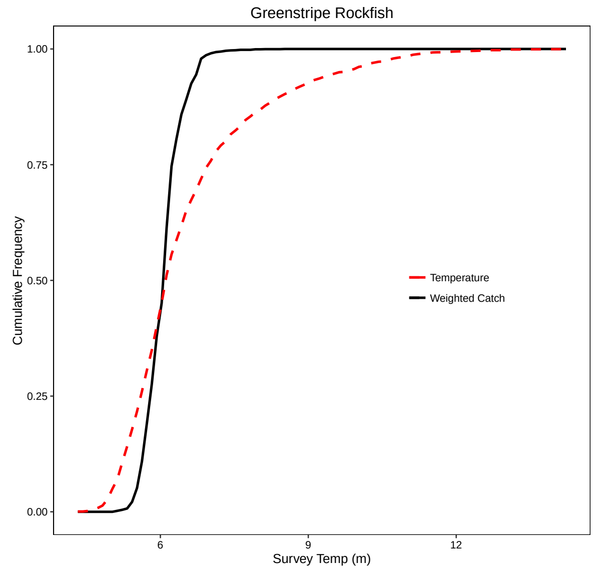


(c) Mean survey fish sex of Greenstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Greenstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.13. Summary of Greenstripe Rockfish data. The shaded cells give an approximation of the area where Greenstripe Rockfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.14. Cumulative frequency distributions of habitat variables and Greenstripe Rockfish catch-weighted data for all groundfish trawls surveys for all years.

A.8 LONGSPINE THORNYHEAD

A.8.1 LIFE HISTORY

Longspine Thornyhead occur on soft bottoms or offshore waters from southern Baja California to Aleutian Islands of Alaska at depths of 370 to 1,600 m (Hart, 1973). They are abundant from 600 to 1200 m (Wakefield, 1990). Juveniles occur in at midwater depths (Eschmeyer et al., 1983). Longspine Thornyhead do not aggregate but are uniformly dispersed (Wakefield, 1990). Approximately 50 to 60% of both sexes have reached sexual maturity at 190 mm (Ianelli et al., 1994). The larval phase is pelagic for a relatively long period of time and are dispersed over wide areas due to prevailing ocean currents (Jacobson and Vetter, 1996).

A.8.2 PREDATORS AND PREY

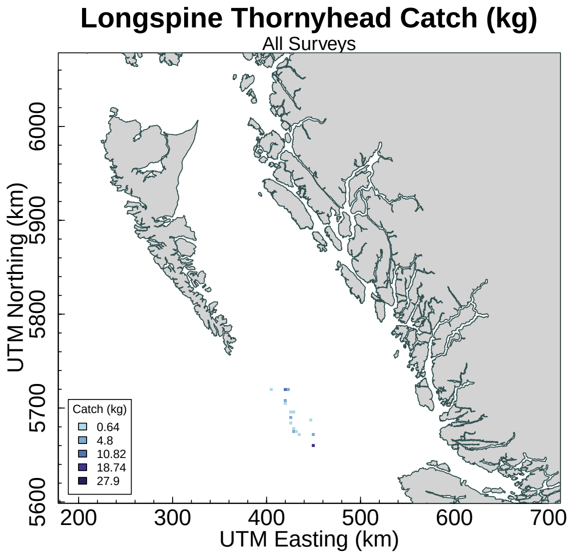
Longspine Thornyhead are consumed by Shortspine Thornyhead and sablefish (*Anoplopoma fimbria*) (Jacobson and Vetter, 1996; Buckley et al., 1999)

A.8.3 ENVIRONMENT

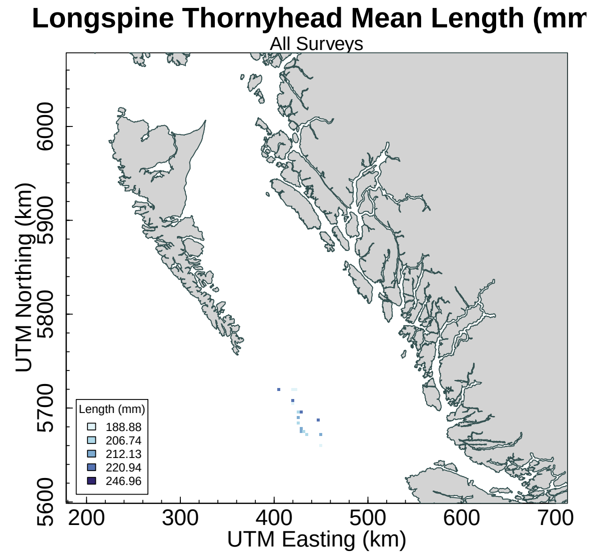
A.8.4 OTHER SPECIES

Longspine Thornyhead are captured in fisheries with Dover Sole and sablefish.

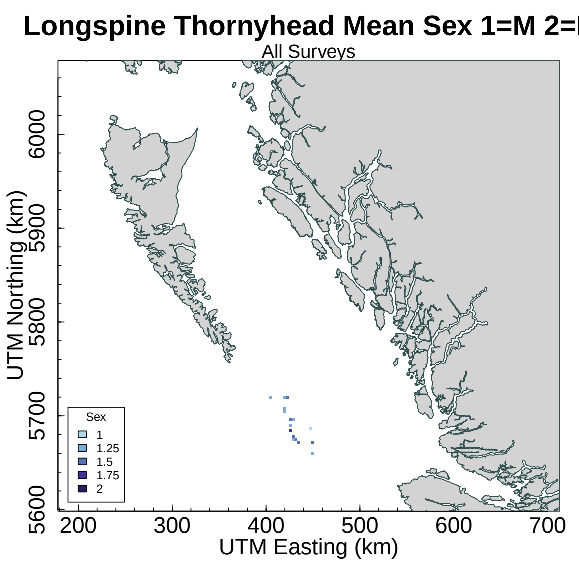
A.8.5 FIGURES



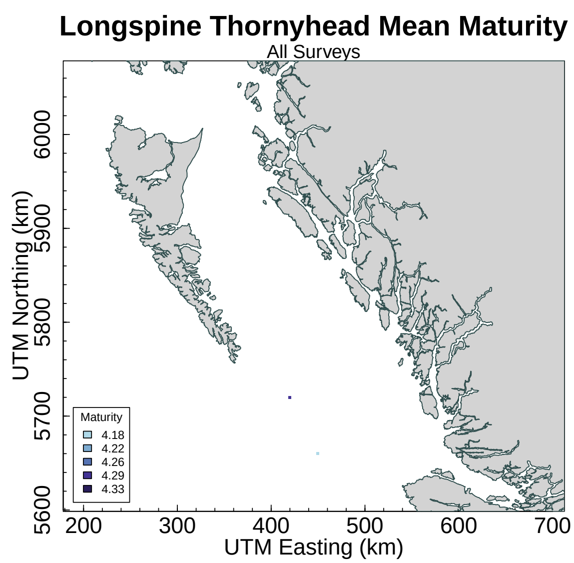
(a) Mean survey catch (kg) of Longspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Longspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

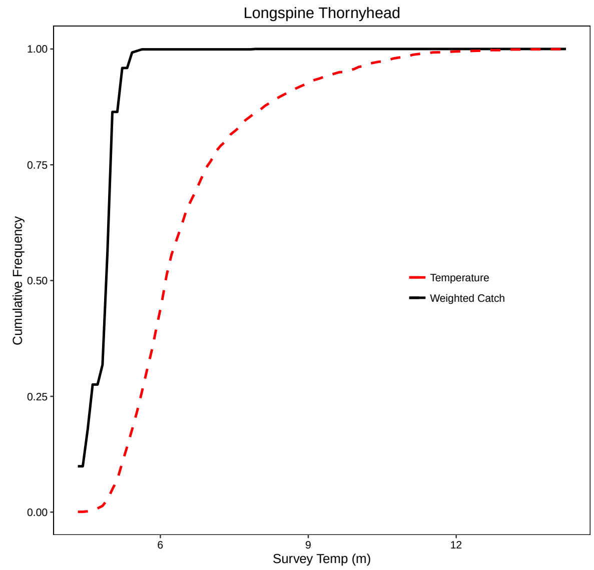


(c) Mean survey fish sex of Longspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Longspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.15. Summary of Longspine Thornyhead data. The shaded cells give an approximation of the area where Longspine Thornyhead was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.16. Cumulative frequency distributions of habitat variables and Longspine Thornyhead catch-weighted data for all groundfish trawls surveys for all years.

A.9 PACIFIC COD

A.9.1 LIFE HISTORY

A.9.2 PREDATORS AND PREY

Pacific Cod are omnivores, eating a diet of mainly marine invertebrates, including amphipods, euphausiids, shrimp and crabs. At around 50 to 55 cm they also become piscivorous, with Pacific Sand Lance (*Ammodytes hexapterus*) and Pacific Herring (*Clupea harengus pallasi*) becoming important components of the diet *west96*. Juvenile Sablefish (*Anoplopoma fimbria*) and adult Pacific Hake (*Merluccius productus*) have also been reported in the diet of Pacific Cod off the west coast of Vancouver Island (Ware and McFarlane, 1986). Pacific Cod have been reported in the diets of Pacific Halibut (*Hippoglossus stenolepis*), North Pacific Spiny Dogfish, sea birds, seals and sea lions *west96*.

Walters et al. (1986) demonstrated a Pacific Cod-Herring predator-prey interaction in Hecate Strait, in contrast to (Ware and McFarlane, 1986). Simulation models were developed by Walters et al. (1986) to explicitly model the effects of Pacific Cod predation on Pacific Herring. The simulations were able to mimic recruitment trends in both species. Walters et al. (1986) concluded that availability of Pacific Herring prey could be an important driver of Pacific Cod production in Hecate Strait, and, similarly, that Pacific Cod predation could be a significant driver of Pacific Herring abundance. These authors acknowledged that there are alternative hypotheses for cycles in abundance of Pacific Cod and Pacific Herring (e.g., environmental forcing; see below) and suggested that large-scale management experiments may be the only way to distinguish among competing hypotheses.

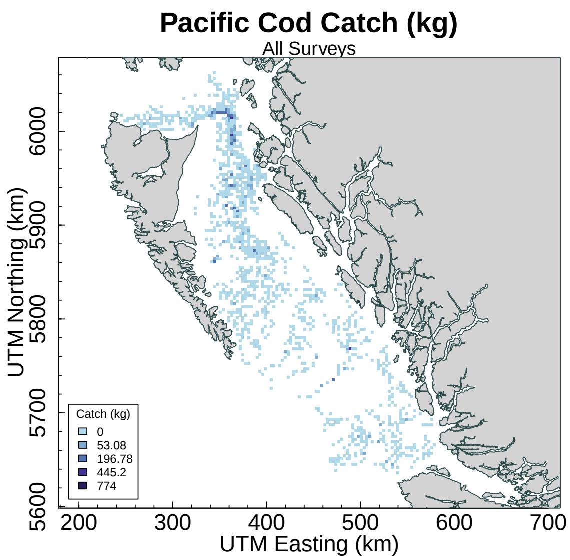
A.9.3 ENVIRONMENT

A large number of studies have investigated linkages between recruitment and environmental indices for Pacific Cod in Hecate Strait. The dominant hypothesis is an inverse relationship between recruitment and northward water transport (i.e., northward advection of larvae) (Tyler and Westrheim, 1986; Tyler and Crawford, 1991). Northward water transport has been shown to be positively correlated with mean annual sea level at Prince Rupert during the spawning season, which in turn has been used as an explanatory variable for recruitment by a number of authors (Fournier, 1983; Sinclair et al., 2001; Sinclair and Crawford, 2005; Sinclair and Starr, 2005). Westrheim (1996) provides a review of the major alternative studies.

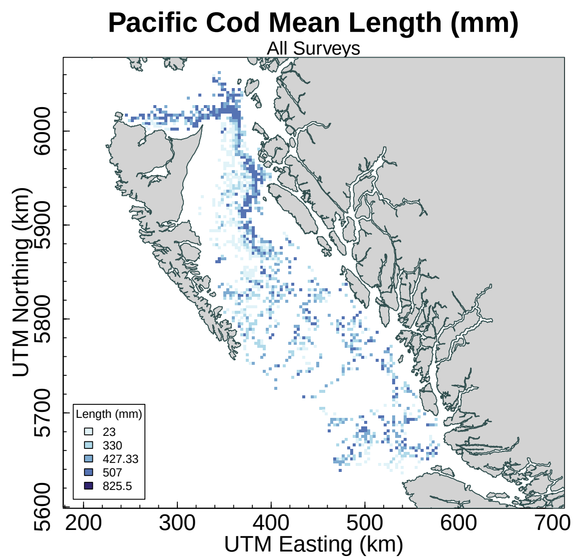
A.9.4 OTHER SPECIES

Other species caught with Pacific Cod include Arrowtooth Flounder (*Atheresthes stomias*), Yellowtail Rockfish (*Sebastes flavidus*), Pacific Ocean Perch (*S. alutus*), Lingcod (*Ophiodon elongatus*), Silvergray Rockfish (*S. brevispinis*), English Sole (*Parophrys vetulus*) and Big Skate (*Raja binoculata*).

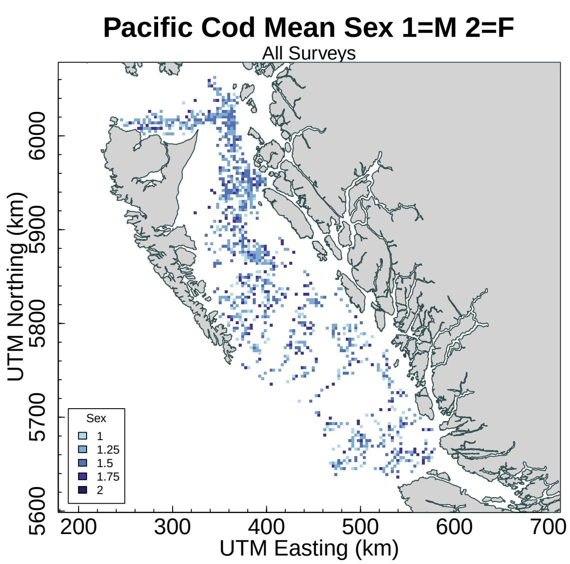
A.9.5 FIGURES



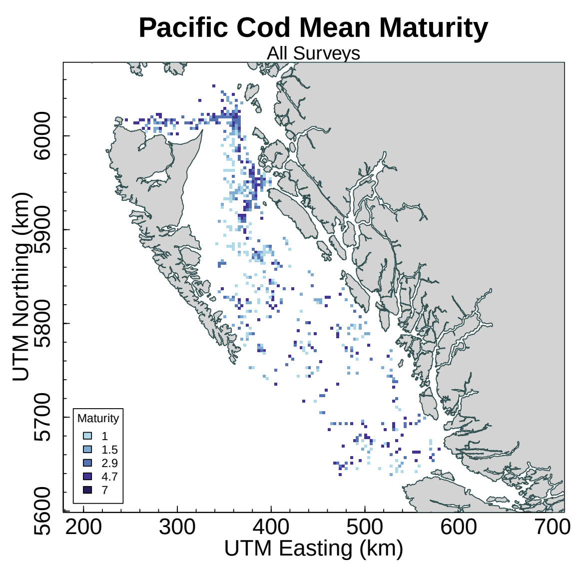
(a) Mean survey catch (kg) of Pacific Cod in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Pacific Cod in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

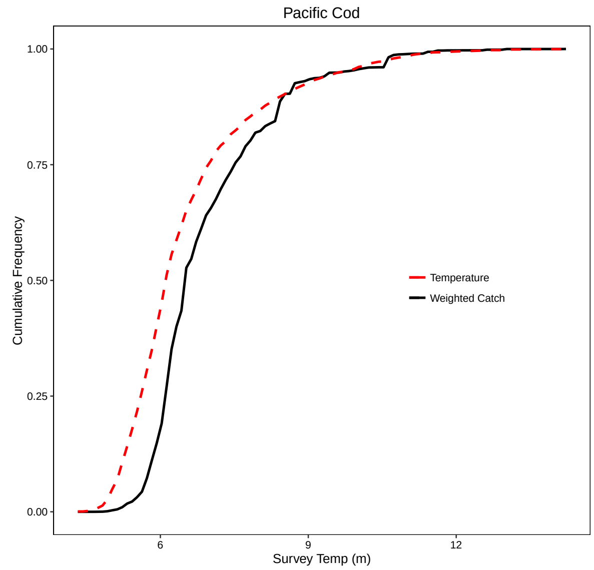


(c) Mean survey fish sex of Pacific Cod in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Pacific Cod in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.17. Summary of Pacific Cod data. The shaded cells give an approximation of the area where Pacific Cod was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.18. Cumulative frequency distributions of habitat variables and Pacific Cod catch-weighted data for all groundfish trawls surveys for all years.

A.10 PETRALE SOLE

A.10.1 LIFE HISTORY

Petrale Sole are distributed from northern Baja California to the Gulf of Alaska and Bering Sea. Individuals are distributed throughout coastal BC with large concentrations along the west coast of Vancouver Island, off Cape Scott, through Queen Charlotte Sound and Hecate Strait, and in Dixon Entrance (Hart, 1973). They are usually occur in deep water (80 to 550 m) but can be found near the surface (Hart, 1973; Starr and Fargo, 1976). Adults are found on sand bottoms. Juveniles (1 to 2 years old) have been found on the ocean floor at depths of 18 to 71 m (Hart, 1973). Petrale Sole can live up to 30 years (Starr and Fargo, 1976). Adults show tolerance for a wide range of bottom temperatures (Perry et al., 1994).

Petrale Sole move from shallow to deeper water during summer and winter, respectively. Spawning occurs during the winter. There seems to be very little norht-south movement by this species (Casillas et al., 1998). Success of spawning depends on meteorological and oceanographic conditions; therefore, it is variable from year to year which leads to changes in the abundance and size of the fish stock (Hart, 1973).

Spawning occurs over the continental shelf and slope from December to April and peaks in January-February. Petrale Sole spawn in the same general area from year to year.

A.10.2 PREDATORS AND PREY

Juvenile Petrale Sole are prey items for large pollock, Pacific Cod and Spiny Dogfish (Starr and Fargo, 1976).

Adult Petrale Sole prey on herring, cephalopods, euphasiids, shrimp and bottom fishes (Hart, 1973; Pearsall and Fargo, 2007). Petrale Sole show seasonal changes in diet by consuming more fish, primarily herring, in the winter diet than the summer and fall diets, and no fish during the summer (Pearsall and Fargo, 2007).

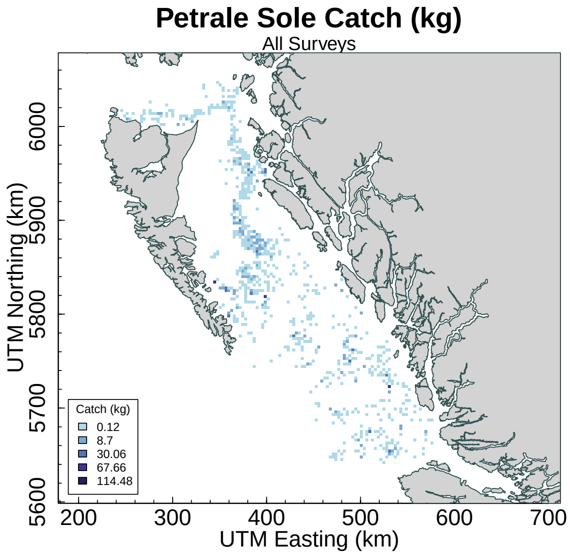
A.10.3 ENVIRONMENT

Castillo et al. (1995) demonstrated that offshore Ekman transport of eggs and larvae accounted for 55% and 65% of the variation in Petrale Sole year-class strength in PMFC Areas 2B and 3A, respectively. They concluded, as have previous investigators, that density-independent survival variation at the early life stages is high compared to variation in spawning biomass (Starr and Fargo, 1976).

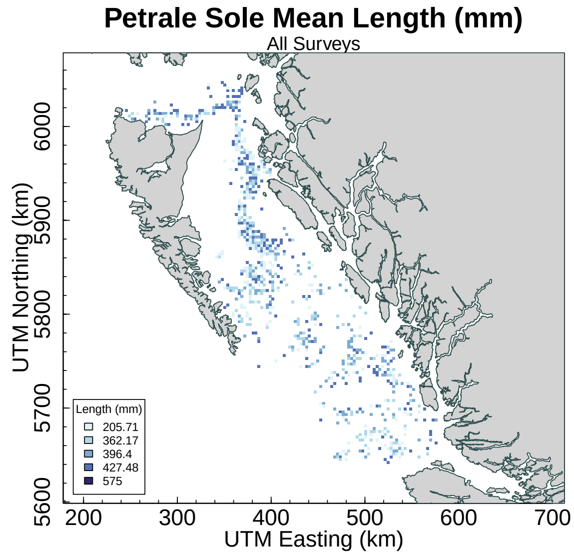
A.10.4 OTHER SPECIES

Petrale sole is an important component of the offshore ecosystem. Studies indicate that this species is a top end predator whose diet overlaps with that of Arrowtooth Flounder (adult and juvenile), Spiny Dogfish Pacific Cod (adult and juvenile), Pacific Halibut, Sand Sole (*Psettichthys melanostictus*) and several rockfish species (Pearsall and Fargo, 2007).

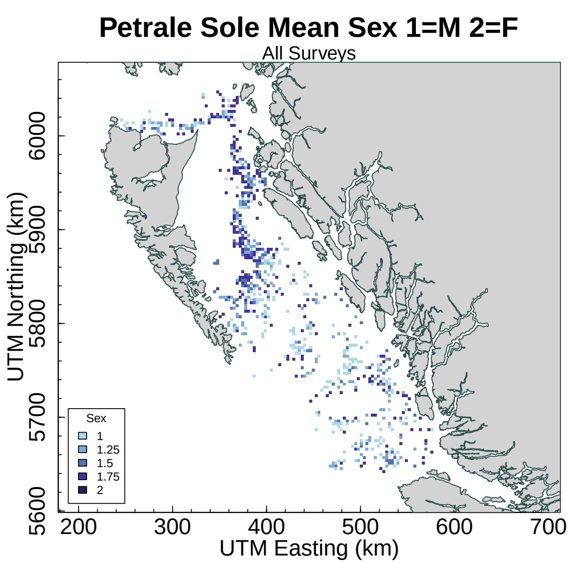
A.10.5 FIGURES



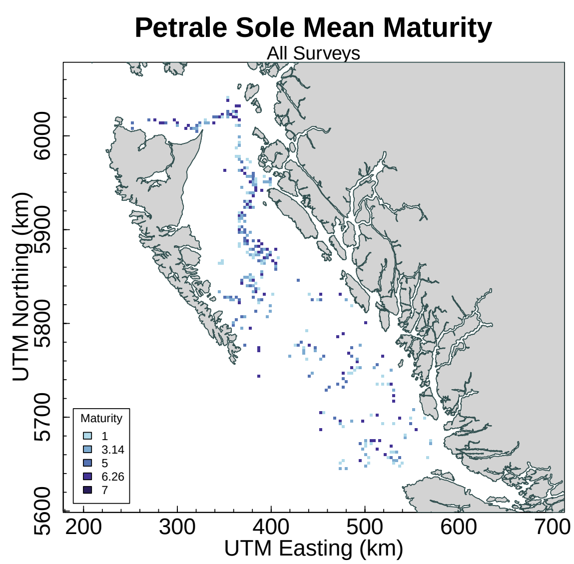
(a) Mean survey catch (kg) of Petrale Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Petrale Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



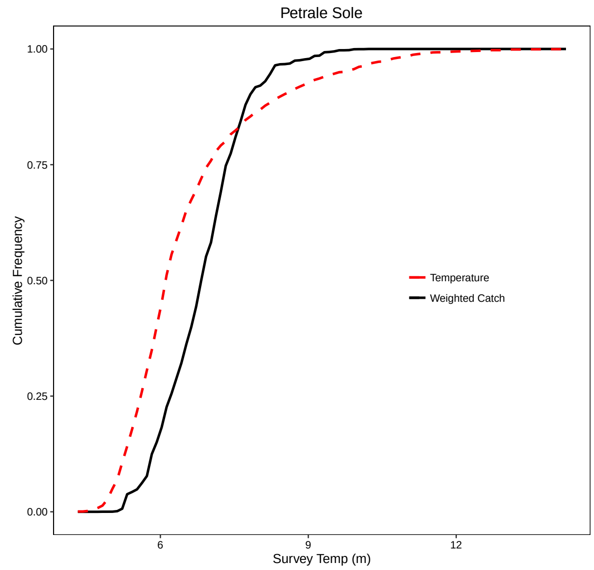
(c) Mean survey fish sex of Petrale Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Petrale Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.19. Summary of Petrale Sole data. The shaded cells give an approximation of the area where Petrale Sole was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.

(a)



(b)

Figure A.20. Cumulative frequency distributions of habitat variables and Petrale Sole catch-weighted data for all groundfish trawls surveys for all years.

A.11 PACIFIC OCEAN PERCH

A.11.1 LIFE HISTORY

Pacific Ocean Perch Pacific Ocean Perch occurs along the North Pacific rim, ranging from Honshu (Japan), through the Bering Sea, along the Aleutian Islands (Alaska), then southward through BC down to central Baja California (Love et al., 2002). The species appears to be most abundant north of 50 °N (Allen and Smith, 1988). They usually occur offshore from the surface to depths of approximately 825 m (Hart, 1973; Allen and Smith, 1988). They are commonly between 165 and 293 m (Kramer and O'Connell, 1995). The life history of POP follows similar patterns to other Sebastes species, with release of larvae that spend periods ranging from about three to twelve months as free-swimming pelagic larvae before settling to the bottom as juveniles. Reproduction appears to follow onshore-offshore migration patterns where females move onshore for insemination and then migrate deeper to the entrances of submarine gullies where they release larvae from February to May (Love et al., 2002). The larvae depend on vertical upwelling to bring them into the upper pelagic zone to facilitate growth and dispersal. The larvae can spend up to a year in the water column before settling on benthic habitat (Kendall Jr. and Lenarz, 1986). Juvenile benthic habitat is shallow (100-200 m), compared to the depths occupied by adult POP, and comprises either rough rocky bottoms or high relief features such as boulders, anemones, sponges, and corals (Carlson and Straty, 1981; N. et al., 2007). The maximum known age appears to be 103 y for a female specimen from Moresby Gully at 364 m in 2002, from the Department of Fisheries and Oceans Canada (DFO) Groundfish database GFBio (Edwards et al., 2012*b*, 2013).

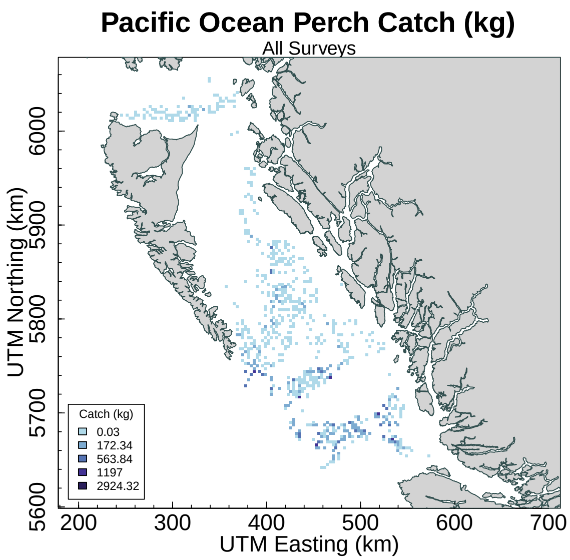
A.11.2 PREDATORS AND PREY

Predators of Pacific Ocean Perch include sablefish, Alaska Pollock, Atka Mackerel (*Pleurogrammus monopterygius*), Chum Salmon (*Oncorhynchus keta*), Pacific Halibut, Albacore (*Thunnus alalunga*), and Sperm Whales (*Physeter macrocephalus*) (Hart, 1973; Major and Shippen, 1970; Orlov, 2001). Pacific Ocean Perch feed on zooplankton, including pteropods and euphausiids, and benthic organisms such as copepods, amphipods, shrimps, prawns, annelids, and juvenile and adult bony fishes (Carlson and Haight, 1976; Somerton et al., 1978).

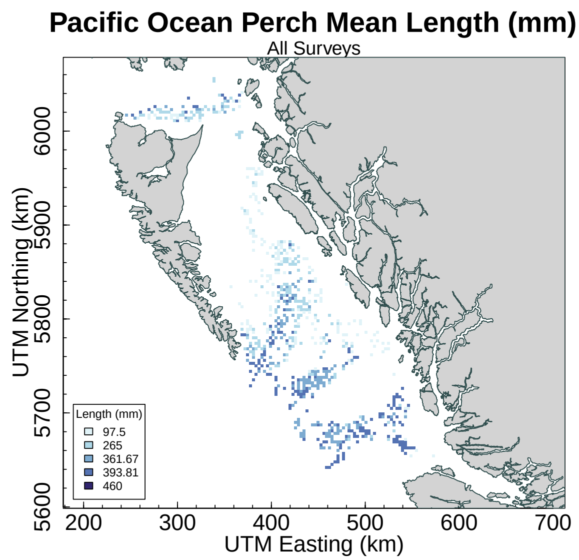
A.11.3 ENVIRONMENT

A.11.4 OTHER SPECIES

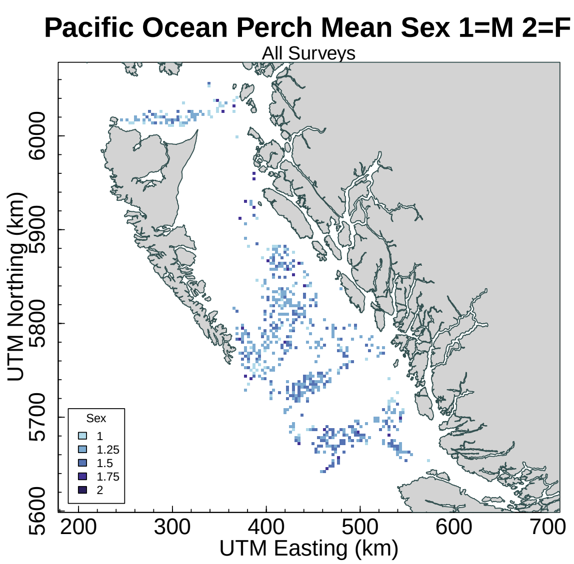
A.11.5 FIGURES



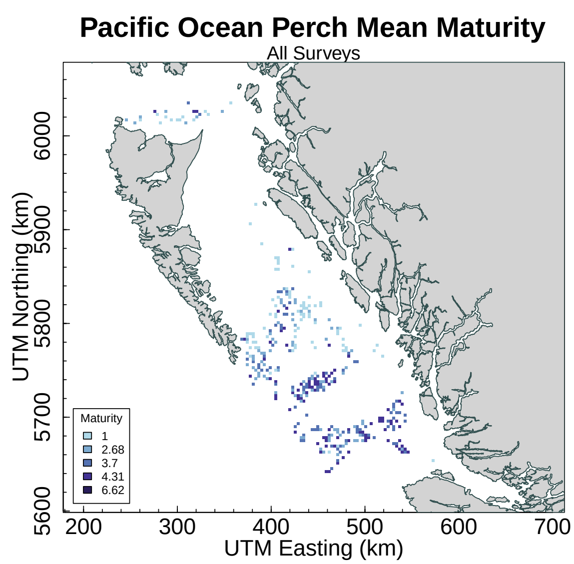
(a) Mean survey catch (kg) of Pacific Ocean Perch in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Pacific Ocean Perch in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

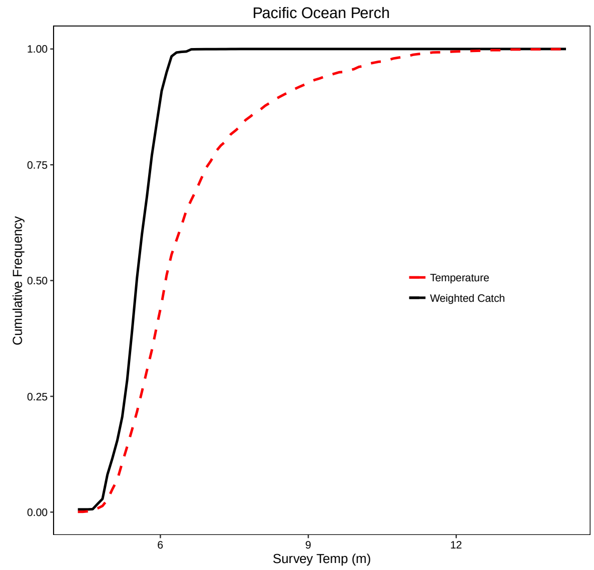


(c) Mean survey fish sex of Pacific Ocean Perch in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Pacific Ocean Perch in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.21. Summary of Pacific Ocean Perch data. The shaded cells give an approximation of the area where Pacific Ocean Perch was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) (b)

Figure A.22. Cumulative frequency distributions of habitat variables and Pacific Ocean Perch catch-weighted data for all groundfish trawls surveys for all years.

A.12 RATFISH

A.12.1 LIFE HISTORY

Ratfish is distributed from the Gulf and Baja of California to southeast Alaska (Wilimovsky, 1954; Grinols, 1965). Ratfish are found in bays, sounds and inland seas at the northern extent of its range. In inland Canadian waters it is most abundant from 90 to 275 m and from 180 to 260 m in offshore waters. They generally occur in deep-water over the continental shelf and slope to depths of 913 m (Alverson et al., 1964). In BC Ratfish have been caught in commercial bottom trawls at depths of 1029 m (J. King, unpublished data in King and McPhie (2015)). In BC the maximum observed size is 670 mm (PCL) for males and 690 mm (PCL) for females (J. King unpub. data in King and McPhie (2015)) which is larger than what has been observed from Washington to California (Barnett et al., 2009*a*). Gestation is approximately 9 to 12 months (Dean, 1906) and parturition peaks between May and October (Barnett et al., 2009*b*). Ratfishare oviparous and lay individual eggs on the ocean floor.

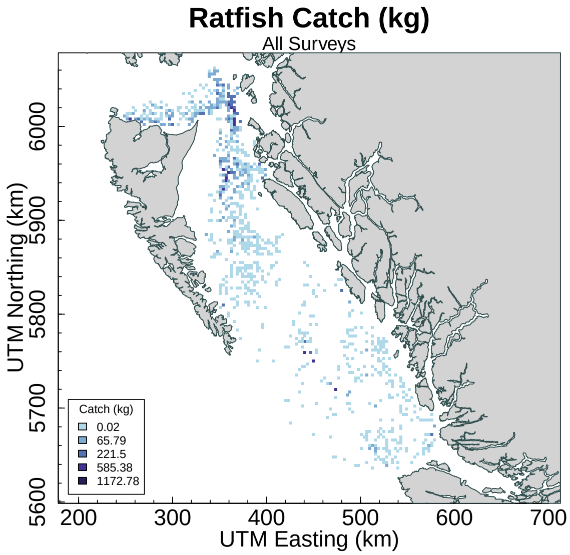
A.12.2 PREDATORS AND PREY

Ratfish are predated upon by Pacific Halibut and shark species (Armstrong, 1996). They are known to feed on mollusks, crustaceans, echinoderms, worms and fishes (Armstrong, 1996; la Cruz Agüero et al., 1997).

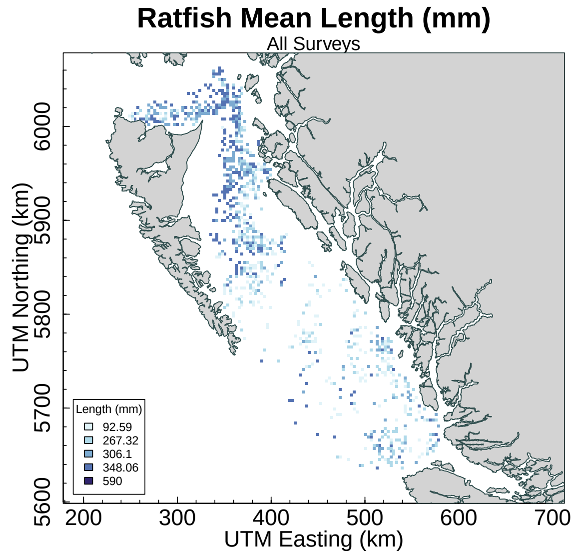
A.12.3 ENVIRONMENT

A.12.4 OTHER SPECIES

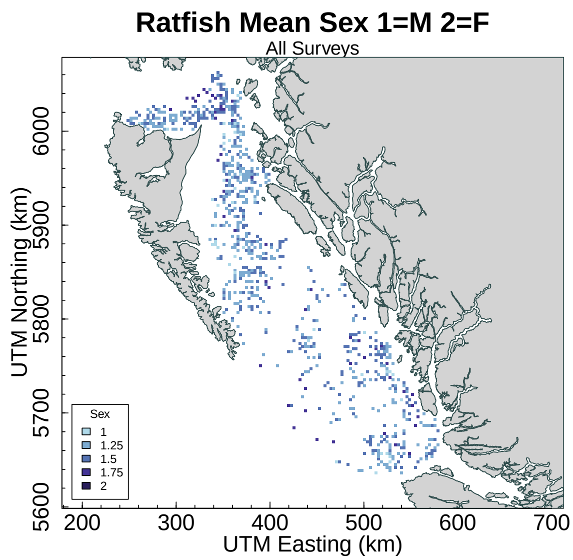
A.12.5 FIGURES



(a) Mean survey catch (kg) of Ratfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

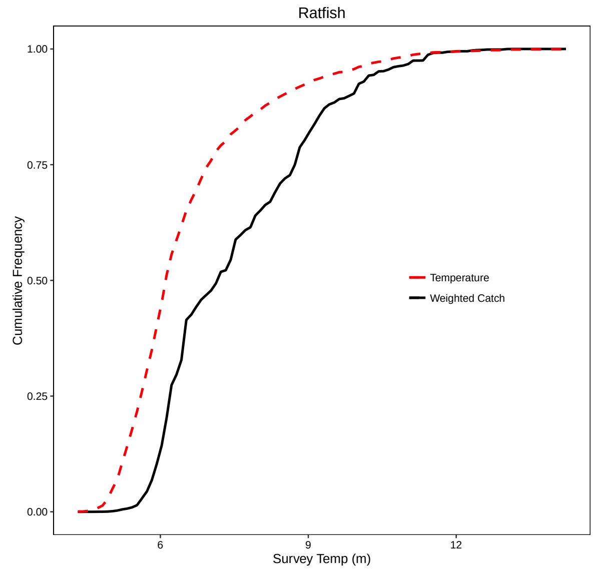


(b) Mean survey fish length (mm) of Ratfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(c) Mean survey fish sex of Ratfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.

Figure A.23. Summary of Ratfish data. The shaded cells give an approximation of the area where Ratfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



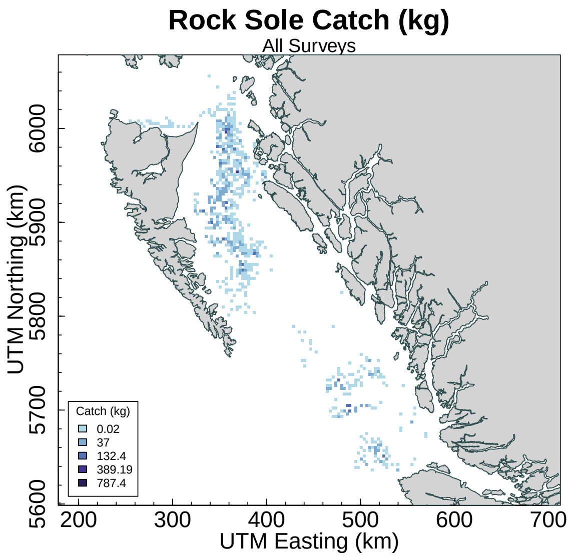
(a) (b)

Figure A.24. Cumulative frequency distributions of habitat variables and Ratfish catch-weighted data for all groundfish trawls surveys for all years.

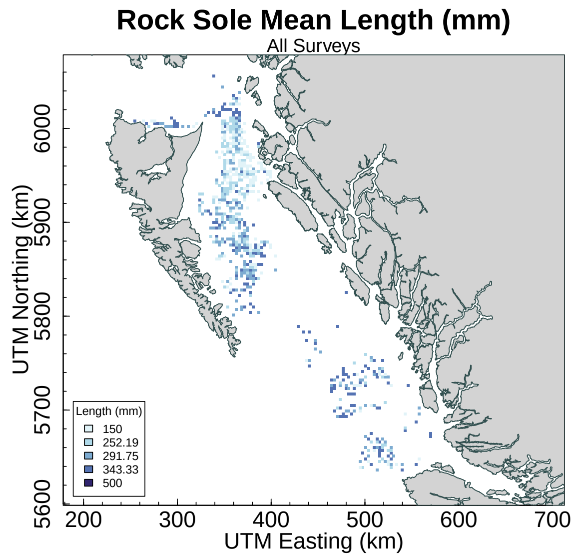
A.12.6 ENVIRONMENT

A.12.7 OTHER SPECIES

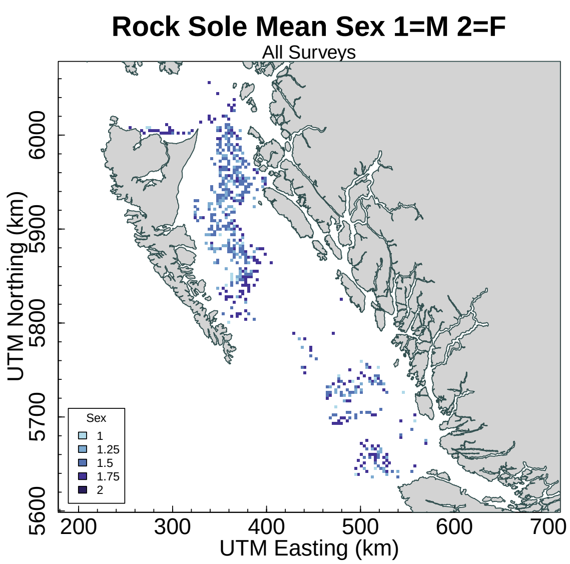
A.12.8 FIGURES



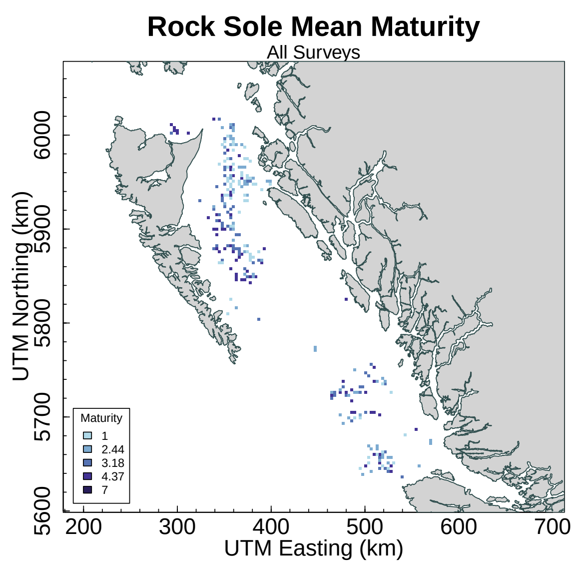
(a) Mean survey catch (kg) of Rock Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Rock Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

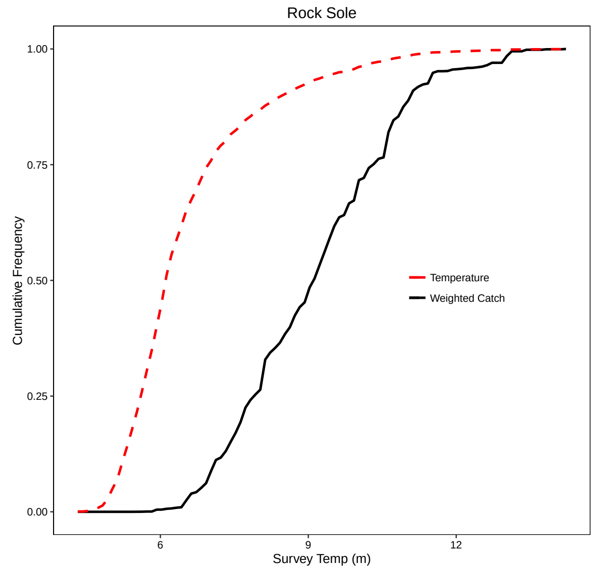


(c) Mean survey fish sex of Rock Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Rock Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.25. Summary of Rock Sole data. The shaded cells give an approximation of the area where Rock Sole was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.26. Cumulative frequency distributions of habitat variables and Rock Sole catch-weighted data for all groundfish trawls surveys for all years.

A.13 REDSTRIPE ROCKFISH

A.13.1 LIFE HISTORY

There is little life history information available in the literature for Redstripe RockfishḢowever, they occur from southern California to Alaska and the Bering Sea at depths ranging from 12 m to 425 m (Allen and Smith, 1988). They occur where rocky reefs or steep silt-covered cliff faces meet gently sloping sand or mud bottoms (Lamb and Edgell, 1986). They oldest reported individual was 55 years old (Cailliet et al., 2001) and a maximum length of 51 cm (Love et al., 1990). no reports

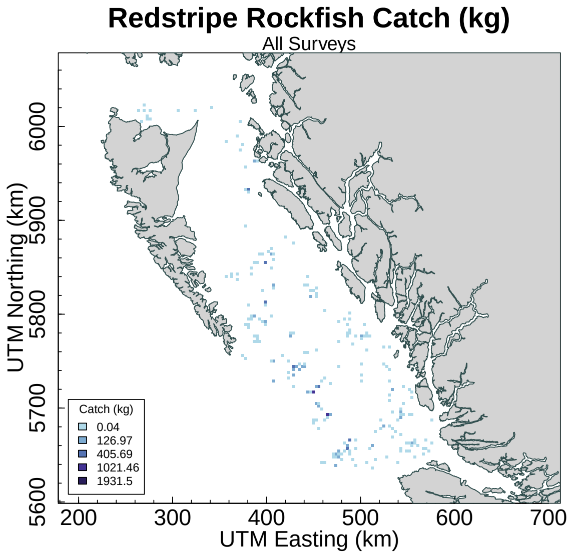
A.13.2 PREDATORS AND PREY

Redstripe Rockfish have been found in the stomachs of Chinook Salmon off the coast of California (Mills et al., 2007). They feed on krill, shrimps and small fishes (Love et al., 2002).

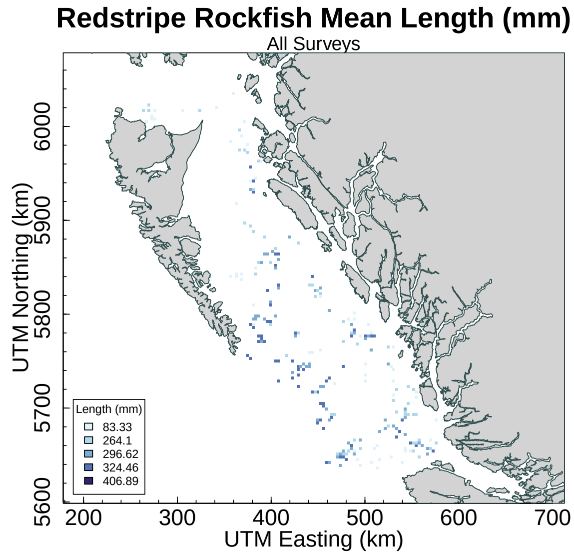
A.13.3 ENVIRONMENT

A.13.4 OTHER SPECIES

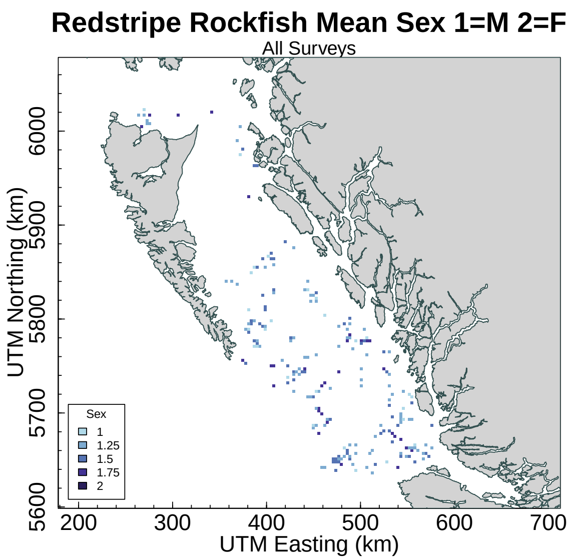
A.13.5 FIGURES



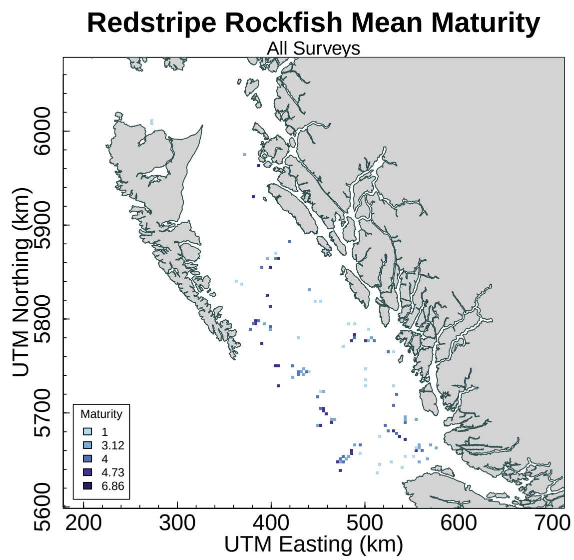
(a) Mean survey catch (kg) of Redstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Redstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

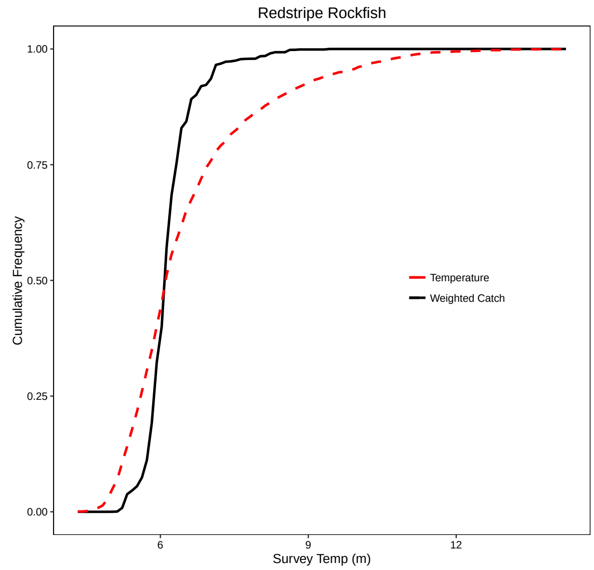


(c) Mean survey fish sex of Redstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Redstripe Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.27. Summary of Redstripe Rockfish data. The shaded cells give an approximation of the area where Redstripe Rockfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) (b)

Figure A.28. Cumulative frequency distributions of habitat variables and Redstripe Rockfish catch-weighted data for all groundfish trawls surveys for all years.

A.14 REX SOLE

A.14.1 LIFE HISTORY

Rex Sole are distributed from southern California to the Bering Sea and occur from the surface to 800 m (Grinols, 1965; Mecklenburg et al., 2002). They are distributed uniformly throught BC (Hart, 1973). In the Gulf of Alaska they are most abundant from 100 to 200 m depths (Stockhausen et al., 2011). They are found on sand or mud bottoms (Eschmeyer et al., 1983).

Little is known about the life history of Rex Sole in BC but it is believed that in Hecate Strait spawning occurs in March or early April. In the Gulf of Alaska, the spawning season spans from October to May (Abookire, 2006). Spawning occurs Off the coast of Oregon from January through June (Hosie and Horton, 1977). Eggs are fertilized on the ocean floor, become pelagic, and hatch after a few weeks (Hosie and Horton, 1977). Larvae remain the pelagic stage for approximately a year before settling on the bottom as 5 cm juveniles (Stockhausen et al., 2011). Young are not found nearshore but juveniles (10 cm long) are occassionally observed in shallow water to 110 m depths (Hart, 1973). Females are more common catches than males.

A.14.2 PREDATORS AND PREY

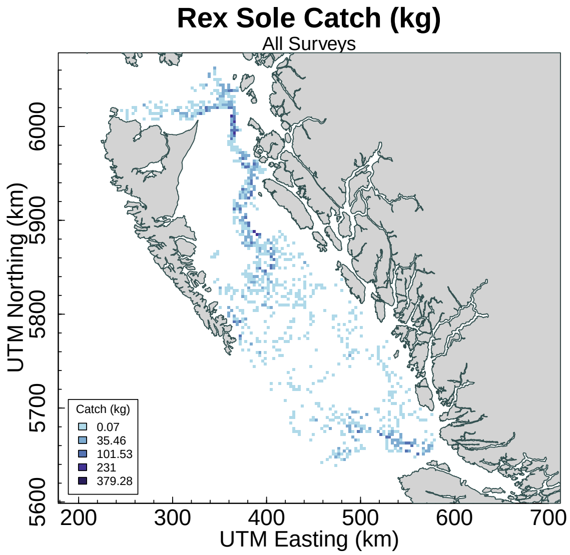
Predators of Rex Sole include Pacific sleeper sharks, Pacific Cod California sea lions, harbour seals and Arrowtooth Flounder (Lowry et al., 1990; Yang and Nelson, 1999; Yang and Page, 1999; Browne et al., 2002).

Rex Sole feed on amphiphods, euphasiids, polychaetes and some shrimp (Pearcy and Hancock, 1978; Brodeur and Livingston, 1988; Stockhausen et al., 2011).

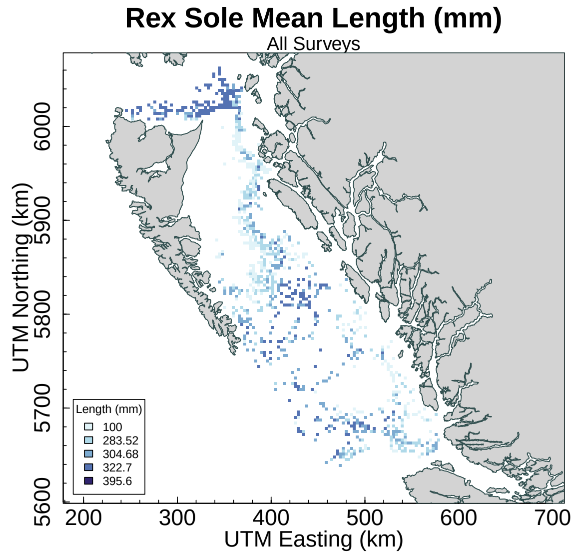
A.14.3 ENVIRONMENT

A.14.4 OTHER SPECIES

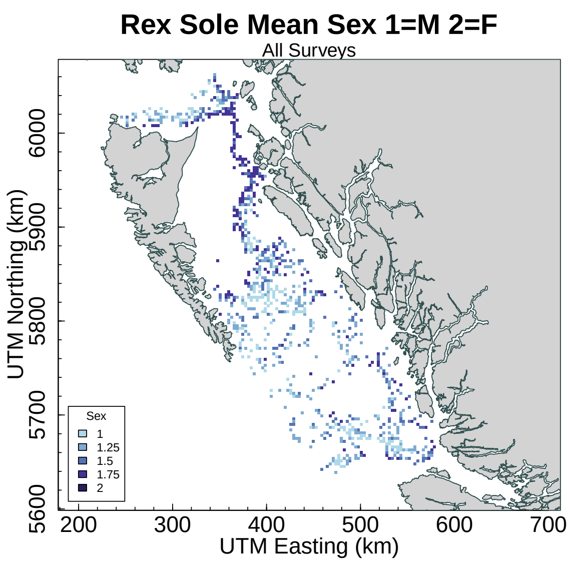
A.14.5 FIGURES



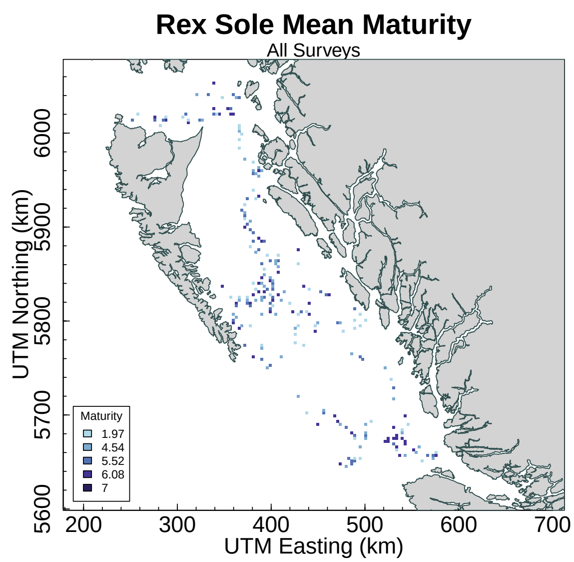
(a) Mean survey catch (kg) of Rex Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Rex Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

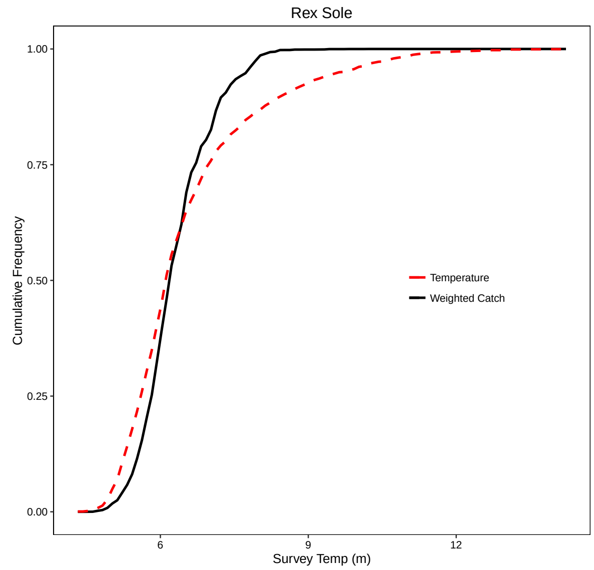


(c) Mean survey fish sex of Rex Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Rex Sole in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.29. Summary of Rex Sole data. The shaded cells give an approximation of the area where Rex Sole was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.30. Cumulative frequency distributions of habitat variables and Rex Sole catch-weighted data for all groundfish trawls surveys for all years.

A.15 SABLEFISH

A.15.1 LIFE HISTORY

Sablefish inhabit shelf and slope waters from Baja California to the Aleutian Islands and Bering Sea to Hokkaido, Japan along mud bottoms (Hart, 1973; Eschmeyer et al., 1983). Their depth range is between 175 and 2740 m; however, they are most abundant at depths between 366 and 915 m (Bourne and Pope, 1969; Allen and Smith, 1988). Sablefish move into deeper water during the winter (Alverson, 1960; Hart, 1973). Spawning occurs from January to March along the continental shelf at depths greater than 300 m. Juveniles migrate inshore over the following six months and rear in near shore and shelf habitats until the ages 2 to 5 when they migrate offshore to deeper waters (DFO, 2011). Young-of-the-year juveniles are found near the surface and in nearshore waters (Armstrong, 1996). Sub-adults are found within shallower waters including the Strait of Georgia, Puget Sound and Juan de Fuca Strait.

The oldest reported Sablefish in BC waters is 92 years (DFO, 2013).

A.15.2 PREDATORS AND PREY

Predators of Sablefish include other Sablefish Pacific Cod Lingcod, Pacific Halibut, Arrowtooth Flounder Widow Rockfish Black Rockfish (*Sebastes melanops*), seabirds, Blue Shark and Orca (*Orcinus orca*) (Rosenthal et al., 1988; Harvey, 1989; Armstrong, 1996; Orlov, 1997; Yang and Nelson, 1999).

Sablefish prey on a variety of amphipods, crabs, cephalopods (cuttlefish and octopi), echinoderms (brittle stars and sea cucumbers), shrimps, prawns and bony fish. Crab species include Tanner Crabs (*Chionoecetes bairdi*) and Snow Crab (*Chionoecetes opilio*) (Orlov, 1997; Yang and Nelson, 1999). Shrimp and prawn food items include Pacific Glass Shrimp (*Pasiphaea pacifica*), Smooth Pink Shrimp (*Pandalopsis dispar*), Humpy Shrimp (*Pandalus goniurus*) and Northern Prawn (*Pandalus borealis*) (Yang and Nelson, 1999). Fish species include other Sablefish Smooth Lumpfish (*Aptocyclus ventricosus*), Pacific Herring, Capelin and Alaska Pollock (Orlov, 1997; Yang and Nelson, 1999).

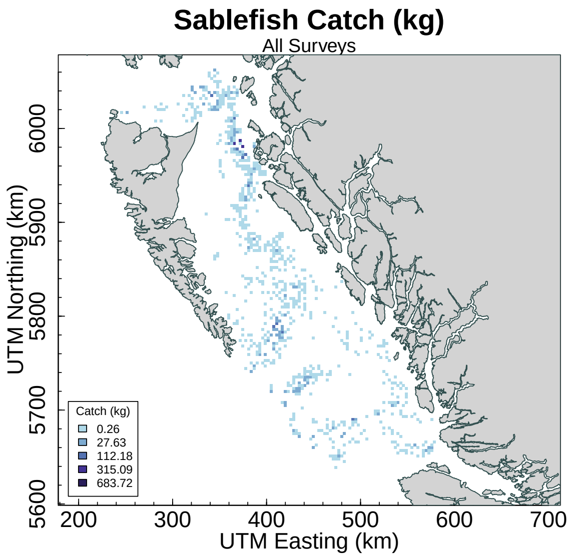
A.15.3 ENVIRONMENT

Within this range, Sablefish also tolerate relatively low oxygen concentrations, which allow this species to occupy the entire slope region to depths greater than 1500 m.

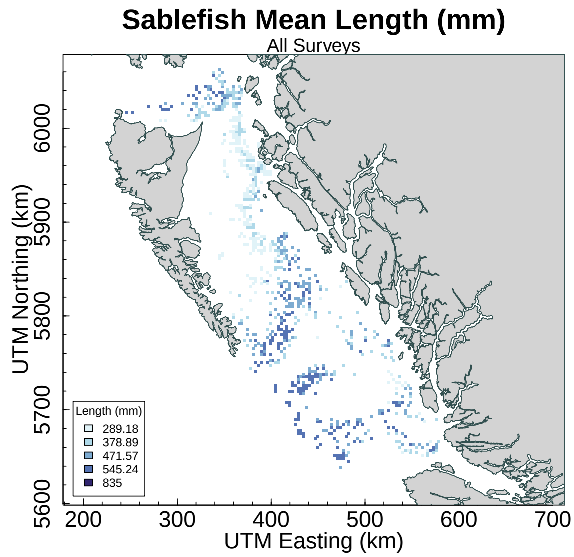
A.15.4 OTHER SPECIES

Sablefish are caught incidentally by longline hook fisheries directed at Pacific Halibut, rockfishes, lingcod, Spiny Dogfish and other demersal species (DFO, 2013).

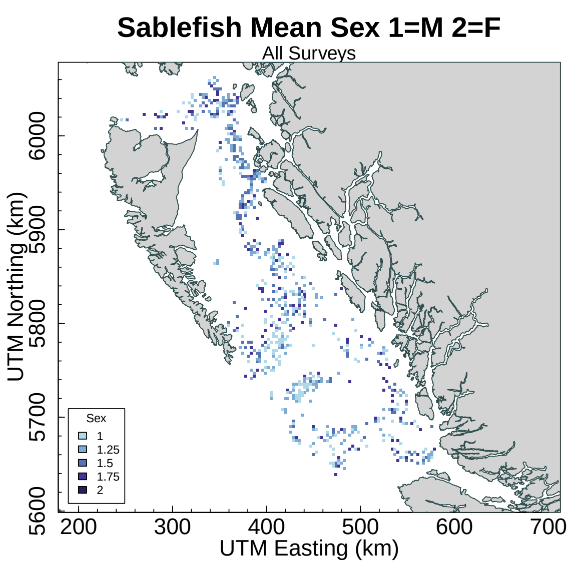
A.15.5 FIGURES



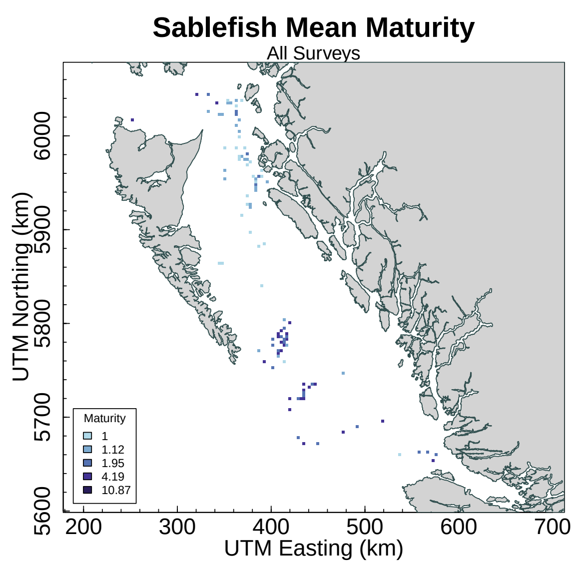
(a) Mean survey catch (kg) of Sablefish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Sablefish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

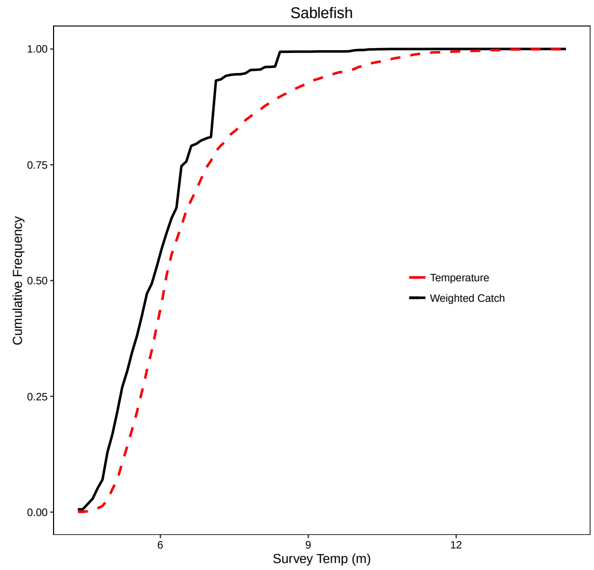


(c) Mean survey fish sex of Sablefish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Sablefish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.31. Summary of Sablefish data. The shaded cells give an approximation of the area where Sablefish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.32. Cumulative frequency distributions of habitat variables and Sablefish catch-weighted data for all groundfish trawls surveys for all years.

A.16 SILVERGRAY ROCKFISH

A.16.1 LIFE HISTORY

Silvergray Rockfish are distributed from southern California to the Bering Sea (Strachan, 1965). Silvergray Rockfish occur just off the bottom and are sometimes found in rocky crevices and caverns (Lamb and Edgell, 1986). Mating is believed to take place from September through January but peaks from December through January (Stanley and Kronlund, 2000). Parturition in BC occurs from April through July with it peaking in June (Stanley and Kronlund, 2000). Off the coast of Oregon it is believed that young are likely not released until late spring or summer; however, they are released in June in Washington (DeLacy and Dryfoos, 1962; Hitz, 1962). The maximum ages observed in BC waters were 82 and 81 years for males and females, respectively (Stanley and Kronlund, 2000).

A.16.2 PREDATORS AND PREY

No information on predators of Silvergray Rockfish was available.

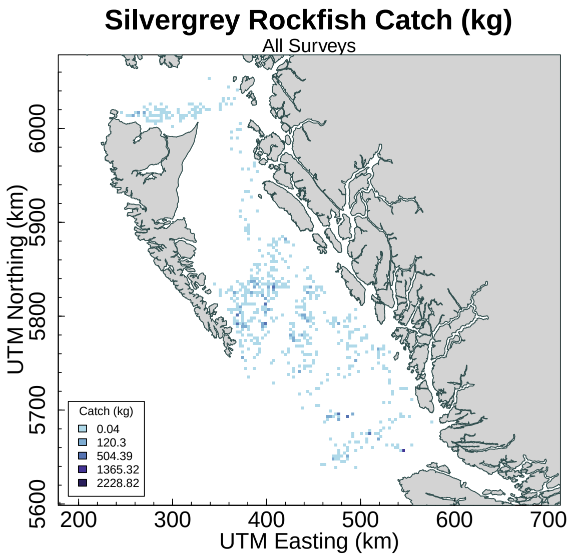
Silvergray Rockfish feed mainly on fish (74% of diet) but also feed on euphausiids (Pearsall and Fargo, 2007).

A.16.3 ENVIRONMENT

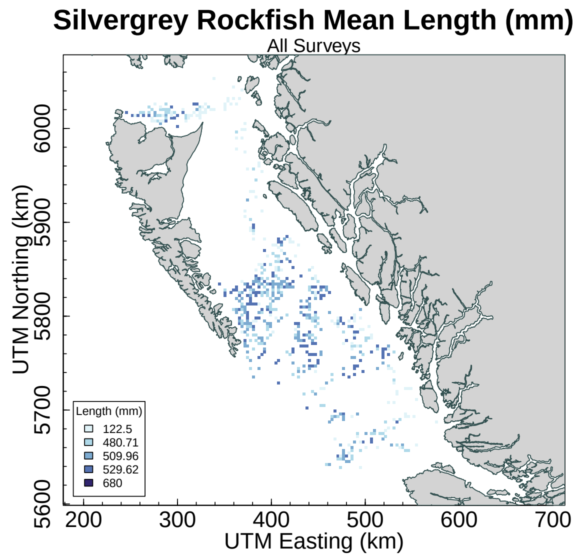
A.16.4 OTHER SPECIES

They form loose groups with other rockfish species (Love et al., 2002).

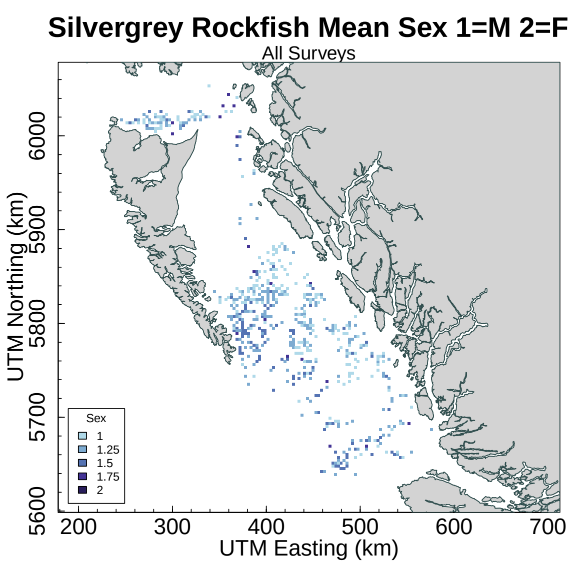
A.16.5 FIGURES



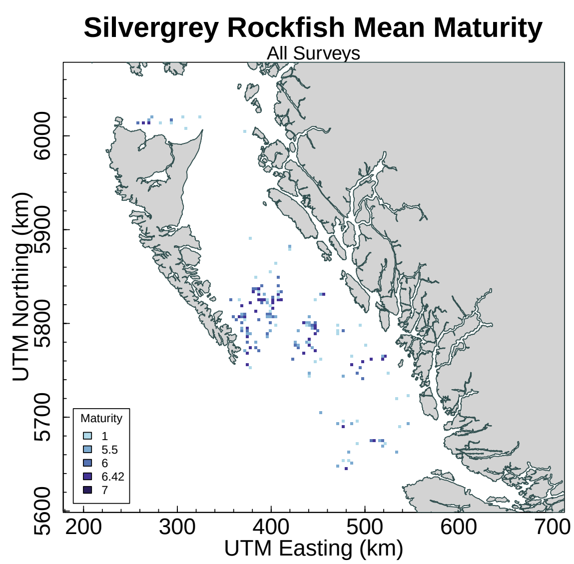
(a) Mean survey catch (kg) of Silvergray Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Silvergray Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

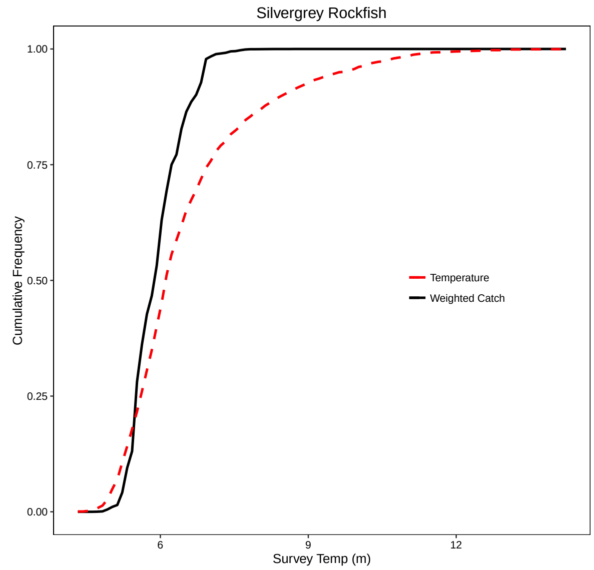


(c) Mean survey fish sex of Silvergray Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Silvergray Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.33. Summary of Silvergray Rockfish data. The shaded cells give an approximation of the area where Silvergray Rockfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) *(b)*

Figure A.34. Cumulative frequency distributions of habitat variables and Silvergray Rockfish catch-weighted data for all groundfish trawls surveys for all years.

A.17 SHORTSPINE THORNYHEAD

A.17.1 LIFE HISTORY

Shortspine Thornyhead are distributed from Baja California to the Okhotsk and Japan seas. They are found between 17 and 1,524 m depth prefer deep water (90 to 1460 m). Shortspine Thornyhead are most abundant from the Northern Kuril Islands to southern California. They are concentrated between 150 and 450 m depth in cooler northern waters, and are generally found in deeper waters (up to 1000 m) in the warmer waters of their range (Love et al., 2002). Shortspine Thornyhead are common off the BC coast in areas such as Juan de Fuca Strait, Strait of Georgia and Queen Charlotte Sound (Hart, 1973).

Shortspine Thornyhead spawn a mass of fertilized eggs which floats in the water column (Love et al., 2002). This is unlike most rockfish species (genus *Sebastes*) which retain fertilized eggs internally and release fully developed larvae. Shortspine Thornyhead spawning takes place in the late spring, between April and July in the Gulf of Alaska and between December and May from Washington to California (Gunderson, 1997). After hatching, larvae and juveniles spend 14 to 15 months in a pelagic phase. Shortspine Thornyhead settle in benthic habitats between 100 and 600 m depth and then migrate deeper with age (Love et al., 2002) where they prefer soft substrate (Eschmeyer et al., 1983).

Shortspine Thornyhead live up to 80 to 100 years of age (Love et al., 2002).

A.17.2 PREDATORS AND PREY

Shortspine thornyheads are consumed by a variety of piscivores, including arrowtooth flounder, sablefish, California sea lions, sperm whales, and sharks. Juvenile shortspine thornyheads are thought to be consumed almost exclusively by adult thornyheads. Thornyheads are an uncommon prey in the Gulf of Alaska, as they generally make up less than 2% of even their primary predators' diets (Lowe et al., 2007).

Over 70% of adult shortspine thornyhead diet measured in the early 1990s was shrimp, including both commercial (pandalid) shrimp and non-commercial (non-pandalid shrimp), and to a lesser extent deepwater crabs (Gaichas and Ianelli, 2005).

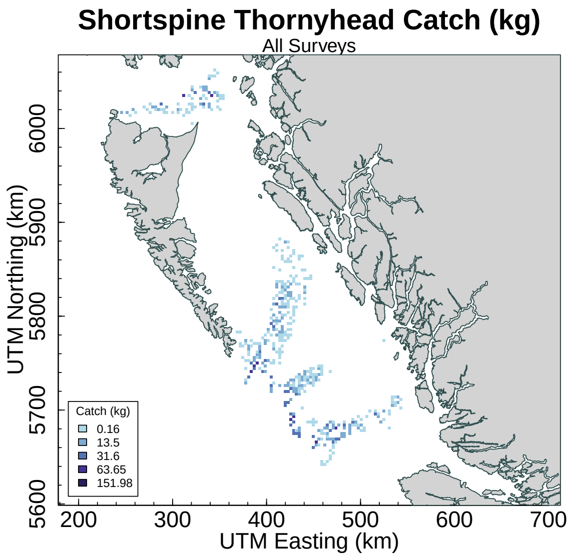
Other important prey of shortspine thornyheads include crabs, zooplankton, amphipods, gastropods, sculpins (family Cottidae) and Capelin *Mallotus villosus* (Yang and Nelson, 1999).

A.17.3 ENVIRONMENT

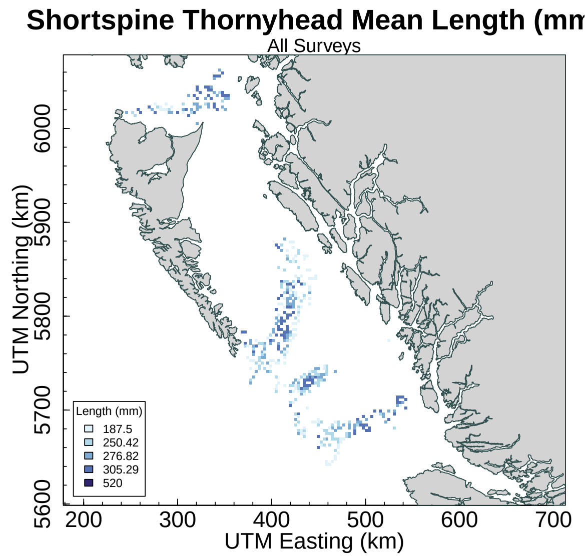
A.17.4 OTHER SPECIES

Shortspine Thornyhead distribute themselves evenly across their habitat and appear to prefer minimal intra-specific interactions.

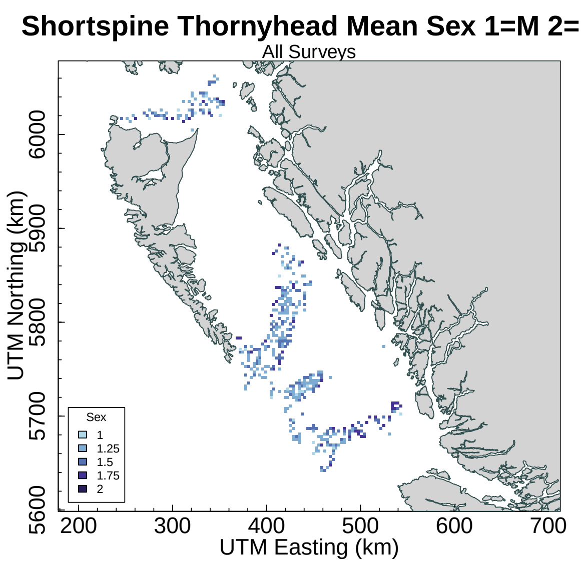
A.17.5 FIGURES



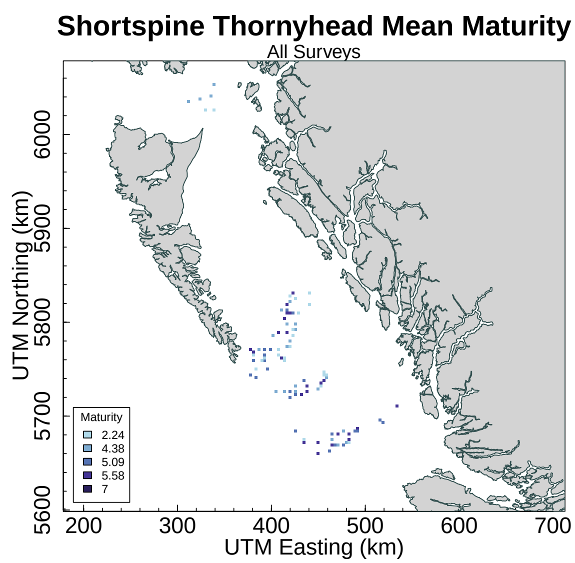
(a) Mean survey catch (kg) of Shortspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Shortspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

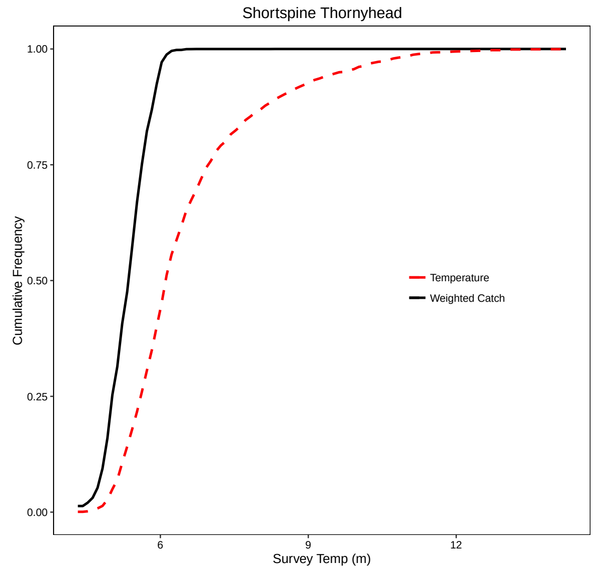


(c) Mean survey fish sex of Shortspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Shortspine Thornyhead in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.35. Summary of Shortspine Thornyhead data. The shaded cells give an approximation of the area where Shortspine Thornyhead was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) (b)

Figure A.36. Cumulative frequency distributions of habitat variables and Shortspine Thornyhead catch-weighted data for all groundfish trawls surveys for all years.

A.18 WIDOW ROCKFISH

A.18.1 LIFE HISTORY

Widow Rockfish occur from Baja California to southeast Alaska. They are found at depths of 90 to 365 m (McAllister and Westrheim, 1965). They are found in midwater above rocky reefs or steep shorelines and will hide among caves and crevices (Lamb and Edgell, 1986).

Along the coast of Oregon young are produced predominantly during January and February (Hitz, 1962; Phillips, 1964).

Oregon data indicates that mating occurs mainly in December with fertilization taking place during January. Gestation lasts 1 to 3 months and spawning occurs once annually (Moser, 1967; Bars and Echeverria, 1987). In BC April is when most parturition occurs (Westrheim, 1975). Young can be found in shallow water (Eschmeyer et al., 1983).

Adults are sometimes solitary but they generally form large schools (Love et al., 2002).

A.18.2 PREDATORS AND PREY

No predators were found within the literature but it is assumed they are similar to other mid-water rockfish species.

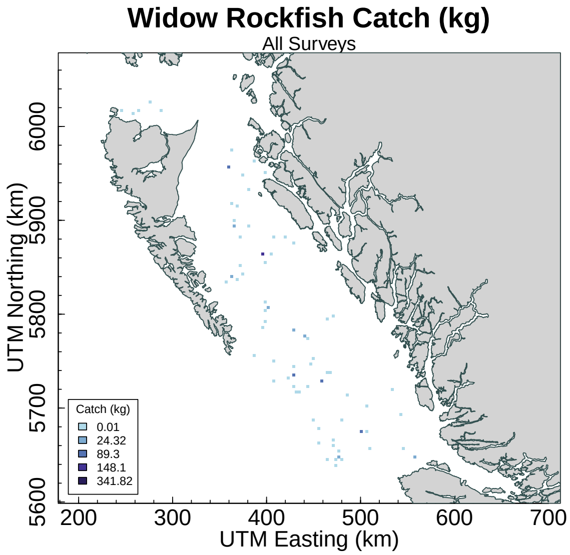
Widow Rockfish have been observed to mainly feed on plankton in California and smallfin lanternfish (*Benthosema suborbitale*) in Oregon (Westrheim, 1975; Peyrera et al., 1983). Eschmeyer et al. (1983) state that they feed predominantly on small pelagic crustaceans and fishes.

A.18.3 ENVIRONMENT

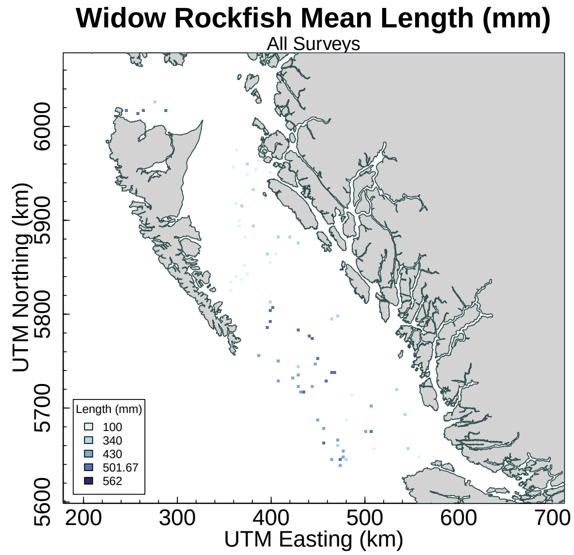
A.18.4 OTHER SPECIES

Adults associate with Yellowtail Rockfish (*Sebastes flavidus*), and in the northern part of their range, Dusky Rockfish *Sebastes ciliatus* (Love et al., 2002).

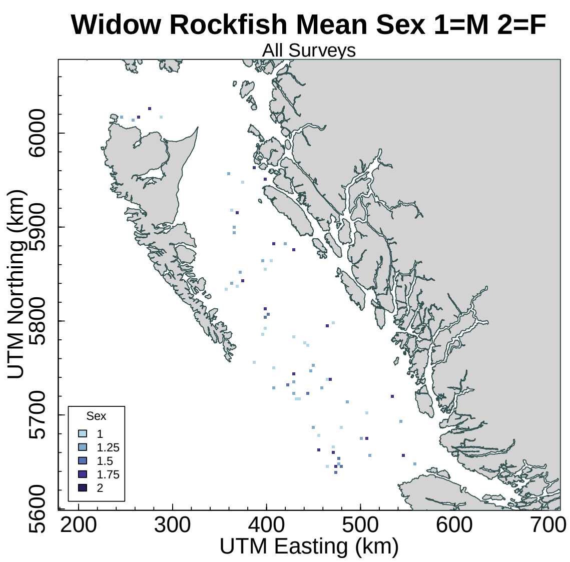
A.18.5 FIGURES



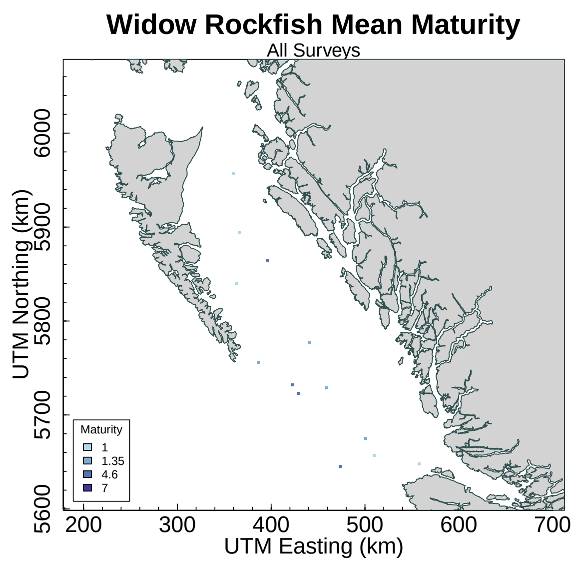
(a) Mean survey catch (kg) of Widow Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Widow Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



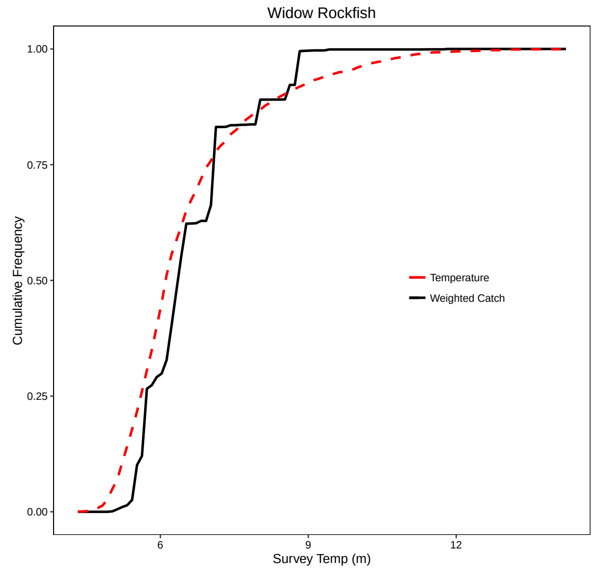
(c) Mean survey fish sex of Widow Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Widow Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.37. Summary of Widow Rockfish data. The shaded cells give an approximation of the area where Widow Rockfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.

(a)



(b)

Figure A.38. Cumulative frequency distributions of habitat variables and Widow Rockfish catch-weighted data for all groundfish trawls surveys for all years.

A.19 YELLOWMOUTH ROCKFISH

A.19.1 LIFE HISTORY

Yellowmouth Rockfish occur from northern California to northern Gulf of Alaska with a depth range of 100 to 431 m (Love et al., 2002). They are predominantly between 274 and 366 m (Kramer and O'Connell, 1995). Adults aggregate at mid-water over high rugosity habitat (Love et al., 2002). There are also density 'hotspots' off the southwest coast of Haida Gwaii (near Cape St. James), off Rennell Sound, off the northwest coast of Haida Gwaii, and off the northwest coast of Vancouver Island. Densities of YMR appear to be low off the west coast of Vancouver Island south of Brooks Peninsula (Edwards et al., 2012*a*).

In BC larvae are released from April to June and parturition peaks in May in (Hart, 1973; Westrheim, 1975; Haigh and Starr, 2008). Pelagic juveniles have been caught in June and July along the Oregon coast (Love et al., 2002).

They can live up to 99 years of age with a maximum length of 54 cm (Love et al., 2002). Fish from northern BC tend to grow more slowly than those from southern end of the province (Love et al., 2002).

A.19.2 PREDATORS AND PREY

No information on predation on Yellowmouth Rockfish is currently available. Juveniles of similar rockfish species (e.g. Darkblotched Rockfish, *Sebastes crameri*) are preyed upon by Pacific Hake in US waters (Harvey et al., 2008) and comprise a significant portion of seabird and Chinook Salmon diets in California (Mills et al., 2007).

Information on Yellowmouth Rockfish prey is also lacking. Similar to other rockfish species, Yellowmouth Rockfish larvae likely feed on copepods, euphasiids and other invertebrates (Enticknap and Sheard, 2005). As rockfish mature they switch to fish and crustacean prey which includes Pacific Herring, Sandlance, crabs, shrimps and euphasiids (Fort et al., 2006).

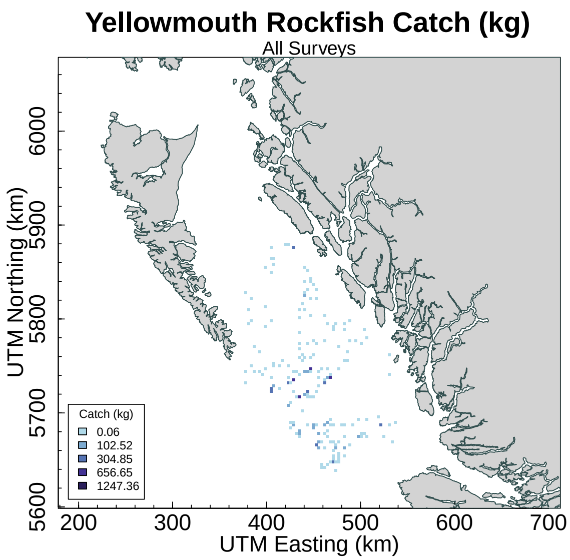
A.19.3 ENVIRONMENT

Similar to other rockfish species, Yellowmouth Rockfish are small (4 to 9 mm) at birth and are weak swimmers (Wourms, 1991). Therefore, survival is strongly affected by environmental factors, such as upwelling events and ocean currents (Shanks and Eckert, 2005). It is estimated that exceptional recruitment occurs every 15 to 20 years in BC (Yamanaka and Lacko, 2001). DFO research and fishery data indicate that 1982 was a particularly strong recruitment year for Yellowmouth Rockfish (Haigh and Starr, 2008).

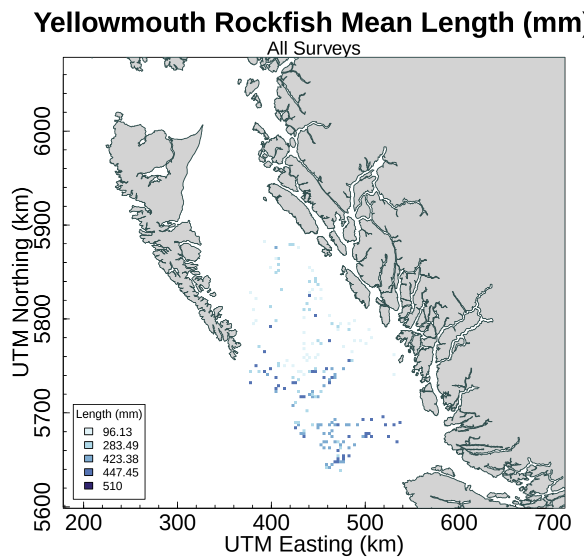
A.19.4 OTHER SPECIES

The depth at which yellowmouth rockfish occurs most frequently is dominated by Pacific Ocean Perch with a substantial presence of Arrowtooth Flounder Redstripe Rockfish Silvergray Rockfish and yellowtail rockfish (*S. flavidus*).

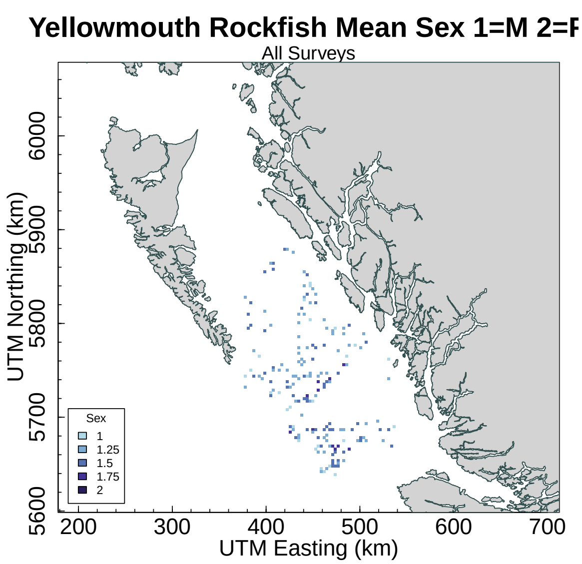
A.19.5 FIGURES



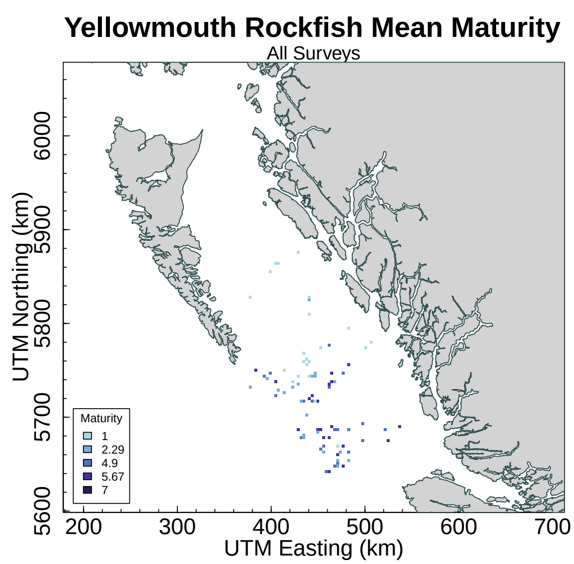
(a) Mean survey catch (kg) of Yellowmouth Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.



(b) Mean survey fish length (mm) of Yellowmouth Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

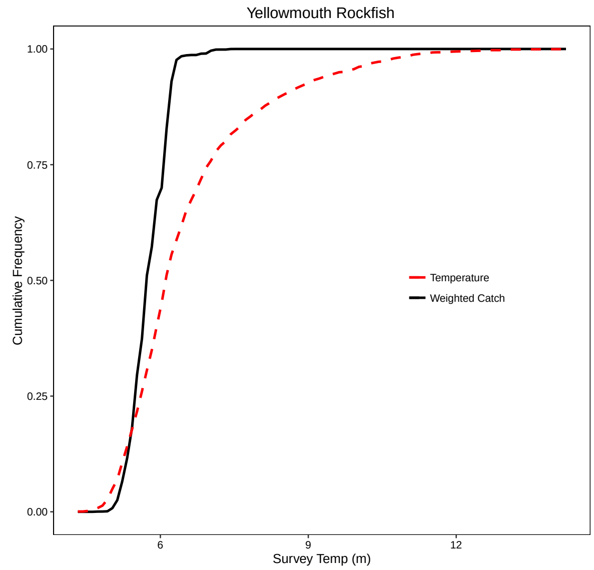


(c) Mean survey fish sex of Yellowmouth Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years. Classified as 1 for male and 2 for female.



(d) Mean survey fish maturity (scored from 0 to 7) of Yellowmouth Rockfish in grid cells 3 km x 3 km for fishing events from all groundfish trawl surveys for all years.

Figure A.39. Summary of Yellowmouth Rockfish data. The shaded cells give an approximation of the area where Yellowmouth Rockfish was encountered by fishing events from all groundfish trawl surveys for all years. See Table XX for a list of surveys.



(a) (b)

Figure A.40. Cumulative frequency distributions of habitat variables and Yellowmouth Rockfish catch-weighted data for all groundfish trawls surveys for all years.

B WEIGHTING OF AGE PROPORTIONS

This appendix summarizes a method for representing commercial and survey age structures for a given species through weighting observed age frequencies x_a or proportions x'_a by catch||density in defined strata. The methodology presented in this appendix is based on that presented by Holt et al. (2014) for Rock Sole.

Ideally, sampling effort would be proportional to the amount of the species caught, but this is not usually the case. Therefore, the stratified weighting scheme presented below attempts to adjust for unequal sampling effort among strata. For commercial samples, strata comprise quarterly periods within a year, while for survey samples, the strata are defined by longitude, latitude, and depth. Within each stratum, commercial ages are weighted by the catch weight (kg) of the species in tows that were sampled, and survey ages are weighted by the catch density (kg/km^2) of the species in sampled tows. A second weighting is then applied: quarterly commercial ages are weighted by the commercial catch weight of the species from all tows within each quarter; stratum survey ages are weighted by stratum areas (km^2) in the survey. Throughout this section, we use the symbol '||' to delimit parallel values for commercial and survey analyses, respectively, as the mechanics of the weighting procedure are similar for both.

For simplicity we illustrate the weighting of age frequencies x_a, unless otherwise specified. The weighting occurs at two levels: h (quarters for commercial ages, strata for survey ages) and i (years if commercial, surveys in series if survey). Notation is summarised in Table B.1.

*Table B.1. Equations for weighting age frequencies or proportions for Arrowtooth Flounder. (**c**) = commercial, (**s**) = survey*

Symbol	Description
	Indices
a	age class (1 to A, where A is an accumulator age-class)
d	(**c**) trip IDs as sample units
	(**s**) sample IDs as sample units
h	(**c**) quarters (1 to 4), 91.5 days each
	(**s**) strata (area-depth combinations)
i	(**c**) calendar years (1977 to present)
	(**s**) survey IDs in survey series (e.g., QCS Synoptic)
	Data
x_{adhi}	observations-at-age a for sample unit d in quarter||stratum h of year||survey i
x'_{adhi}	proportion-at-age a for sample unit d in quarter||stratum h of year||survey i
C_{dhi}	(**c**) commercial catch (kg) of a given species for sample unit d in quarter h of year i
	(**s**) density (kg/km^2) of a given species for sample unit d in stratum h of survey i
C'_{dhi}	C_{dhi} as a proportion of total catch||density $C_{hi} = \sum_d C_{dhi}$
y_{ahi}	weighted age frequencies at age a in quarter||stratum h of year||survey i
K_{hi}	(**c**) total commercial catch (kg) of species in quarter h of year i
	(**s**) stratum area (km^2) of stratum h in survey i
K'_{hi}	K_{hi} as a proportion of total catch||area $K_i = \sum_h K_{hi}$
p_{ai}	weighted frequencies at age a in year||survey i
p'_{ai}	weighted proportions at age a in year||survey i

For each quarter||stratum h we weight sample unit frequencies x_{ad} by sample unit catch||density of the assessment species. For commercial ages, we use trip as the sample unit, though at times one trip may contain multiple samples. In these instances, multiple samples from a single trip will be merged into a single sample unit. Within any quarter||stratum h and year||survey i there is a set of sample catches||densities C_{dhi} that can be transformed into a set of proportions:

$$C'_{dhi} = \frac{C_{dhi}}{\sum_d C_{dhi}} \ . \tag{B.1}$$

The proportion C'_{dhi} is used to weight the age frequencies x_{adhi} summed over d, which yields weighted age frequencies by quarter||stratum for each year||survey:

$$y_{ahi} = \sum_d \left(C'_{dhi} x_{adhi} \right) \ . \tag{B.2}$$

This transformation reduces the frequencies x from the originals, and so we rescale (multiply) y_{ahi} by the factor

$$\frac{\sum_a x_{ahi}}{\sum_a y_{ahi}} \tag{B.3}$$

to retain the original number of observations.

At the second level of stratification by year||survey i, we calculate the the annual proportion of quarterly catch (t) for commercial ages or the survey proportion of stratum areas (km^2) for survey ages

$$K'_{hi} = \frac{K_{hi}}{\sum_h K_{hi}} \tag{B.4}$$

to weight y_{ahi} and derive weighted age frequencies by year||survey:

$$p_{ai} = \sum_h \left(K'_{hi} y_{ahi} \right) \ . \tag{B.5}$$

Again, if this transformation is applied to frequencies, it reduces them from the original, and so we rescale (multiply) p_{ai} by the factor

$$\frac{\sum_a y_{ai}}{\sum_a p_{ai}} \ . \tag{B.6}$$

to retain the original number of observations.

Finally, we standardise the weighted frequencies to represent proportions-at-age:

$$p'_{ai} = \frac{p_{ai}}{\sum_a p_{ai}} \ . \tag{B.7}$$

If initially we had used proportions x'_{adhi} instead of frequencies x_{adhi} , the final standardisation would not be necessary. However, its application does not affect the outcome.

The choice of data input (frequencies x *vs*. proportions x') can sometimes matter: the numeric outcome can be very different, especially if the input samples comprise few observations. Theoretically, weighting frequencies emphasises our belief in individual observations at specific ages while weighting proportions emphasises our belief in sampled age distributions. Neither method yields inherently better results. However, if the original sampling methodology favoured sampling few fish from many tows rather than sampling many fish from few tows, then weighting frequencies probably makes more sense than weighting proportions. In this assessment, we weight age frequencies x.