FATE Proposal Cover Sheet

1. Title: **Investigating petrale sole recruitment mechanisms via larval transport: insights into population connectivity**
2. Principal Investigator: Dr. Melissa Haltuch[1]
3. Principal Investigator Institution: [1] NWFSC, Fisheries Research Analysis and Monitoring
4. Associated NMFS Fisheries Science Center: NWFSC, FRAMD
5. Research Priority: 1, 2, 4, and 6; this project provides the groundwork to meet the goals of research priority 5.
6. Project Duration: 2 years
7. Total Funding Request: $137,716
8. Year 1 Request (*all institutions*): $83,864
9. Year 2 Request (*all institutions*): $53,852
10. Lead NMFS Investigator: Dr. Melissa Haltuch
11. Lead NMFS Investigator organization: NWFSC/FRAM
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19. List institutional breakdown of Year 1 budget:
    Rutgers Total $54,790
    CINAR (U of Concepcion) Total $26,774
    NWFSC Total $2,300
20. List institutional breakdown of Year 2 budget:
    Rutgers Total $2,520
    CINAR (U of Concepcion) Total $49,332
    NWFSC Total $2,000

Background

Petrale sole (Family: *Pleuronectidae*, *Eopsetta jordani*) is the most commercially valuable flatfish targeted in the California Current (CC). By the 1980s to 2000s the spawning biomass reached minimums around or below 10% of unexploited levels, in part due to fishery targeting of winter (November–February) spawning aggregations (Haltuch et al. 2013). Recently, the spawning stock biomass, and therefore fishery catch, has fluctuated in response to above average recruitments followed by a lack of incoming recruits (Figure 1), with the fishery essentially depending on incoming recruits to remain at or near the target stock size (Haltuch et al. 2013).

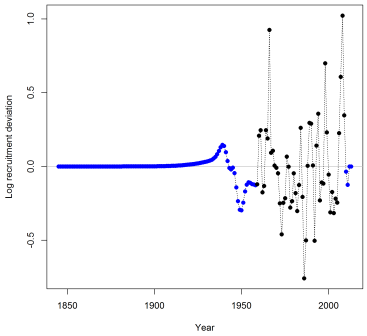

Figure 1. Log recruitment deviations from the 2013 stock assessment (Haltuch et al. 20013). Blue points represent time periods with little data and black points have length and age composition data to inform recruitment estimates.

Petrale sole prefer soft substrates at depths up to 550 m (Love 1996, Haltuch et al. 2013). Adults move inshore during the spring and summer to feeding grounds and offshore during the fall and winter to discrete deep water spawning grounds, with peak spawning taking place from December to February (Harry 1959, Best 1960, Gregory and Jow 1976, Garrison and Miller 1982, MBC Appl. Environ. Sci. 1987, Horton 1989, Love 1996, Castillo et al. 1993, Castillo 1995, Love 1996, Moser 1996, Casillas et al. 1998) (Figure 2). Tagging studies suggest high site fidelity (Di Donato and Pasquale 1970, Pederson 1975).

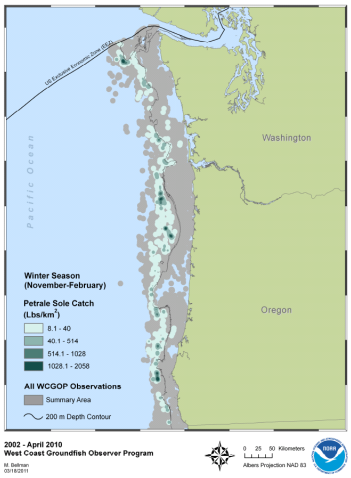

Figure 2. The 2002-2010 spatial distribution of winter petrale sole catch (lbs/km2) off of WA and OR. Dark green areas indicate localized fishing grounds.

Females spawn once each year and fecundity varies with fish size, with one large female laying as many as 1.5 million planktonic eggs (Porter 1964). Eggs are found in deep water at temperatures of 4 to 10 degrees C and salinities of 25 to 30 ppt, size ranges from 1.2 to 1.3 mm (Best 1960, Ketchen and Forrester 1966, Alderdice and Forrester 1971, Gregory and Jow 1976). Egg stage duration ranges from 6 to 14 days (Alderdice and Forrester 1971, Love 1996, Casillas et al. 1998) with the most favorable conditions for egg incubation and larval growth being 6–7 degrees C and 27.5–29.5 ppt (Ketchen and Forrester 1966, Alderdice and Forrester 1971, Castillo et al., 1995). Planktonic petrale sole larvae range in size from approximately 3 to 20 mm, and are found up to 150 km offshore (Moser 1996, MBS Appl. Env. Sci 198, Casillas et al. 1998). The larval duration, including the egg stage, spans approximately 6 months with larvae settling at about 2.2 cm in length on the inner continental shelf (Pearcy et al. 1977). While there is limited information regarding larval petrale sole vertical migration, species in the *Pleuronectidae* family exhibit diel vertical migration, generally within the upper 50 m of the water column, as well as horizontal swim speeds that increase with larval growth (Verheijen and DeGroot 1966, Pearcy et al. 1977, Hoar and Randall 1978, Fukuhara 1988, Grioche et al. 2000, Lanksbury et al. 2007,

Bailey et al. 2008, Domenici and Kapoor 2010, Hoffle et al. 2013). In the waters off British Columbia juveniles are found at 19–82 m and large juveniles at 25–125 m (Starr and Fargo 2004). Juveniles are benthic and found on sandy or sand-mud bottoms (Eschmeyer and Herald 1983; MBS Appl. Environ. Sci. 1987). While, no specific areas have been identified as nursery grounds for juvenile petrale sole beyond soft substrate areas on the continental shelf, these nursery areas are spatially distinct from the deep water spawning areas.

The recent emergence of a horizontal-advection bottom-up forcing paradigm, in which large-scale climate forcing drives regional changes in alongshore and cross-shelf ocean transport that directly impact ecosystem functions (e.g., productivity, species composition, spatial connectivity) (Di Lorenzo et al. 2013), provides a mechanistic framework for testing the hypothesis that cross-shelf and alongshore advection are drivers of petrale sole recruitment strength. This paradigm provides mechanistic pathways through which climate variability and change could drive petrale sole recruitment. **Specifically, this proposal tests the hypothesis that cross-shelf transport of pelagic petrale sole from deep water spawning grounds shoreward towards nursery areas on the continental shelf results in stronger recruitments than transport off-shore away from nursery areas.** Previous research supports this hypothesis, suggesting that density-independent survival during early life stages is impacted by offshore transport of eggs and larvae (Castillo 1992; Castillo et al. 1995). Furthermore, decadal scale variability in wind driven changes in cross-shelf transport of pelagic life stages of other flatfish species towards favorable nursery areas have been shown to impact recruitment strength (Hollowed et al. 2009, Wilderbuer et al. 2014). Variability in cross-shelf transport in the CC is important for understanding population and ecosystem dynamics because of variable offshore and northward transport of nutrients, mass, and organisms (Combes et al. 2013, Di Lorenzo 2013). Waters from the poleward flowing California Undercurrent can be either coastally upwelled or advected offshore, likely impacting fish life cycles via transport of larvae and by altering connectivity patterns (Combes et al. 2013, Di Lorenzo 2013).

Recent oceanographic studies illustrate the influence of large scale climate drivers, such as the Pacific Decadal Oscillation (PDO), on mesoscale processes in the CC that drive cross-shelf and alongshore transport at local scales (Keister et al. 2011, Combes et al. 2013). Keister et al. (2011) show a direct mechanistic link between PDO-related changes in horizontal surface advection and multiyear variability in zooplankton communities. During the positive PDO phase the Aleutian Low is stronger and the Northeast Pacific is characterized by downwelling wind anomalies that drive positive sea level height anomalies (Di Lorenzo et al. 2013). These higher SSH anomalies lead to anomalies in the poleward flow of the California Under Current (Combes et al. 2013, Di Lorenzo et al.2013).

This proposal provides a mechanistic test of the horizontal-advection bottom-up forcing paradigm (Di Lorenzo et al. 2013) for petrale sole by linking the winter commercial spawning aggregation fishery data with a biophysical individual-based model (IBM) driven by ROMS to determine how cross-shelf and alongshore transport of petrale sole pelagic life states from spawning grounds to benthic settlement on the continental shelf drives recruitment (e.g. Gaughan et al. 2001, Dorman et al.2011, Keister et al. 2013). Petrale sole are an excellent candidate for mechanistic investigations into oceanographic drivers of recruitment strength because 1) the petrale sole data available for the CC are likely the most information-rich groundfish data set/stock assessment due to the large amount of age and length data that spans multiple generations (compared <1 generation for most CC rockfishes), 2) petrale sole spawn in known, localized locations during winter, 3) the stock assessment model, and thus recruitment estimates,

is one of the most stable CC groundfish assessment models, 4) both previous fisheries and oceanographic research suggests a clear mechanism for oceanographic drivers of petrale sole recruitment, but a mechanistic test of this hypothesis has not been conducted.

Approach

This study will build an IBM of larval drift (e.g. Parada et al. 2010, Parada et al. 2014, Hinckley et al. 2015) for CC petrale sole, allowing for the determination of the direction of larval drift from discrete spawning grounds off the U.S. west coast for the years 1990-2009, as well as record larval oceanographic histories. **The IBM will enable the theoretical determination of which spawning grounds most greatly contribute to recruitment success via on-shelf transport as well as the variability of recruitment success through time.** The center of spawning success will be evaluated to identify potential changes in phenology during the study time period. The years 1990-2009 encompass years with both high and low recruitments that are well estimated in the stock assessment as well as a range of environmental conditions, including both El Niño and La Niña years and both positive and negative phases of the PDO and North Pacific Gyre Oscillation (NPGO). The IBM is forced by annually varying ROMS hydrodynamic model with output for the CC (Curchitser et al. 2005, Hermann et al. 2009, Danielson et al. 2011). A time series (1950-2009) of ROMS model output on both ~10 km and 2 km grids (NEP) are currently available. **Oceanographic outputs from the ROMS model will be validated with physical oceanographic data collected during the NWFSC Pacific hake acoustic survey, including temperature, salinity, currents, as these data are not used in the ROMs model.** With a few exceptions, due to equipment failure or survey conflicts, data are available for survey years during 1992 to 2015. The coupled IBM-ROMS model will inform the transport dynamics of petrale sole during their pelagic life stages, allowing for the impacts of variability in cross-shelf and alongshore transport in the CC to be quantified (e.g. Combes et al. 2013). Combes et al. (2013) found that 10 km ROMS models were able to capture both the mean large-scale features of the mesoscale activity, which influences cross-shelf transport, and the subsurface poleward flow in the CC which is likely to be important for petrale sole pelagic transport.

Spatial locations for release of larvae will be derived from the commercial spawning aggregation fishery logbook data stored in the Pacific Fisheries Information Network (PacFIN). Fishery spawning aggregation data will provide mature female distribution that allows for the generation of spatially-explicit reproductive potential indices. The reproductive potential indices will be generated as a function of female fecundity, female abundance (Haltuch et al. 2013), and size-at-maturity (Hannah et al 2002). The CC will be spatially discretized into strata for larval release areas and settlement areas. Larval petrale sole will be released on the winter spawning grounds during November through February and transport will be followed through the larval stages to settlement (May-August). Individual larvae will be released at the spawning depth and rise to the mixed layer where they are likely to be retained. Egg development, larval growth, mortality, settlement behavior will be specified based on existing literature (see introduction). Alternative hypotheses regarding active behaviors will be compared to examine the impact on transport.

Temperature dependent growth through the larval stages will be modeled, as well as settlement mechanisms. Settlement habitat will be defined based on maps of sediment types available for the CC (Henkel et al, In Press), with a preference for soft substrates. The model will increase the mortality rate on individuals that settle on non-preferred, off-shelf or rocky, habitat. Settlement criteria will be specified such that larva that do not find appropriate settlement habitat within 6 months after being spawned die.

The IBM output will consist of larval release locations, daily locations (i.e. larval spatial trajectories), individual characteristics such as age and stage, oceanographic conditions and settlement location (from which distance from shore, water depth, and transport compass direction between start and end points will be computed). Each model run will be characterized by the spawning and settlement season that runs from November of year 1 through August of year 2. **Juvenile petrale sole settlement distributions from the coupled IBM-ROMS model will be validated using statistical techniques that contrast the spatio-temporal consistency of the model output (Hinckley et al. 2015) with both 1) maps of the smallest sizes of petrale sole encountered in the NWFSC annual groundfish survey (Keller at al. 2007) (~10-20 cm juveniles) available from 2003-2014 and 2) maps of the distribution and abundance of small petrale sole in the NWFSC survey data produced via a spatial habitat model (Shelton 2014), that can account for environmental covariates such as latitude and depth.** Transport from the winter deep water spawning grounds will be summarized using maps of the distribution of settlers each year, which will be discretized in space and calculated as fish density on the same scale as the ROMS model. This settlement index will be contrasted with stock assessment recruitment estimates for the corresponding year to check for the consistency of the IBM modelling results. Connectivity maps will be used to define the potential areas of spawning success and failure in the CC. Empirical Orthogonal Function (EOF) analysis will be used to understand the modes of variability over the connectivity matrices across varying time and space scales. EOF analysis aids in understanding spawning-nursery ground connections. The EOFs will be spatially correlated with climate/oceanographic indices to describe the spatial impact of environmental drivers (Parada, 2015). Additionally, each model run will be summarized by the monthly and seasonal spatial mean and anomalies of the transported petrale sole. Following Combes et al. (2013) transects at increasing distance from the coast will be specified and the time series of the amount of pelagic petrale reaching each transect will be computed to investigate upwelling as an indicator of the amount of cross-shelf transport.

A change point analysis (Lanzante, 1996) will be used to identify concurrent shifts through time in oceanographic covariates derived from the coupled IBM-ROMs model, the estimates of petrale sole recruitment from the most recent stock assessment (Stawitz et al. 2015), and a standardized index of the smallest fish from the NWFSC survey data. Each season will be characterized as an El Niño, LA Niña, or average years as well as negative or positive PDO and NPGO phases for the purposes of analyzing the resulting simulated settlements. A Principle Component Analysis (PCA) of the oceanographic histories of petrale sole larvae from the IBM, ENSO, PDO, and NPGO will be used as a data reduction technique to create a recruitment index that can be evaluated in the stock assessment model. The impact of oceanographic covariate(s) from the PCA on recruitment and stock trajectory will be evaluated prior to the next petrale sole stock assessment (Haltuch et al. 2013, Stawitz et al. 2015). Evaluation of the impact of oceanographic covariate(s) within the stock assessment model will include two methods 1) treating the oceanographic covariate(s) as a survey index of recruitment, and 2) forcing the stock-recruitment dynamics directly with the oceanographic covariate(s). Models with and without the oceanographic covariate(s) will be evaluated based on their ability to fit the data. The impact and feasibility of using oceanographic covariate(s) to provide both historical and short-term forward projections of recruitment strength will be evaluated via model sensitivity runs. The implication of alternative models with and without the oceanographic drivers on management reference points will be quantified.

Benefits

This study leverages an information rich data set/stock assessment for the CC petrale sole stock to provide a mechanistic framework for investigating oceanographic influences, specifically the impact of cross-shelf and alongshore ocean transport on petrale sole recruitment strength and population connectivity, thus directly informing the stock assessment used by the management process as well as ecosystem models (e.g. Atlantis), assessments, and reports that directly use stock assessment outputs (FATE priorities 1, 2, 4, 6). Indices of oceanographic drivers of petrale sole recruitment derived from the coupled IBM-ROMS model will be directly evaluated in the stock assessment (FATE priority 6).

There is little information regarding the dispersal and connectivity of petrale sole pelagic life stages to the settled benthic juveniles. While petrale sole are widely distributed, this study provides an assessment of the connectivity and spatial scale over which petrale sole life-history operates via the investigation of pelagic dynamics and climate variability, and will aid in determining the spatial scales over which recruitment takes place and thus population dynamics (FATE priorities 1, 4). Therefore, this study is relevant for protecting both the temporal and spatial reproductive potential of the stock from overfishing. Investigating the spatial component of interplay between population connectivity and recruitment is important for addressing demographic questions such as 1) are successful recruitments always from the same spawning grounds, and 2) are the spawning grounds that contribute the most to the adult stock shifting over time. Answering the above questions is important for the spatial allocation of fishing effort. If individual fishing grounds are contributing disproportionately to the stock abundance (measured as juveniles successfully settled) then fishing effort in areas that contribute the most to stock abundance must be carefully monitored (e.g. Gaughan et al. 2001). This is particularly important as petrale sole show the ability to home to their natal spawning grounds (Haltuch et al. 2013) and the spatial impacts of a single, region wide-fishing mortality need to be considered to avoid localized depletion.

This study addresses the first and second steps for a unified approach to forecasting the implications of climate change on production of marine fish as outlined in Hollowed et al (2009) (FATE priority 1). This proposal also lays the groundwork necessary to hindcast petrale sole recruitment strengths where there is great uncertainty in the stock assessment model due to either a total lack of age and length composition data, or where the data are sparse. Hindcasting recruitments is of particular interest because most of the fishery removals took place prior to the collection of good age and length composition data, resulting in greater uncertainty during early model years. Oceanographic indices identified during this study (FATE priorities 1, 2) could be used as a survey index of recruitment in the stock assessment during the historical time period.

Deliverables

1. Spatial analysis of particle (pelagic petrale) transport in the CC, and population connectivity, so that managers can consider the stock wide impacts of the commercial spawning aggregation fishery.
2. Analyses of temporal oceanographic transport indicators for successfully settled petrale larvae to identify an oceanographic index of petrale sole recruitment for incorporation into both the stock assessment as well as the CC Integrated Ecosystem Assessment.
3. Publication of results from this study in peer reviewed scientific journals.
4. Presentations to the Pacific Fishery Management Council Advisory Bodies and at professional conferences.

References

Alderdice, D.F., and C.R. Forrester. 1971. Effects of salinity and temperature on embryonic development of the petrale sole (Eopsetta jordani). J. Fish. Res. Bd. Canada 28:727-744.

Bailey, K.M., Abookire, A.A., Duffy-Anderson, J.T. 2008. Ocean transport paths for the early life history stages of offshore-spawning flatfishes: a case study in the Gulf of Alaska. Fish and Fisher. 9: 44–66.

Best, E.A. 1960. Petrale Sole. In: California ocean fisheries resources to the year 1960, p 58-60. California Department of Fish and Game. 79 p.

Casillas, E., L. Crockett, Y. deReynier, J. Glock, M. Helvey, B. Meyer, C. Schmitt, M. Yoklavich, A. Bailey, B. Chao, B. Johnson, and T. Pepperell. 1998. Essential Fish Habitat West Coast Groundfish Appendix, National Marine Fisheries Service, Seattle, Washington. Located at website http://www.nwr.noaa.gov/1sustfsh/efhappendix/page1.html

Castillo, G.C. 1995. Latitudinal patterns in reproductive life history traits of northeast Pacific flatfish. In: Proceedings of the International Symposium on North Pacific Flatfish, p 51-72. Alaska Sea Grant College Program, Fairbanks, Alaska.

Castillo, G.C., H.W. Li, and J.T. Golden. 1993. Environmental induced recruitment variation in petrale sole, Eopsetta jordani. Fisheries Bulletin 92:481-493.

Castillo, G.C. 1992. Fluctuations of year-class strength of petrale sole (Eopsetta jordani) and their relation to environmental factors. M.S. thesis, Oregon State University. 99 p.

Castillo, G.C., J.T. Golden, H.W. Li. 1995. Variations in relative abundance and year-class strength of petrale sole off Oregon and Washington. Proceedings of the International Symposium On North Pacific Flatfish, Alaska Sea Grant AK-SG-95-04.

Combes, V., Chenillat, F., Di Lorenzo, E., Rivière, P., Ohmane, M.D., Bograd, S.J. 2013. Cross-shore transport variability in the California Current: Ekman upwelling vs. eddy dynamics. Prog. Ocean. 109: 78–89.

Curchitser, E.N., D.B. Haidvogel, A.J. Hermann, E. Dobbins, T.M. Powell and A. Kaplan, 2005. Multi-scale modeling of the North Pacific Ocean: Assessment of simulated basin-scale Vari- ability (1996-2003). J. Gophys. Res., 110, C11021, doi:101029/2005JC002902.

Danielson, S., E. Curchitser, K. Hedstrom, T. Weingartner, and P. Stabeno, 2011. On ocean and sea ice modes of variability in the Bering Sea. J. Geophys. Res., 116, C12034, doi:10.1029/2011JC007389.

DiDonato, G. and N. Pasquale. 1970. Migration of petrale sole tagged in deep water off the Washington coast. Wash. Dept. Fish. Res. Pap. 3:53-61.

Di Lorenzo, E., Mountain, D., Batchelder, H.P., Bond, N., and Hofmann, E.E. 2013. Advances in marine ecosystem dynamics from US GLOBEC: The horizontal-advection bottom-up forcing paradigm. *Oceanography* 26(4):22–33, http://dx.doi.org/10.5670/oceanog.2013.73.

Domenici, P., and B.G. Kapoor. 2010. Fish Locomotion: An Eco-ethological Perspective. CRC Press, Taylor and Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487.

Dorman, J. G., T. M. Powell, W. J. Sydeman, and S. J. Bograd. 2011. Advection and starvation cause krill (Euphausia pacifica) decreases in 2005 Northern California coastal

populations: Implications from a model study, Geophys. Res. Lett., 38, L04605, doi: 10.1029/2010GL046245.

Eschmeyer, W.N. and E.S. Herald. 1983. A field guide to Pacific coast fishes North America. Houghton Mifflin CO., Boston, MA. 336 p.

Fukuhara, O. 1988. Morphological and functional development of larval and juvenile *Limanda yokohamae* (Pisces: *Pleuronectidae*) reared in the laboratory. Mar. Bio. 99(2):271-281.

Garrison, K.J. and B.S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fisheries Research Institute, School of Fisheries University of Washington, Contract No. 80-ABA-3680, Unpublished report FRI-UW-8216. 729 p.

Gaughan, D. J., White, K. V., and Fletcher, W. J. 2001. The links between functionally distinct adult assemblages of *Sardinops sagax*: larval advection across management boundaries. – ICES J. Mar. Sci. 58: 597–606.

Gregory, P.A. and T. Jow. 1976. The validity of otoliths as indicators of age of petrale sole from California. California Department of Fish and Game 62(2):132-140.

Grioche, A., Harlay X., Koubbi, P., and L.Fraga Lago. 2000. Vertical migrations of fish larvae: Eulerian and Lagrangian observations in the Eastern English Channel. J. Plank. Res. 22(10): 1813-1828. doi: 10.1093/plankt/22.10.1813.

Haltuch, M.A., Ono, K., Valero, J. 2013. Status of the U.S. petrale sole resource in 2013. Pacific Fishery Management Council.

Hannah, R.W., S.J. Parker and E.L. Fruth. 2002. Length and age at maturity of female petrale sole (Eopsetta jordani) determined from samples collected prior to spawning aggregation. U.S. Fish. Bull. 100:711-719.

Harry, G.Y. 1959. Time of spawning, length at maturity, and fecundity of the English, petrale, and dover soles (Parophrys vetulus, Eopsetta jordani, and Mircrostomus pacificus, respectively). Fisheries Commission of Oregon, Research Briefs 7(1):5-13.

Henkel, SK, Goldfinger C, et al. In Press. Survey of Benthic Communities near Potential Renewable Energy Sites Offshore the Pacific Northwest. US Dept. of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region. OCS Study BOEM.

Hermann, A.J., E.N. Curchitser, E.L. Dobbins and D.B. Haidvogel, 2009. A comparison of remote versus local influence of El Nino on the coastal circulation of the Northeast Pacific. Deep-Sea Res. II, doi:10.1016/j.dsr2.2009.02.005.

Hinckley, S., Parada, C., Horne, J., Mazur, M., Woillez, M. 2015. Comparison of individual-based model output to data using a model of walleye pollock early life history in the Gulf of Alaska. Deep Sea Res. II Special Issue GOAIERP. In Press.

Hoar, W.S., and D.J. Randall. 1978. Fish Physiology, Volume VII Locomotion. Academic Press, 111 Fifth Ave, New York, New York, 10003.

Hoffle, H., Nash R.D.M., Falkenhaug, T., and P. Munk. 2013. Differences in vertical and horizontal distribution of fish larvae and zooplankton, related to hydrography. Mar. Biol. Res. 9(7): 629-644.

Hollowed, A. B., Bond, N. A., Wilderbuer, T. K., Stockhausen, W. T., A'mar, Z. T., Beamish, R. J., Overland, J. E., and Schirripa, M. J. 2009. A framework for modelling fish and shellfish responses to future climate change. ICES J. Mar. Sci. 66: 1584–1594.

Horton, H.F. 1989. Species profile: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest). Dover and rock soles. U.S. Fish and Wildlife Service Biological Report 82(11.123), 27 p.

Keister, J.E., E. Di Lorenzo, C.A. Morgan, V. Combes, and W.T. Peterson. 2011. Zooplankton species composition is linked to ocean transport in the Northern California Current. Global Change Biol. 17:2,498–2,511, http://dx.doi.org/10.1111/j.1365-2486.2010.02383.x.

Keller, A.A., V.H. Simon, B.H. Horness, J.R. Wallace, V.J. Tuttle, E.L. Fruh, K.L. Bosley, D.J. Kamikawa, and J.C. Buchanan. 2007. The 2003 U.S. west coast bottom trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U.S. Dept. Commer. NOAA Tech. Memo. NMFS-NWFSC-86, 130p.

Ketchen, K.S. and C.R. Forrester. 1966. Population dynamics of the petrale sole, Eopsetta jordani, in waters off western Canada. Fish. Res. Bd. Canada Bull. 153. 195 p.

Lanksbury, J.A., Duffy-Andreson, J.T., Mier, K.L., Busby, M.S., and P.J. Stabeno. 2007. Distribution and transport patterns of northern rock sole, Lepidopsetta polyxystra, larvae in the southeastern Bering Sea. Prog. Ocean. 72: 39–62.

Lanzante, J. R. (1996). Resistant, robust, and non-parametric techniques for the analysis of climate data: theory and examples, including applications to historical radiosonde station data. Int. J. Climatology. 16: 1197–1226.

Love, M. 1996. Probably More Than You Want To Know About The Fishes Of The Pacific Coast. Really Big Press, Santa Barbara, California, 381 p.

Moser, H.G. (Editor). 1996. The early stages of fishes in the California Current region. California Cooperative Oceanic Fisheries Investigations, Atlas No. 33. Allen Press, Inc., Lawrence, Kansas. 1505 p.

MBC Applied Environmental Sciences. 1987. Ecology of important fisheries species offshore California. U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, Los Angeles, CA. MMS Contract No. 14-12-0001-30294.

Parada, C., D.A. Armstrong, B. Ernst, S. Hinckley, J.M. Orensanz. 2010. Spatial dynamics of snow crab (*Chionoecetes opilio*) in the eastern Bering Sea – putting together the pieces of the puzzle. Bull. Mar. Sci. 86(2):413-437.

Parada, C., B. Ernst, S. Hinckley, J.M. Orensanz, D.A. Armstrong, E.N. Curchitser and A.J. Hermann. 2014. Patterns of connectivity and potential settlement regions of snow crab (Chionoecetes opilio) larvae in the eastern Bering Sea. Accepted. Prog. Ocean.

Parada, C. 2015. Unpublished results. University of Concepcion, Concepcion, Chile.

Pearcy, W.G., M.J. Hosie, and S.L. Richardson. 1977. Distribution and duration of pelagic life of larvae of Dover sole, Microstomus pacificus; rex sole, Glyptocephalus zachirus; and petrale sole Eopsetta jordani, in waters off Oregon. Fish. Bull. 75:173-183.

Pedersen, M.G. 1975. Movements and growth of petrale sole (Eopsetta jordani) tagged off Washington and southwest Vancouver Island. Fishery Research Board of Canada Progress Report 32(1):2169-2177.

Porter, P. 1964. Notes on fecundity, spawning, and early life history of petrale sole (Eopsetta jordani), with descriptions of flatfish larvae collected in the Pacific Ocean off Humboldt Bay, California. M.S.thesis, Humboldt State College. 98 p.

Shelton, A.O., Thorson, J.T., Ward, E.J., Feist, B.E. 2014. Spatial semiparametric models improve estimates of species abundance and distribution. Can. J. Fish. Aquat. Sci. doi:10.1139/cjfas-2013-0508.

Starr, P.J. and J. Fargo. 2004. Petrale sole stock assessment for 2003 and recommendations for management in 2004. CSAS Res. Doc. 2004/036. 92 p.

Verheijen, F.J. and S.J. deGroot. 1966. Diurnal activity of plaice and flounder (*Pleuronectidae*) in aquaria. Neth. J. Sea Res. 3: 383-390.

Wilderbuer,T., Stockhausen, W., Bond, N. 2014. Updated analysis of flatfish recruitment response to climate variability and ocean conditions in the Eastern Bering Sea. Deep Sea Res. II. 94: 157-164.