

NPRB GOA-IERP Summary Page

Proposal Title: Exploring temporal and spatial variability in Gulf of Alaska groundfish dynamics with integrated biophysical models

GOA-IERP Component: Ecosystem Modeling

Project Period: Start date: May, 2010 End date: February, 2015

Subaward Recipient(s):

University of Alaska Fairbanks: Gwendolyn (Maggie) Griscavage, Office of Grants and Contracts Administration, University of Alaska Fairbanks, 907-474-6446, gmgriscavage@alaska.edu

NOAA/Alaska Fisheries Science Center: Jennifer Ferdinand, 7600 Sand Point Way NE, Seattle, WA 98115, 206-526-4075, Jennifer.Ferdinand@noaa.gov

University of Washington/JISAO: Lynne Chronister, 4333 Brooklyn Ave E, Seattle, WA 98195, 206-616-3589, lchronis@u.washington.edu

NOAA/Pacific Marine Environmental Laboratory: Cynthia Loitsch, 7600 Sand Point Way NE, Seattle, 98115, 206-526-6236, Cynthia.L.Loitsch@noaa.gov

Principal Investigators & Co-investigators:

PI#1: Georgina Gibson, University of Alaska Fairbanks, ggibson@iarc.uaf.edu

PI#2: Sarah Hinckley, Alaska Fisheries Science Center, sarah.hinckley@noaa.gov

Co-PI#1: William Stockhausen, Alaska Fisheries Science Center, william.stockhausen@noaa.gov

Co-PI#2: Sarah Gaichas, Alaska Fisheries Science Center, sarah.gaichas@noaa.gov

Co-PI#3: Albert Hermann, University of Washington, hermann@u.washington.edu

Co-PI#4: Carolina Parada, University of Washington, carolina.parada@dgeo.udec.cl

Co-PI#5: Carol Ladd, Pacific Marine Environmental Laboratory, carol.ladd@noaa.gov

Co-PI#6: Kenneth Coyle, University of Alaska Fairbanks, coyle@ims.alaska.edu


Summary of Proposed Work: The Gulf of Alaska (GOA) is a dynamic ecosystem which supports important fisheries and the communities dependent on them. Marine fish recruitment is hypothesized by the UTL component to be determined between offshore spawning sites and the end of the YOY stage, the “gauntlet”. Understanding recruitment is central to rational fishery and ecosystem planning. Recruitment is thought to be controlled by physical processes such as climate and transport, and biological processes, such as growth, starvation and predation. We will use the Regional Ocean Modeling System (ROMS) with a fully integrated Nutrient-Phytoplankton-Zooplankton (GOANPZ) model, and five Individual-Based Models (IBMs) to examine recruitment mechanisms and derive indices related to recruitment. We will incorporate the indices in a multispecies model to explore the consequences of recruitment variability on the ecosystem and fishery interactions in the GOA. We will focus on recruitment processes for the five species identified by the UTL project (Moss et al.): arrowtooth flounder, walleye pollock, Pacific cod, Pacific Ocean perch, and sablefish. The models will serve as a tool to integrate the other components of GOA-IERP; we will use information derived from the UTL, MTL, and LTL projects to develop, initialize and validate the models, and we will provide information to the other components. We will use models to address questions important to the program. Indices produced, and conclusions about the effects of

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	Requested	Other Support
University of Alaska	\$ 545,889	\$ 0
Alaska Fisheries Science Center	\$ 35,848	\$ 223,540
University of Washington	\$ 386,639	\$ 0
Pacific Marine Environmental Laboratory	\$ 31,619	\$ 111,901
Total:	\$ 999,995	\$ 335,441

Legally Binding Authorization Signature and Affiliation

Signature:  Date: March 17th 2010
 Georgina Gibson, Lead Principal Investigator
 Post Doctoral Associate, International Arctic Research Center
 University of Alaska Fairbanks

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Project Period: Start date: October 1, 2010

End date: October 31, 2014

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University of Alaska Fairbanks: Gwendolyn (Maggie) Griscavage, Office of Grants and Contracts

Administration, University of Alaska Fairbanks, 907-474-6446, gmgriscavage@alaska.edu

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Instituto de Investigacion Pesquera: Carla Sepulveda, Avda. Cristobal Colon 2780, Talcahuano, Chile, 56(41)2920410 csepulveda@inpesca.cl

Principal Investigators & Co-investigators:

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	Requested	Other Support
University of Alaska	\$ 564,523	\$ 0
Alaska Fisheries Science Center	\$ 34,051	\$ 383,797
University of Washington	\$ 158,640	\$ 0
Pacific Marine Environmental Laboratory	\$ 29,590	\$ 111,901
Instituto de Investigacion Pesquera	\$ 213,194	\$ 0
Total:	\$ 999,999	\$ 495,698

Legally Binding Authorization Signature and Affiliation: *For each agency requesting AND/OR providing matching funds for this project, provide a legally binding authorization signature, affiliation and date of signature. A separate summary page for each agency requesting and/or providing matching funds is necessary. See example below. Also provide one overall summary page signed by the lead Principal Investigator of the overall proposal.*

Example for individual summary pages:

Signature: William Kirk Date: 6-22-2010

Type the Name of legally binding authorize person

Type the title and affiliation of legally binding authorize person

NPRB GOA-IERP Summary Page

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Signature:  Date: 03-22-2010

Lynne Chronister, Executive Director, Sponsored Programs
University of Washington

Grant & Contract Administrator
Office of the Executive Director
University of Washington

ORIGINAL

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Signature: 
Cynthia L. Voitsch, Program Support Officer
NOAA/Pacific Marine Environmental Laboratory

Date: 3/10/2010

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Signature:  _____

Date: 3/22/10

*Andrew Parkerson-Gray
Director, Office of Sponsored Programs
University of Alaska Fairbanks*

RESEARCH PLAN

A. Project Title: Exploring temporal and spatial variability in Gulf of Alaska groundfish dynamics with integrated biophysical models.

B. Proposal Summary: The Gulf of Alaska (GOA) is a dynamic ecosystem which supports important fisheries and the communities dependent on them. Fish recruitment is hypothesized by the upper trophic level (UTL) component to be determined between offshore spawning sites and the end of the young of year (YOY) stage, the so-called “gauntlet”. Understanding recruitment is central to rational fishery and ecosystem planning. Recruitment is thought to be controlled by physical processes (i.e. climate and transport) and biological processes (i.e. growth and predation). We will use the Regional Ocean Modeling System (ROMS), a Nutrient-Phytoplankton-Zooplankton (GOANPZ) model, and five Individual-Based Models (IBMs) to examine recruitment mechanisms and derive indices related to recruitment. We will also incorporate the indices in a multispecies model (MSM) to explore the consequences of recruitment variability on the GOA ecosystem and fisheries. We will focus on recruitment processes for the five species identified by the UTL project (Moss et al.): arrowtooth flounder, walleye pollock, Pacific cod, Pacific Ocean perch, and sablefish. The models will serve as a tool to integrate the other components of GOA-IERP; Information from the UTL, middle trophic level (MTL), and lower trophic level (LTL) projects will be used to develop, initialize and validate the models. We will use models to address questions important to the program. Indices produced, and conclusions about the effects of physical and biological processes on the GOA ecosystem under different physical regimes will aid in the management of these important fish stocks.

C. Soundness of Project Design and Conceptual Approach

1a. Objectives: The objective of this project is to identify how recruitment of five target groundfish species in the GOA is affected by environmental variability in the region. ‘Recruitment’ here refers to the number of young fish entering a fishery each year; its strength is thought to be set by the end of the YOY juvenile stage (Moss et al., UTL Proposal). In this proposal we define ‘regimes’ as the dominant modes of oceanographic variability present in the GOA that may persist on an inter-annual time scale. We will project the effects of different environmental regimes, and the resulting recruitment variability, on upper trophic level ecosystem dynamics for the GOA under current fishing regimes. The resulting information will aid resource managers in formulating successful management responses to future climate change.

1b. Hypotheses: Historically the GOA has been under the influence of different physical regimes which affect variability in recruitment of the five UTL focal species and the ecosystem dynamics as a whole. An understanding of this historical variability will enhance our ability to predict future regimes under different scenarios of climate change. To achieve our objectives we will address the following hypotheses:

1. *Historical environmental variability in the GOA can be characterized in terms of a few (≤ 6) distinct physical regimes and we can identify these regimes from ROMS simulations.*
2. *Recruitment variability of the five focal species is primarily influenced by variability in the proportion of young fish transported from offshore spawning areas to nearshore nursery areas (connectivity) due to interannual differences in the strengths of the physical regimes that characterize the GOA environment.*
3. *Recruitment variability is secondarily influenced by the survival of young fish successfully transported to nursery areas, which varies due to differences in physical factors (wind speed and direction, water temperature, runoff, mixing) and biological processes (prey abundance, competition, predation) encountered along the transport pathways.*

70 studies at various scales, identify gaps in our knowledge, design field studies, interpolate data to fill in
71 information for areas not studied, and perhaps most importantly, allow us to project the quantitative
72 implications of our theories and what may happen in the future.

73 ***C2a1. Essential Elements:***

74 Our proposed work centers on identifying factors important to recruitment success for the five target
75 groundfish species identified by the UTL proposal. The focus on recruitment processes and early life
76 history dynamics of these five species necessitates inclusion of models of the physical environment,
77 which sets the stage for recruitment variability, and of the lower trophic levels (nutrients, phytoplankton,
78 and zooplankton) upon which these species depend for prey production. Thus we will use pre-existing and
79 validated hydrodynamic (ROMS, Shchepetkin and McWilliams, 2005; Haidvogel et al., 2008; Hermann
80 et al. 2009b; Dobbins et al., 2009) and lower trophic level (GOANPZ, Hinckley et al., 2009; Coyle et al.,
81 In prep.) models, both partially developed with NPRB support. Individual based models (IBMs) of the
82 five focal groundfish species will allow us to study egg, larval and YOY transport paths, the connectivity
83 between spawning areas and juvenile nursery areas, and processes occurring along these trajectories. A
84 pre-existing IBM for walleye pollock (Hinckley et al., 1996; Megrey et al., 2001; Hermann et al., 2001;
85 Hinckley et al., 2008) and a Multi Species Model (MSM, Aydin et al., 2007) will also be used. We will
86 develop additional IBMs of Pacific cod, arrowtooth flounder, sablefish and Pacific Ocean perch. A unique
87 aspect of IBMs is the ability to track the entire history of individuals. These histories can be compared
88 with different environmental and biological factors affecting survival along their trajectories (temperature,
89 currents, prey, predation, etc.), using information derived from coupled models of physics and biology
90 (ROMS/GOANPZ). Indices related to recruitment derived from the IBMs will be fed into a MSM to
91 provide an integrated framework for evaluating the relative effects of spatially averaged physical, lower
92 trophic level and recruitment processes along with alternative fishery management strategies. Using this
93 framework, alternative fishery management strategies can be developed and tested for robustness to
94 different physical forcing regimes and the variability inherent in the ecosystem, although we do not
95 propose to do so as part of this project. Figure 1 illustrates how each of our essential modeling elements is
96 vertically linked and how each of these elements relates to our hypotheses, and to the other GOAIERP
97 components.

98 ***C2a2. Essential Processes: Physical processes:*** Candidate physical mechanisms affecting recruitment
99 include the presence of eddies in the Alaskan Current-Alaskan Stream system (Ladd, 2007; Okkonen et
100 al., 2003), annual and interannual variation in wind stress curl (Fiechter and Moore, 2009; Hermann, et
101 al., 2009a), onshore transport in the presence of downwelling-favorable winds, and flows through
102 canyons intersecting the shelf (Ladd, et al. 2005). Our analysis will allow us to relate physical variability
103 to recruitment variability.

104 *Lower trophic level processes:* The lower trophic level model will be used to simulate LTL ecosystem
105 dynamics to provide prey for the five focal species. Prey production is affected by primary production,
106 which varies with light, nutrient availability and water column stability, and is also affected by mortality
107 and growth of mesozooplankton which vary with temperature and food availability. Oceanic and coastal
108 waters support different levels and types of prey for young fish, due to the interaction of zooplankton life
109 cycles and nutrient regimes. Offshore areas are characterized by low iron levels, small phytoplankton
110 cells and large zooplankton, whereas coastal areas are characterized by higher iron supporting small and
111 large phytoplankton cells, and both large and small zooplankton (Strom et al., 2000; 2006; Coyle et al.,
112 2005). Elevated small copepod production inshore means this region is significantly richer in larval fish
113 food than offshore waters.

114 *Recruitment Processes:* Variability in recruitment is mainly due to variability in three processes:
115 transport to appropriate nursery areas, growth, and mortality. Transport is influenced by: (1) physical
116 processes (e.g., currents, stratification, eddies), and (2) biological processes, such as depth distribution

117 and vertical migration behavior. Growth is influenced by many factors (prey density and patchiness, prey
118 species composition, feeding behaviors, and bioenergetics) which are in turn affected by physical
119 variables (temperature, turbulence, salinity). Changes in growth influence the duration of life stages
120 (elevated growth rates shorten early high-mortality stages, thus lowering cumulative mortality). Mortality
121 from starvation or predation also affects survival. Rates of predation are high amongst early life stages
122 (Bailey and Houde, 1989), and predation fields change as young fish grow and migrate. Survival of larval
123 and juvenile fish depends to some extent on the trajectories through space that the physical system
124 imposes on them, as well as the biological environment that they encounter along the trajectories. We will
125 use the IBMs to examine transport, growth and survival processes of the early life history stages of the
126 five focal fish species.

127 *Multispecies processes:* The MSM will be used to evaluate the effects of changes in lower trophic
128 level production and recruitment on adult groundfish populations, non-target species including marine
129 mammals and birds, and fisheries. The essential processes captured by the MSM model include species
130 biomass dynamics, trophic interactions, and fishing at annual and regional scales. In addition, basic age
131 structured population dynamics for major groundfish are modeled, allowing testing of alternative
132 recruitment hypotheses. The MSM results will provided the means for integrating the effects of
133 recruitment variability, trophic interactions, competition, and fishing within the context of a management
134 strategy evaluation, although this is beyond the scope of this proposal.

135 ***C2a3. Present State of Knowledge. Physical Environment:*** Circulation in the GOA is dominated by two
136 current systems, the cyclonic subarctic gyre in the basin and the Alaska Coastal Current (ACC) on the
137 continental shelf. The ACC is a baroclinic current driven by winds and freshwater runoff. The phasing
138 and magnitude of winter runoff influences spring stratification in the ACC, and the ACC plays a primary
139 role in transporting freshwater alongshore (Weingartner, et al., 2005). Due to seasonal cycles in forcing,
140 the ACC has a strong seasonal signal with maximum baroclinic flow in autumn and maximum total
141 transport in winter (Schumacher, et al., 1989). On interannual timescales, freshwater runoff is correlated
142 with ACC transports and freshwater content. In addition, both the PDO (Pacific Decadal Oscillation) and
143 an index of sea level pressure gradient have been found to be significantly correlated with runoff
144 (Weingartner, et al., 2005).

145 The eastern boundary current of the subarctic gyre is the Alaska Current flowing northward along the
146 shelf-break. The Alaska Current is broad and highly variable. Eddies forming in Alaska Current are
147 important sources of coastal water with associated nutrients, iron, and biota to the high- nutrient low-
148 chlorophyll (HNLC) Central Gulf of Alaska (Crawford and Whitney, 1999; Ladd, et al., 2009; Ladd, et
149 al., 2007; Okkonen, et al., 2003). At the head of the GOA, the current turns southwestward following the
150 shelf-break to form the Alaskan Stream, the western boundary current of the eastern subarctic gyre.
151 Alaskan Stream eddies, adjacent to the shelf, can influence cross-shelf exchange (Okkonen, et al., 2003,
152 Janout et al).

153 Physical and biological processes in the GOA are correlated and strongly influenced by large-scale
154 forcing, such as the El Nino Southern Oscillation (ENSO) or Pacific Decadal Oscillation (PDO), or the
155 Aleutian Low (AL, Chhak, et al., 2009; Combes, et al., 2009; Henson, 2007; Mantua, et al., 1997) as well
156 as more local or regional processes such as freshwater runoff, local wind stress or wind stress curl (Doyle,
157 et al., 2009; Fiechter and Moore, 2009; Pinchuk, et al., 2008; Hermann et al., 2009a). Mechanisms
158 underlying these correlations are unclear. Strong downwelling winds are associated with strong mesoscale
159 (~200 km) eddy activity at the shelf break (Combes and Di Lorenzo, 2007; Combes, et al., 2009; Henson
160 and Thomas, 2008; Hermann et al. 2009b). Eddies in the GOA influence the biology of the region from
161 phytoplankton (Brickley and Thomas, 2004; Crawford, et al., 2005; Okkonen, et al., 2003) to zooplankton
162 (Batten and Crawford, 2005; Mackas and Galbraith, 2002; Mackas, et al., 2005) to upper trophic levels
163 (Ream, et al., 2005).

164 *Lower trophic levels:* The GOA consists of the oceanic HNLC environment, characterized by iron
165 limitation, and the coastal downwelling environment with high iron levels from runoff, and a spring

166 bloom and nutrient depletion cycle. Cross-shelf movement of water masses mixes coastal and oceanic
167 ecosystems. The GOA shelf seasonal cycle is characterized by nitrate depletion in the upper euphotic
168 zone occurring between mid April and July (Childers et al., 2005). Phytoplankton are largely light limited
169 during spring, however, nitrate exhaustion generally limits primary production throughout the summer
170 (Strom et al., 2006). Spring production is fueled by a series of intense phytoplankton blooms in April-
171 May, apparently caused by thermal stratification (Henson, 2007). Annual mesozooplankton biomass
172 peaks are usually observed in May, when the community is dominated by *Neocalanus* (Coyle and
173 Pinchuk, 2003, 2005). *Neocalanus* leave surface waters to diapause at 500–2000 m depth in June-July,
174 and are therefore largely absent from shelf waters by July. Copepod abundance during summer is usually
175 dominated by small coastal copepod species such as *Pseudocalanus* spp. Euphausiid populations are
176 dominated by *Euphausia pacifica*, *Thysanoessa inermis* and *T. spinifera*, and spawning of the latter two
177 species is linked to the spring phytoplankton bloom (Pinchuk et al., 2008).

178 *Walleye pollock*: Walleye pollock (*Theragra chalcogramma*) recruitment dynamics have been studied
179 extensively in the GOA (Kendall et al., 1996). Pollock are very fecund with highly variable mortality and
180 growth rates in early life. Shelikof Strait was the predominant spawning region in the GOA, but spawning
181 may have shifted to other areas in recent years (Bacheler, et al., In press). Eggs are released at 200-300 m
182 depth in March-April and hatch about 2 weeks later. Yolk-sac larvae can survive for about a week without
183 feeding. Feeding larvae begin diel migration at about 7 mm standard length (SL). They become juveniles
184 at about 25 mm, and gradually increase their swimming capacities until they become independent of
185 currents during their 0-age year. Nurseries occur over broad areas of the shelf, with major ones around the
186 Shumagin Islands, and Sutwik Island (M. Wilson, NOAA/AFSC, pers. comm.). Juveniles are also found
187 in bays. Elevated temperature (6-7 °C) increases survival, but the mechanisms are not clear. Optimal prey
188 levels for larvae depend on larval size, temperature, light, turbulence and turbidity (Porter et al. 2005).
189 Effects of growth rate on survival have not been demonstrated in pollock, although some strong year
190 classes are a larger size-at-age as 0-age juveniles. Predation on juvenile pollock may be important to
191 recruitment, particularly as groundfish predator abundance has increased since the 1980s, before which
192 larval survival was key (Bailey, 2000). Although survival of year classes is affected by variability in the
193 physical and biological environment, multiple spawning locations and a long life span with multiple age
194 classes in the population may buffer these dynamics.

195 Arrowtooth flounder (*Atheresthes stomias*), Pacific Ocean perch (*Sebastes alutus*), and sablefish
196 (*Anoplopoma fimbria*) all spawn in deep water at the edge of the continental shelf and slope in the GOA.
197 In contrast Pacific cod (*Gadus macrocephalus*) spawn on the shelf in shallower water. However, all four
198 species utilize shallow inshore habitats as juvenile nursery areas. Consequently, early life stages of all
199 these species must somehow move across the shelf and find shallow nursery habitats in order to
200 successfully recruit to their respective populations. Details of spawning activity and early life stage
201 characteristics differ among these four species.

202 *Arrowtooth Flounder*: Various studies have found arrowtooth flounder spawning along the
203 continental slope at depths between 100 and 500 meters, but most spawning occurs between 400-500 m
204 (Blood et al., 2007). Spawning probably begins in December (Blood et al, 2007, Rickey, 1995). Eggs are
205 pelagic and duration of the egg stage is temperature dependent. Most eggs and small larvae have been
206 collected at >400 m depth, where hatching occurs (Blood et al., 2007). Late-stage eggs have been
207 collected principally near troughs and canyons where downwelling relaxation and cross-shelf flow
208 typically occur in winter. Newly hatched larvae possess a relatively large yolk sac; mean size at hatching
209 is 4.4 mm SL (Blood et al. 2007). Yolk absorption is complete by 6.5-7 mm SL. Flexion occurs at 13.4
210 mm SL and transformation occurs about 45 mm SL (Blood et al., 2007, Bouwens et al., 1999). Larvae
211 begin to ascend to shallower depths prior to complete yolk sac absorption. While most larvae are located
212 along the outer shelf and slope, larger larvae tend to be further inshore and are associated with the deep-
213 sea valleys and troughs that penetrate the shelf (Bailey and Picquelle, 2002). This association may
214 provide enhanced transport pathways to nearshore nursery grounds. The instantaneous growth rate for
215 larva of 8.5-40 mm is 0.017 mm d⁻¹. Interannual variation in size is small compared to intra-annual

216 variation, suggesting that arrowtooth flounder hatch over an extended time period (Bouwens et al., 1999).
217 Settlement starts at the beginning of August and finishes by the end of October.

218 *Pacific Ocean perch*: Pacific Ocean perch are members of the *Sebastes* genus, a primitive viviparous
219 group with females extruding larvae rather than eggs (Love et al. 2002). At both the larval and juvenile
220 stage, individuals cannot be distinguished among several congeners without genetic identification, so
221 most available early life history information probably represents a combination of characteristics from
222 several species (Westerheim, 1975; Matarese et al., 2003, Kendall et al. 2007). Reproduction occurs in
223 April-May in the GOA (Westerheim 1975). In British Columbia, adult females, migrate to the mouths of
224 submarine canyons and release their larvae at depth (500-700 m). Larvae remain at depth for a month or
225 more prior to moving to shallower depths (Love et al. 2002). Newly-extruded larvae begin feeding at 3-7
226 mm SL (Kendall and Lenarz 1987). Evidence from upwelling regions of the west coast of North America
227 suggests that rockfish larvae occupy the near-surface layers and do not migrate on a diel basis (Ahlstrom
228 1959, Boehlert et al., 1985, Sakuma et al., 1999, Matarese et al., 2003). However, the GOA is dominated
229 by downwelling (Ware and McFarlane, 1989), which may alter survival strategies. The vertical behavior
230 of POP larvae in the GOA is thus uncertain. The duration of the larval stage in the GOA may be 1-2
231 months (Matarese et al., 2003). The larval stage is complete at 20-30 mm SL. Early juveniles in the GOA
232 remain in the water column for several months until fall, at which time they take up a demersal existence
233 in subtidal habitats with complex topography and extensive cover (Carlson and Haight, 1976).

234 *Sablefish*: Sablefish spawn pelagic eggs in winter near the edge of the continental shelf (Kendall &
235 Matarese, 1987). Eggs are found deeper than 200 m (Mason, et al., 1983). Prior to hatch, they sink to
236 depths exceeding 400-500 m and maintain that position. Eggs require about 2 to 3 weeks to hatch. Time
237 from hatch to first feeding is about 2 weeks (Boehlert and Yaklovich, 1985). The largest larvae found at
238 depth are a little over 7 mm, perhaps a month old. As the yolk sac is absorbed, larvae swim to the surface
239 and grow about 2 mm per day from about 10 to 80 mm SL in the neuston during the spring. Young
240 sablefish move inshore at the surface for about 4 months. They are considered epipelagic juveniles at
241 about 35 mm. Although sablefish larger than ~50 mm SL have been found nearshore (McFarlane and
242 Beamish, 1983), some up to 250 mm SL have been collected offshore in the surface waters. Grover and
243 Olla (1986) found morphological evidence of starvation in larvae <12.5 mm SL. Smaller fish (40 mm SL)
244 grow by about 13-15 % body weight per day, while 110 mm SL fish grow by about 5-7% body weight per
245 day (Sogard and Olla, 2000, Hurst, T. pers. comm.). Sablefish are one of the fastest growing epipelagic
246 juvenile fish studied to date (Shenker and Olla, 1986). There appears to be about a four-fold variation in
247 year class strength for sablefish, but the causes for this variability are not known.

248 *Pacific cod*: Mature or spawning adult Pacific cod have been collected in the GOA between February
249 and July (Dunn and Matarese, 1987). Egg and larval dispersal may be limited. Eggs are demersal,
250 spawned over rocky substrates at depth of 20-200 m (Hurst et al., 2009). Eggs are semiadhesive,
251 stenothermal, euryhaline and euryoxic, with optimum temperatures for development between 3.5 and 4°C
252 (Alderdice and Forrester, 1971). Hatching occurs at 21-26 days after fertilization at 4°C. Pelagic larvae
253 hatch at 3-4 mm SL, and yolk sac larvae show a strong surface orientation as early as one day post hatch
254 (Hurst et al., 2009). Small, preflexion larvae (<10 mm SL) show no response to light, however there was
255 a strong response to temperature. Larval depths are highly variable. After flexion (10-17 mm) larvae show
256 diel vertical migration, with greater depths during the day and distributions nearer the surface at night.
257 Larvae are transported towards shore (Rugen and Matarese, 1988). Length at transformation is 25-35 mm
258 SL. By July, cod settle to the bottom. Juvenile nursery areas are primarily shallow, coastal embayments
259 (Abookire et al., 2007; Laurel et al., 2003). Densities of YOY fish are highest in depths of 15-20 m, and
260 where percent cover by emergent structures (sea cucumber mounds) and salinity are highest (Abookire et
261 al. 2007) or where eelgrass occurred (Laur and Haldorson, 1996; Dean et al., 2000). Juveniles may,
262 however, be caught at depths to 70 m (Smith et al., 1984). Availability of suitable habitat may limit
263 Pacific cod recruitment (Laurel et al., 2003). Information on larval and juvenile growth rates,
264 bioenergetics parameters and depth distribution is available (Hurst, pers. comm.). Genetic studies indicate
265 that dispersal distances of Pacific cod between birth and reproduction are less than 30-km (Cunningham

266 et al., 2008). Genetic differences are particularly noticeable where circulation features and bottom
 267 topographies are complex. Pacific cod make annual feeding migrations and return to prior spawning
 268 locations, but some stock components may be nonmigratory.

269 *Ecosystem relationships:* The food web in the GOA is midway between a benthic-dominated
 270 ecosystem and a pelagic ecosystem (Aydin et al., 2007). Species at the high trophic levels (such as Pacific
 271 cod, arrowtooth flounder, Pacific halibut) have a high biomass density, relative to the forage biomass. The
 272 highest biomass consumers are Pacific cod and arrowtooth flounder. Arrowtooth flounder is especially
 273 influential in the food web, and stands out even in the context of whole ecosystem comparisons where
 274 consumption by high turnover groups (microbes and zooplankton) would be expected to swamp signals
 275 from higher trophic levels. Approximately 3.5% of primary production exits the system via fisheries. The
 276 halibut fishery is the highest trophic level consumer and remove substantial predator production, but far
 277 less base ecosystem production than arrowtooth flounder, the dominant predator. The GOA biomass
 278 distribution departs from the classic pyramid where few predators subsist on many prey; here analysis
 279 indicates a predator-dominated ecosystem, with far higher densities of arrowtooth flounder and halibut in
 280 proportion to the forage base than in the Bering Sea or Aleutian Islands. The current state of knowledge
 281 for all three food webs is described in detail in Aydin et al. (2007) for the GOA.

282
 283 ***C2a4. Relation to UTL Component:*** The proposed work will focus on the five groundfish species
 284 identified by the UTL component (arrowtooth flounder, walleye pollock, Pacific cod, Pacific Ocean perch
 285 and sablefish). We will develop IBMs for all of these species focusing on recruitment processes and
 286 connectivity in conformity with the UTL component. Trajectory analysis from the IBMs will provide
 287 information on transport processes connecting offshore spawning areas to inshore nursery areas.
 288 Processes (growth, competition, predation) during the YOY stage will also be modeled in the IBMs.
 289 Indices of recruitment from the IBMs will be incorporated into the MSM to examine the consequences of
 290 different regimes and recruitment levels at the greater ecosystem level, including fisheries. Transport and
 291 connectivity predicted from the POP IBM will be corroborated by genetic data on regional and local
 292 populations if this becomes available. The coupled ROMS/GOANPZ model will generate hindcasts and
 293 provide model-based physical and LTL biological indices related to recruitment to be used in the MSM.
 294 This modeling work will integrate and expand on the work of the UTL and other GOA-IERP components
 295 and will allow us to address a wide range of programmatic goals and questions.

296
 297 ***C2a5. Relation to PIs other projects.*** Previous and ongoing work related to this project by the PI's is
 298 described in section E1a.

299 ***C2a6. Data Sources.*** Retrospective, current and anticipated future data sources for all of the vertically
 300 integrated models are summarized in section C6.

301
 302 ***C2a7. Spatial and Temporal Scales:*** The Coastal GOA (CGOA) 3-km resolution ROMS/GOANPZ
 303 model covers the entire GOA including the focus regions of the UTL component and will be our primary
 304 tool for simulate the GOA environment. A 10-km resolution ROMS/GOANPZ model will be run to
 305 provide boundary conditions to the finer resolution grid. However, the 10-km North East Pacific (NEP5)
 306 grid is too coarse to adequately resolve eddies, currents, meanders, canyons, banks and fronts influencing
 307 transport. The minimum depth of the Coastal Gulf of Alaska (CGOA) grid is 10 m. To represent the
 308 shallower nearshore areas not captured by the ROMS grids (e.g. small estuaries), during the IBM
 309 simulations we will add a "nearshore compartment" with locally-based migration rules.

310 The ROMS/GOANPZ model has a time step of 150 seconds to ensure numerical stability, however
 311 daily averages of physical and LTL fields will be used to force the IBMs off line. The IBMs will have a
 312 subdaily timestep to better resolve feeding, movement, vertical migration, and tidal interactions. The
 313 MSM has an annual or monthly timestep and broad, basin-wide spatial scale which is the same as the
 314 single species stock assessments used in fishery management in the North Pacific. The GOA MSM

315 represents 291,840 km² of the continental shelf from 50 to 1000 m depth and from 170° W to 140° W.
316 Data supplying the MSM is divided into nine strata representing geographic regions and depth/habitats
317 account for within-region variability in the Central and Western GOA (Aydin et al., 2007).

318 **C2b + C3. Analytical Approach and Simulation Plans.** We discuss the 4 main models types (elements)
319 in detail in section C6 below. Here we describe analytical approaches and number and types of
320 simulations required to specifically address our hypotheses. Methods for validation of model results will
321 also be described in section C6.

322 We plan to provide the field scientists with the other GOA IERP components with several years' of
323 simulations from the 3-km ROMS/GOANPZ model ahead of the 2011 field season. This will give them a
324 good idea of the hydrology, event timing and spatial distributions of the LTL ecosystem components and
325 the variability that they are likely to encounter, allowing fine tuning of survey designs.

326 To address Hypothesis 1, we will analyze NEP5 simulation runs (Curchitser, pers. comm.) for
327 several decades, encompassing the 1976/77 inter-decadal regime shift. Using these hindcast runs, we will
328 develop maps of the magnitude of variables important to the ecosystem (cross-shelf exchange, eddy
329 activity, stratification, mixing, etc.), determine climatological seasonal cycles for these variables and
330 calculate anomalies from the seasonal cycles. Using Empirical Orthogonal Function (EOF) analysis, we
331 will analyze the interannual and spatial scales of variability and covariance to identify a small number
332 (≤ 6) of distinct physical regimes that comprise the major components of environmental variability in the
333 GOA. This analysis will allow us to categorize each year as representative of a particular regime. We will
334 also identify physical indicators for the different regimes that can easily be monitored such that future
335 years can be rapidly categorized as one of the identified regimes, or as a previously unidentified mode.

336 Addressing the remaining hypotheses requires the development, refinement, testing and validation of
337 IBMs for each of the five focal species. Information from the 2011 field season will aid in development.
338 New information from other GOA-IERP components on competition, predation and larval depth
339 distribution will be incorporated into the IBMS as it becomes available. Observed physical and plankton
340 distributions will be used to validate the ROMS/GOANPZ model. We will compare the Lagrangian
341 particle tracking algorithms used in the five IBMs through "head-to-head" comparisons to assure similar
342 performance.

343 Long time series of simulations may be computationally prohibitive and of limited use. A more
344 effective approach to address Hypotheses 2 and 3 involves selection of hindcast years to maximize
345 contrast among variables critical to recruitment. We therefore propose to select years for simulation based
346 on a combination of the following criteria: (1) analysis of the NEP5 hindcasts as mentioned above, (2)
347 results from the retrospective analysis undertaken by the UTL project relating recruitment variability to
348 environmental variables, and (3) recruitment time series from the appropriate stock assessment models, to
349 find years of high vs. low recruitment.

350 We expect to find 4-6 major regimes or 'modes' in the NEP5 analysis (Stabeno, pers. comm.). We
351 will run the ROMS/GOANPZ model for 2-3 representative years for each regime type, resulting in a total
352 of approximately 10-18 hindcast runs. We will re-run each IBM multiple times for each of the
353 ROMS/GOANPZ runs, varying underlying parameters within expected ranges between runs. Multiple
354 IBM runs will allow us to develop error bars around the indices and predictions from the IBM's. We will
355 then run the MSM using biomass estimates of recruitment and zooplankton for each regime type.

356 To address Hypothesis 2, we will perform connectivity analysis following the methods described in
357 North et al., (2009). This analysis involves calculating the proportions of individuals that arrive at
358 juvenile nursery areas from specific source areas (spawning regions or early larval distributions). There is
359 strong spatial structure for some of the target fish species and possible connectivity between Eastern and
360 Western GOA for others.

361 To address Hypothesis 3, an innovative approach towards analyzing individual trajectories and
362 histories from the IBM will be developed using time series techniques. We will examine the differences
363 between survivors and non-survivors (or those who do not reach nursery areas) by examining correlations

364 between physical and LTL variables and individual characteristics along individual trajectories through
365 the YOY stage. We will perform time series analysis of biophysical and physical information in
366 accordance with the methods of Emery and Thomson (2001). Criteria to be defined to analyze trajectories
367 will depend on algorithms in each IBM relating individual processes to physical and biological factors.
368 These algorithms will depend, in turn, on the information available for each species. For example, we
369 could compare time series of temperature and growth along individual trajectories from an IBM that
370 includes temperature-dependent growth. If the trajectories of survivors and non-survivors are associated
371 with significant differences in degree days, or the timing or frequency of encounter with water of a certain
372 temperature, we could create an index of recruitment based on the observed temperature at particular
373 times or places that the analysis suggests are most closely related to recruitment success.

374 Indices related to recruitment success will be calculated from the IBM results for each of the five
375 focal groundfish species. One such index will be the proportion of individuals that successfully recruit to
376 the nursery area. This index would reflect inter-annual differences in dispersal patterns under different
377 physical regimes. Others will reflect the results of the analyses of trajectory-specific environmental
378 conditions among model cases, such as (for example) the temperature index discussed above. We will
379 also derive indices from the GOANPZ model of prey abundance in the areas that prove to be critical to
380 recruitment success. These indices will be transformed into recruitment biomasses by specifying
381 anomalies around average recruitment related to the value of the index. For comparison with recruitment
382 estimates from stock assessment models, the resulting indices will necessarily reflect GOA-wide
383 recruitment because that is the current scale of the assessment models. However, if the UTL component
384 develops region-specific (East vs. West) stock assessments for particular target species, we would
385 develop corresponding regional recruitment indices, making it possible to make region-specific
386 comparisons between the stock assessment estimates and IBM predictions.

387 Recruitment biomass time series from the IBMs will be incorporated into the MSM model to test how
388 the effects of the different environmental regimes on recruitment interact with population dynamics
389 processes and fisheries.

390 Formal predictions of recruitment and ecosystem dynamics using IPCC scenarios to force the
391 vertically linked models do not make sense, because they fail to adequately capture freshwater input
392 (Stabeno and Bond, pers. comm.) which is essential to predicting GOA circulation. In the future,
393 recruitment predictions using IPCC scenarios may be possible; however our focus on hindcasts and
394 indices to make predictions of recruitment related to regimes appears to be the best strategy at this time.

395 A chronological description of our research activities along with projected completion dates for each
396 milestone is included in Table 1.

397

398 **C4. Data needed from other GOA IERP components:** Table 2 outlines in detail the expected data from
399 other GOA IERP components that will be useful for the models, for development, tuning or validation.
400 From the LTL component we will need hydrographic and current meter data, particularly from the eastern
401 GOA where data are scarce, information on nutrient concentration, phytoplankton and micro- and
402 mesozooplankton biomasses (prey for larval and juvenile fish), production rates and carbon-chlorophyll
403 ratios to corroborate the GOANPZ model, larval survey results (including vertical distribution) for
404 starting locations and/or validation of the IBM results, and larval length-weight relationships for the five
405 target fish species. From the MTL component we will need distribution and abundance of forage fish and
406 YOY target species juveniles, information on YOY and forage fish diet, consumption, predation, and
407 YOY length-weight relationships for the five target fish species to parameterize the IBMs and the MSM.
408 From the UTL component, we will need retrospective analysis on correlative factors affecting recruitment
409 to aid in design and corroboration of model hindcasts. To initialize the IBMs, we will need information
410 regarding the spawning distributions of the target species. If validating regional recruitment variability is
411 of interest, then we will need region-specific (East vs. West) stock assessment model estimates of
412 recruitment for the target species. We will also need information on the effects of competition on YOY
413 growth and ecosystem-dependent predation functions and bioenergetics to account for loss of YOY

414 juveniles to UTL species (including Sea lions and sea birds) in the MSM. Finally, we request that genetic
 415 samples of the five focal species are collected by the LTL, MTL and UTL field programs for use in future
 416 verification of our connectivity results.

417

418 **C5. Long-term monitoring:** Continuation of Seward Line monitoring is needed for validation of the
 419 ROMS and GOANPZ models in a temporal context. It is the only comprehensive long term monitoring
 420 study in the GOA, a requirement for validation of the suite of model state variables from specific runs.

421 **C6. Detailed Model Descriptions** *Physical Oceanography Model:* ROMS will be used to simulate
 422 circulation (both tidal and sub-tidal) and hydrography of the GOA. ROMS is a state-of-the-art, free-
 423 surface, terrain-following, hydrostatic primitive equation ocean circulation model. We will use a model
 424 grid with a horizontal resolution of 10-km (NEP grid) to provide boundary conditions for the 3-km grid
 425 (CGOA grid). Vertical resolution varies with depth, but resolution is finer in the upper water column
 426 where more detail is required. The 3-km CGOA grid can be run on existing computational resources with
 427 up to 60 vertical layers. Both physical and biological boundary condition for the 3-km grid will be
 428 extracted from 10-km resolution simulations of the North East Pacific done for this project (NEP grid),
 429 which are in turn derived from Simple Ocean Data Assimilation (SODA) global reanalysis. Forcing files
 430 for hindcasts will be based on the CORE-2 atmospheric reanalysis of National Center for Atmospheric
 431 Research (NCAR), or from North American Regional Reanalysis (NARR). The latter, plus ocean
 432 products from the National Center for Environmental Prediction (NCEP) Climate Forecast System
 433 Reanalysis, HYbrid Coordinate Ocean Model (HYCOM) or of the Circulation and Climate of the Ocean
 434 (ECCO), will be particularly useful for nowcasts from the field years. A basic description of the 3-km
 435 CGOA model, and its validation with field data, can be found in Dobbins et al. (2009). Recent
 436 improvements to the model include more accurate tides, a finer temporal resolution (monthly) scheme for
 437 coastal freshwater runoff using a climate hydrology model (Royer, NPRB project 734) and calibration to
 438 resolve the shelf-break eddies. Model output will be used to (a) drive the transport of larval fish and
 439 biological fields in the IBMs and GOANPZ model, and (b) produce indices of the physical state of the
 440 ocean.

441 *Lower Trophic Level Model:* The lower trophic level dynamics will be simulated by a Nutrient-
 442 Phytoplankton-Zooplankton (GOANPZ) model developed by Hinckley et al. (2009) specifically for the
 443 Gulf of Alaska under the GOA GLOBEC program and NPRB Project 614. The model includes nitrate and
 444 ammonium, limiting nutrients on the Central GOA shelf (Childers et al., 2005), and iron, a critical
 445 component structuring plankton communities on and off the shelf (Wu et al., 2009). Iron has additionally
 446 been incorporated into the freshwater runoff driver file to enable seasonal and inter-annual differences in
 447 iron concentration to be captured. The model does not include silicate, which is not limiting on the
 448 Central GOA shelf (Whitledge, pers. comm.). The model includes large and small phytoplankton,
 449 microzooplankton, a large interzonal calanoid component (represented by *Neocalanus* spp.), a smaller
 450 copepod component and a euphausiid component (euphausiids are a major dietary item of pollock: Adams
 451 et al., 2007; Wilson et al., 2006; Yang et al., 2006). The model incorporates ontogenetic migrations of the
 452 *Neocalanus* component. The model is run online (i.e. fully integrated with ROMS). The GOANPZ model
 453 run on the 10-km NEP grid and 3-km CGOA grid has been calibrated using field observations of plankton
 454 concentrations and production along the Seward Line (Coyle et al., NPRB Project 614) and model
 455 parameters have been optimized such that the model captures key features of the GOA ecosystem
 456 dynamics including: biomass and production levels of phytoplankton, primary production, timing of the
 457 spring phytoplankton bloom, the observed contrast between small and large phytoplankton communities
 458 in the HNLC offshore and low nutrient high chlorophyll coastal environments, seasonal and vertical
 459 nutrient distributions observed on the shelf, and microzooplankton and mesozooplankton patterns similar
 460 to field observations (Lessard, field data, Coyle and Pinchuk, 2005; Strom et al., 2006, 2007).

461 *Individual Based Models:* Five IBMs will be developed or adapted, one for each of the focal species
 462 of this program. These models will generate transport trajectories for early life stages from spawning or

463 early larval stages, through the YOY stage. They will also provide histories of individuals environment
464 along those trajectories for each individual. Information on feeding, growth, mortality from UTL
465 predators, and competitors will be incorporated. We will derive indices of connectivity and survival
466 which will be used to generate recruitment biomasses for the different physical regimes from the IBMs
467 for input to the MSM.

468 Walleye pollock IBM: The pollock IBM, which simulates four developmental stages (eggs, yolk-sac
469 larvae, feeding larvae, and juveniles) of 0-age individuals from spawning to autumn, will be driven by
470 ROMS simulations output from the 3 (or 10) km CGOA grid.

471 Mortality and growth in this model are stage-dependent (Hinckley et al., 1996; Megrey and Hinckley
472 2001). Growth of yolk-sac larvae depends on the number of degree days. Larvae surviving after yolk-sac
473 depletion enter the feeding stage, where larval dry weight depends on assimilation efficiency (Houde,
474 1989), consumption (modified from MacKenzie et al., 1994), and daily respiration rate (Yamashita and
475 Bailey, 1989). Feeding rules and the transition from first feeding to feeding larvae are modeled according
476 to Hinckley (1999). Prey consumption and bioenergetics (including digestion) of juveniles are estimated
477 according to Ciannelli et al. (1998). Net growth estimates (mass, g) are updated each time step and
478 converted to growth in length (mm) for use in subsequent time steps.

479 To model sufficient numbers, each particle is considered a superindividual made up of many
480 individuals (Scheffer et al., 1995; Megrey & Hinckley, 2001). Each superindividual contains an initial
481 number of eggs proportional to the egg production estimated by pollock stock assessments for that year
482 (Dorn et al., 2005). Starvation mortality is included by removing individuals whose weight falls below a
483 stage- and size-specific critical level. Algorithms for particle depth are stage dependent. Egg depth
484 depends on water density. Feeding larvae begin diel migrations at 6 mm, with swimming speeds a
485 function of length (Kendall et al., 1987, 1994). Vertical positions of juveniles at each time step are based
486 on the depth at the previous time step and the vertical mean velocity, with directed movement (up/down)
487 as a random variable. Horizontal positions of juveniles are determined using a correlated random walk
488 (Kareiva and Shigesada, 1983). The position of juvenile superindividuals at each time step depends on the
489 position in the previous time step, the length of the juvenile, and the turning angle.

490 Arrowtooth flounder (ATF): The ATF IBM will be developed for this project. Simulated ATF eggs
491 will be “spawned” in deep (~400 m) areas along the continental slope and in troughs and sea valleys
492 intersecting the shelf, from December to April. Eggs will be neutrally-buoyant. Temperature dependent
493 egg duration will be modeled according to Blood et al. (2007); otherwise a fixed duration for the egg
494 stage will be used. Larvae will gradually ascend following hatching (Bailey and Picquelle, 2002). Larval
495 growth will initially be modeled as linear (see Bouwen et al., 1999), with potential incorporation of
496 temperature-dependent growth rates. Initial larval size will be 4.4 mm SL (Blood et al., 2007), with size at
497 transformation and settlement at 45 mm SL. UTL habitat suitability maps will define locations of suitable
498 nursery areas. Selective Tidal Stream Transport (STST) will be applied to the ATF model to simulate
499 enhanced onshore transport and will be compared with results using shoreward horizontal swimming
500 against bathymetric gradients.

501 Pacific Ocean Perch (POP): The POP IBM will also be developed for this project. Summer POP
502 distributions from groundfish surveys will aid in initializing the model, as adult POP show site fidelity.
503 Simulated adults will produce early-stage pelagic larvae at depth from mid-March to late April. Vertical
504 distribution and larval growth in the GOA are uncertain; it is hoped that the LTL component will
505 characterize vertical distribution. POP ontogenetic stages will be modeled as: preflexion, post-flexion,
506 and pelagic juvenile. Following results from British Columbia (Love et al. 2002), preflexion larvae will
507 remain at ~ 400 m for 45 days until reaching the post-flexion stage (~12 mm SL). Post-flexion larvae will
508 rise to a preferred depth of 20-40 m (Sakuma et al., 1999). At 25 mm SL, post-flexion larvae will
509 transform to pelagic juveniles. The nominal duration for pelagic juveniles will be modeled as 60 days
510 (Carlson and Haight, 1976). Dispersal distance over the life of an individual POP is thought to be < 50 km
511 (A. Gharrett, pers. comm.). In lieu of specific information on retention mechanisms, larval/juvenile

512 dispersal or retention in the model must be speculative; we will compare STST and non-STST directed
513 horizontal movements.

514 Sablefish: The sablefish IBM will be developed for this project. Biological information on this
515 species, including data on spawning, early life history, age and growth, and population structure, is
516 relatively meager; therefore the model will be relatively simple. Using locations of adult spawning
517 aggregations from existing fisheries surveys, if available (otherwise larvae from LTL field sampling will
518 be used to initialize the model) spawned eggs will be seeded along the continental slope, shelf gullies, and
519 in deep fjords at depths from 300 to 500 meters from January through March. The newly spawned eggs
520 will be given a slow sinking speed that enables them to descend to depths of 400-500 m. Hatching into
521 larvae at 5-6 mm NL will occur two weeks after spawning and first feeding occur after a further two
522 weeks. Feeding larvae will slowly move to the surface, while horizontal movements will be passive. The
523 growth of larvae and juveniles will follow the sigmoid, Laird-Gompertz growth model developed by
524 Boehlert & Yoklavich (1985). We will test whether purely passive behavior will result in the observed
525 drift of pelagic juveniles inshore. We will also explore the influence of temperature on growth.

526 Pacific Cod: The Pacific cod IBM will be developed for this project. Demersal habitat maps
527 generated by the UTL component, and/or NMFS groundfish surveys, where available, will be used to
528 delineate the spawning areas for cod. Eggs are demersal, and will remain at the bottom (stationary) until
529 hatch. (If we are not successful in delineating spawning habitat, we will initialize the model with larval
530 distributions.) Duration from spawning until hatching, and larval size at hatch will depend on temperature
531 (Alderdice and Forrester, 1971). Larvae will move to the surface at rates that are faster at higher
532 temperatures. After flexion (~10 mm SL), larvae will begin diel migrations. The length at transformation
533 into juveniles will be between 25 and 35 mm SL. Suitable settlement locations will be determined by the
534 UTL component. Habitat suitability maps provided by the UTL component will define nursery areas for
535 focal species with greater precision than the simple depth range now used by other models. We will
536 therefore modify the frameworks to incorporate the GIS-based habitat suitability maps from the UTL
537 component.

538 *Multispecies Model:* Relationships between target species, the environment, and fisheries in the
539 western and central GOA will be evaluated using a static mass balance model of the food web. The mass
540 balance established in the GOA food web model will be used as the initial condition for dynamic
541 ecosystem modeling of species bioenergetics and population growth linked by predator-prey functional
542 response parameters. This MSM predicts the effects of alternative fishing strategies on the ecosystem, and
543 serves as a strategic management tool. The GOA food web model includes 122 living groups, 5 detritus
544 groups, and 14 fisheries. Pollock, sablefish, POP, arrowtooth flounder, and Pacific cod are all separate
545 groups within the model. Several seabird groups and marine mammals including Sea lions are also
546 included. The GOA food web is parameterized with area- and time-specific biomass, production,
547 consumption, and diet composition parameters based on research surveys and single species stock
548 assessments. Fishery catches were reconstructed from National Marine Fisheries Service (NMFS)
549 Observer catch composition data, Alaska Department of Fish and Game (ADF&G) catch statistics, and
550 International Pacific Halibut Commission (IPHC) research surveys and literature values. Details of model
551 construction and parameterization for the entire GOA food web are documented in Aydin et al. (2007).
552 Our method is based on Ecopath with Ecosim (EwE), but we implemented an independent version of
553 EwE to accommodate the large number of functional groups in the GOA food web, and extended the
554 model to accommodate more elaborate functional responses as well as more sophisticated statistical
555 evaluation of fits to data. Modeling the food web on this broad scale allows most of the data collected for
556 single species population models to be used in food web modeling, and best accommodates the scale of
557 current regional management needs. Our equations for major groundfish incorporate age structure, and
558 are identical in scale to single species population dynamics models applied in fisheries. Therefore, the
559 effects of fishing on the species in the model, including their predator-prey relationships and recruitment
560 processes, can be examined at the same scale as current management and stock assessments in the GOA.
561 However, smaller scale ecological processes may be lost in the spatial and temporal averaging. Neither

562 resources from this project, nor data exist to parameterize a food web model at the finer scales used by the
 563 other models. Also, resources do not exist to construct a comparable model for the eastern GOA.

564 While the most recent generation of bio-physical oceanographic models have been both
 565 parameterized and validated with environmental empirical data, it is extremely difficult to compare
 566 predicted larval trajectories with realized dispersal in the field. However, the emerging field of seascape
 567 genetics (Galindo et al., 2006, Galindo et al. *in review*, Selkoe et al., 2008), the marine analog to
 568 landscape genetics (Manel et al., 2003), allows explicit comparison between predicted and observed larval
 569 connectivity patterns. While not an essential model element, we will use the genetic model of Galindo et
 570 al. (2006, In review) to attempt to validate IBM trajectories. The population genetic model developed by
 571 Heather Galindo and colleagues uses the connectivity matrices output from bio-physical oceanographic
 572 simulations to predict the spatial genetic patterns we would see if larvae are dispersing according to the
 573 circulations patterns in the bio-physical model. Input to the genetic model includes variable population
 574 sizes, population productivity, and connectivity matrices. Essentially, the particles in the genetic model
 575 move around according to the connectivity matrices and carry their genes with them. At the end of a
 576 given simulation, the model details the allele frequencies for each locus in each of the populations across
 577 the seascape.

578
 579 ***C6a. What is the model intended to predict?*** The overall goal of our vertically coupled suite of models is
 580 to predict recruitment success of the UTL components five target species under different environmental
 581 conditions. The specific predictions of each of our four essential model elements are as follows:

582 The ROMS model will predict currents and scalars properties (temperature, salinity, etc.) at every
 583 grid location and time step. By identifying physical indicators that characterize each regime we aim to
 584 develop a list of properties that can be easily monitored and allow early prediction of regime change.

585 The GOANPZ model will predict the biomass/concentrations of LTL state variables and primary and
 586 secondary production at each time step and grid point. Our work will provide an understanding of how the
 587 lower trophic level ecosystem production changes with the difference in the physical regime and the
 588 indices we develop will allow prediction of LTL dynamics under alternate regimes.

589 The IBMs will predict, for every time step, the vertical and horizontal location of individuals of the
 590 five target species during their early life stages of target species, as well as the location and timing of
 591 settlement. Development of recruitment indices will enable predictions of how, under a particular regime,
 592 recruitment for the five groundfish species may differ from mean recruitment levels. The more complex
 593 of the IBMs will also predict characteristics such as length, weight, age and condition. Our connectivity
 594 analysis, combined with a genetics model, will enable us to predict the likelihood of genetic
 595 differentiability between the YOY nursery areas.

596 The MSM evaluations will provide predictions of relative impacts of different environmental
 597 conditions (production regimes) and groundfish recruitments on the GOA food web and fisheries.

598
 599 ***C6b. What specific aspect of the prediction is anticipated to be of direct value for fisheries
 600 management?*** The indices of recruitment of the five target groundfish species and the predictions from
 601 the MSM are expected to be of direct value for fisheries management. Additionally, the mechanistic
 602 understanding of how recruitment of the five species is affected by environmental conditions will assist
 603 managers in planning for future climate regimes. Our identification of distinct physical regimes, the
 604 linking of these regimes to production and recruitment patterns and the development of indices which
 605 may be easily monitored will aid managers' abilities to identify regimes shifts in the GOA and respond
 606 with appropriate shifts in management schemes to mitigate harm to the ecosystem and groundfish stocks.

607
 608 ***C6c. What measure of "accuracy" in the prediction is crucial to determining the usability of that
 609 prediction to fisheries management?*** The ROMS and LTL models could be considered accurate if the
 610 simulated and observed 95% confidence intervals of each variable overlaps. Due to the complexity of the
 611 GOA ecosystem, model results are unlikely to exactly replicate field observations at any given location

612 and time and a point by point comparison in time and space is considered inappropriate. To assess model
613 accuracy we will therefore compare model output combined over a range of times and locations to the
614 corresponding grouped field observations. Recruitment predictions from the IBMs can be considered
615 useful to fishery managers if the index, or combination of indices is able to explain >50% of the
616 variability in past recruitment (Oliviera and Butterworth, 2005). True assessment of the accuracy of MSM
617 predictions would require implementing the alternative management strategies in the field under different
618 environmental conditions, which is impractical. Rather, we test the accuracy of the management
619 assumptions under changing conditions within the model. This provides useful information for fishery
620 managers about the risk of certain management strategies and allows them to evaluate which strategy
621 might be most conducive to sustainability given the uncertainty in environmental conditions.
622

623 ***C6d. What alternative models are plausible competitors whose performance should be tested against***
624 ***the model being developed?*** OSCURS is a competing hydrodynamic model to ROMS. OSCURS is a
625 coarse-scale estimate of near-surface flow, which combines daily wind drift with long-term mean
626 geostrophic currents. Despite its coarse spatial resolution it has been used in many fisheries applications.
627 Stockhausen (NOAA/AFSC, pers. comm.) has conducted side-by-side comparisons of float paths from
628 OSCURS, ROMS, and drogued drifters in the Bering Sea. Surface float tracks are reasonably similar,
629 however OSCURS cannot produce accurate subsurface trajectories. DiLorenzo et al. (2009) have
630 developed 20- and 10-km resolution models of the Northeast Pacific, and Chao et al. (pers. comm.) have
631 data-assimilating nested models of the GOA. However, to our knowledge ours is the only model at an
632 advanced stage of development with a grid resolution of 3-km (or less) that simultaneously covers the
633 *entire* GOA (both east and west), contains tides (and the effects of tidal mixing on subtidal dynamics),
634 and has validated hindcasts of the CGOA (Dobbins et al., 2009, Coyle et al., in prep.). We consider that
635 the 10-km resolution of the ROMS model presently in use for many applications too coarse a resolution
636 for this study in the GOA, given the complex topography and intense flows, however we will test this
637 perception under this study.

638 Fiechter et al. (2009) have implemented a five component NPZ model on a 10-km grid centered on
639 the Kenai peninsula. However, during the GLOBEC program the observational field scientists found this
640 level of detail insufficient to capture observed ecosystem dynamics. Plausible alternative NPZ models
641 with sufficient level of complexity include the NEMURO model parameterized for the North Pacific
642 (Kishi et al., 2007). However, this model fails to include seasonal vertical migration of *Neocalanus* and
643 does not have a temporally dependent introduction of iron with the freshwater, as does the GOANPZ.
644 Both enhancements are crucial for simulating seasonal and interannual dynamics in GOA.

645 Alternatives to IBMs, providing transport information and individual histories are not common.
646 Eulerian models, as opposed to Lagrangian IBMs, assume that all individuals at a particular gridpoint and
647 time are the same, thereby ignoring the differences due to life history thought to play an important role in
648 determining recruitment. Complex behaviors and mechanisms are also harder (if not impossible) to
649 include in aggregated Eulerian models. Potential averaging errors could be minimized by fully integrating
650 IBMs within ROMS (i.e. running the IBMs online), and this method would provide 2-way coupling
651 between larval fish and their prey and predators. However, this method is new and untested, and would
652 require much further development, delaying its implementation. Also, if this type of model were to be run
653 with sufficiently fine grid resolutions in the ROMS model, computational requirements would be
654 prohibitive. A significant advantage to our approach of running the IBMs offline is that multiple IBM
655 runs can be performed for each realization of the ROMS/GOANPZ model. This permits much more
656 extensive model tuning, sensitivity analysis and optimization. Finally, correlative models comparing
657 recruitment to physical and biological factors will be developed to examine recruitment mechanisms in a
658 non-spatial, statistical sense. The retrospective recruitment models that will be developed under the UTL
659 component will be useful, to compare with IBM recruitment predictions, and recruitment-environment
660 relationships. These models, however, provide no information about the mechanism relating bio-physical
661 factors to recruitment success and often do not hold up in the long term. Our modeling approach will

662 examine mechanistic links, including areas where the correlative models break down.

663 Many possible competing models exist for the MSM, including simpler minimum realistic models of
664 a subset of linked groundfish species in the GOA, fully spatial ecosystem models such as Atlantis (Fulton,
665 et al., 2003), and multiple options between. The more complex models such as Atlantis would be
666 impossible to implement alongside the planned NPZ and IBM models with the resources and timeframe
667 allocated for GOA IERP modeling.

668

669 ***C6e. How will the achieved predictive power of the model be compared against the performance of***
670 ***plausible alternatives, and how will this guide subsequent choices about model form and***
671 ***parameterization?*** We will compare our vertically linked model estimates of recruitment, and predictions
672 of important indicators of recruitment to the UTL retrospective correlative model. While we plan to use
673 information from the correlative model to aid in choosing hindcast years, the suite of vertically linked
674 models will not specifically use the correlates as drivers. We will not have the resources available to run
675 any alternative oceanographic or NPZ models under this proposal to compare with our model. However,
676 the 10-km ROMS/GOANPZ model will be run for each of the planned 3-km model simulations to
677 provide boundary conditions for the finer resolution grid. We will therefore be able to perform a direct
678 comparison of the two grids by running the IBMs on both for at least a few years. Divergence of
679 trajectories will be assessed and the appropriateness of the 3-km grid determined. Given the relative
680 simplicity of the MSM model, many runs are possible with alternative (or random) base food web
681 parameterizations and alternative environmental conditions/recruitment time series produced by the NPZ
682 and IBM models.

683

684 ***C6f. What data are available to drive, calibrate, and test the model?*** Historical data that we
685 anticipate using for model forcing, development, and validations is outlined in Table 2. We have access to
686 most of these data (and the scientists who collected them) locally at UAF and AFSC, and analysis
687 software has already been developed to compare observations with model output.

688

689 ***C6g. How will the existing data be used to quantify model fit and predictive power?*** Our approach to
690 quantifying model fit and predictive power are described below for each of the essential model elements.

691 ROMS: Validation of the 10-km NEP ROMS model is underway by Danielsen (pers. comm.) for the
692 Bering Sea. To ensure that the 3-km ROMS model is capturing all dominant physical modes of
693 variability, we will compare the dominant spatial/temporal modes (via EOF analysis) in historic data (i.e.
694 temperature and currents) with their equivalent derived from ROMS model output. We have used an
695 analogous approach in past studies of the Northeast Pacific (Hermann et al., 2009b) and previous physical
696 modeling of the CGOA (Dobbins et al., 2009). We will develop Taylor diagrams to examine the
697 correspondence between model and data.

698 GOANPZ: This model has already been extensively tuned to the Seward Line data for the GLOBEC
699 years 2001-2003 (NPRB Project 614, Coyle et al. in prep.) using 1D and 3D versions of the model. The
700 model parameters have been optimized such that the model captures key features of the GOA ecosystem
701 dynamics. Model output is unlikely to exactly replicate field observations at any given location and time,
702 as 3D simulations cannot replicate eddies and meanders generated in nature, except in a statistical sense.
703 To validate model performance we will compare grouped (over time and space) GOANPZ model output
704 to the corresponding grouped historic field observations from independent data. In addition to comparing
705 mean and standard deviations for model and data, model performance will be assessed through a series of
706 statistical indices including the correlation coefficient, the Root Mean Squared Error, and the Modeling
707 Efficiency (Stow et al., 2008). The variables of focus will be nitrate, ammonium, chl-a, and
708 mesozooplankton biomass. Statistical indices will be calculated for the hindcast years to assess model
709 skill. Statistical measures of model skill will be recalculated following any modifications to the model
710 formulation to assess if model predictive power is significantly improved. The uncertainty of predictions
711 associated with the ROMS/GOANPZ model has been assessed via Monte Carlo analysis for a version of

712 the NPZ model adapted to the Bering Sea ecosystem under the BEST-BSIERP program (Gibson and
713 Spitz, in prep.). This analysis followed the approach of Megrey and Hinckley (2001). As the
714 ROMS/GOANPZ and the ROMS/BESTNPZ models are structurally similar, this analysis provides a good
715 indication of the relative impact of each biological model parameter on each of the model state variables
716 and on magnitude of the state variable response to parameter variability. Satellite ocean color data will
717 provide a broader spatial-temporal context for chlorophyll concentration (Henson, 2007), although, due to
718 known problems with calibration this data has to be treated with caution. If satellite data is of sufficient
719 quality for our focus years we will calculate model skill scores (Jolliff et al., 2008) to determine the
720 models ability to simulate observed patterns in chl-a relative to the historic average chl-a field.

721 IBMs: With the exception of a few sets of larval and juvenile distributions data and recruitment
722 assessments from the stock assessment models, data to fit the IBM models is unavailable from historical
723 sources. Spatially inexplicit parameters can be optimized using a 1D version of the IBM which will allow
724 sufficient realizations for meaningful statistical analysis. Model sensitivity analyses and optimization will
725 most likely be done using Prism Latin Hypercube algorithms (Megrey and Hinckley, 2001). One
726 dimensional optimization will be carried out on less-well known parameters and those that are determined
727 by prior sensitivity analysis to be the ones that most effect model behavior. The 1D IBM is
728 computationally inexpensive, making it possible to perform thousands of iterations. We expect to be able
729 to complete about 100 runs of each of the five 3D IBMs for the historic years. Error bars will be
730 generated from these multiple runs. This set of linked models can be fit to data with respect to non-spatial
731 outputs (estimated recruitment, primary production, biomasses) or with respect to spatial outputs. We
732 intend to use standard statistical techniques such as multiple linear or nonlinear regressions, general
733 additive models (GAMs), correlations, etc. to compare these non-spatial outputs to data. Spatial outputs
734 will most likely be fit via the use of “pattern analysis”, rather than calculating a point-by-point estimate of
735 the difference between model output and spatial data. Expected patterns will be generated from prior
736 knowledge of the system and habitat maps produced by the UTL component. For example, the edges of
737 banks are known to be areas of higher production. IBM connectivity analyses cannot truly be validated
738 using comparisons with static fish distribution patterns as transport pathways cannot be known.
739 Methodologies such as mass-marking or tagging will not work on our widely distributed, highly fecund
740 species, at life stages with extremely high mortality rates. A simple genetics model using connectivity
741 maps derived from the IBMs and simple genetics principles will be used to indicate whether genetic
742 differences are likely or possible. Most commonly, the F_{ST} statistic is used to indicate the relative amount
743 of genetic differentiation among populations or groups (Weir and Cockerham, 1984). The presence or
744 absence of a statistically significant F_{ST} between two groups can be directly compared between the
745 predicted and observed patterns, providing a relatively simple metric of whether the bio-physical model is
746 capable of generating spatial genetic breaks at the same locations they are observed in the field. In order
747 to validate any IBM on POP, it is necessary to be able to distinguish POP larvae and juveniles collected in
748 the LTL, MTL and UTL field samples. We have requested that the GOAIERP field scientists collect
749 samples for genetic analysis. However, there is insufficient funding to analyze them under this RFP; thus
750 it will not be possible to completely validate the model under this project.

751 MSM: Dynamic species interaction (functional response) and production parameters for the MSM
752 can be estimated by fitting to time series data using likelihood methods. Time series of biomass,
753 production, consumption, and or diet can be incorporated into the model. Historic time series data has
754 already been incorporated for the focal species in the GOAIERP study and conventional time series
755 fitting, estimating a set of parameter values minimizing the negative log likelihood of the data as a
756 function of the parameters, has been carried out within the Ecosim-type dynamic model (Aydin et al.,
757 2007) using the Davidon-Fletcher-Powell (DFP) algorithm as implemented in Press et al. (1992). A
758 lognormal likelihood was assumed for fitting to both biomass and catch time series, while a multinomial
759 likelihood was assumed for fitting to diet compositions for a particular species.

760

761 **C6h. What pertinent future data are anticipated to become available within the time frame of the**
 762 **project?** Anticipated future data is outlined in Table 2.

763
 764 **C6i. How will the future data be used to quantify model fit and predictive power?** The 2011 field data
 765 will initially be used to validate the ROMS, GOANPZ and IBM models (forecast ability) using validation
 766 techniques described in section C6g. However, 2011 will be our main source of IBM data. Therefore,
 767 subsequent to the initial model validation the 2011 data will be used for further model fitting and then the
 768 adjusted models will be re-validated with the independent 2013 field data.

769
 770 **C6j. How has it been determined that the proposed quantity and quality of data can be expected to be**
 771 **sufficient for the intended use in tuning and testing the model?** Ideally the field scientists would be
 772 collecting repeat samples at each station in order to determine the standard deviation of the observed data.
 773 However, following discussions with field scientist it appears unlikely that this assessment of inherent
 774 variability in the system will occur due both to fiscal constraints of the field sampling program and the
 775 high inherent sampling variability. Therefore, the best we will be able to do is group the field data into
 776 regions of the GOA (i.e. east, central, west, on-shelf, off-shelf) and perform statistical comparisons
 777 between models and data for each region. At the time of writing this proposal the exact number and
 778 location of the LTL, MTL and UTL field stations is still under debate. However, after an initial validation
 779 exercise using 2011 data, we plan to use the 2011 field data to parameterize and tune the LTL and IBM
 780 models and use the equivalent 2013 data as an independent data set to validate the ROMS, LTL and IBM
 781 models. The broad scale of the MSM allows most of the data collected for single species population
 782 models to be used in food web modeling, and best accommodates the scale of current regional
 783 management needs. Our dynamic equations for major groundfish incorporate age structure, and are
 784 identical in scale to single species population dynamics models applied in fisheries. However, no amount
 785 of field data is sufficient to tune and test this model for all hypothesized ecosystem states over all
 786 management strategies.

787
 788 **C6k. How will the probabilistic nature of model forecasts be represented in model output, and how will**
 789 **this be communicated to eventual users of the model predictions?** The main investigation of uncertainty
 790 in the vertically integrated modeling project will focus on species responses (recruitment) to alternate
 791 physical forcing regimes. We expect to find approximately 5-6 patterns or regime types from our analysis
 792 of the NEP5 model output (P. Stabeno, pers. comm.). Ideally, the fully implemented 3D
 793 ROMS/NPZ/IBM should be run thousands of times on the 3-km CGOA grid with slight variations in
 794 forcing and parameter values to generate data sets against which statistical inferences can be made at any
 795 given time and location. Unfortunately, available computer resources severely limit the number of times
 796 the 3D model can be run. Therefore, for each regime, we will run the ROMS/GOANPZ model for 2-3
 797 representative years, for a total of 10-18 runs of the full model. Each of the ROMS/NPZ runs will be used
 798 to force multiple IBM runs (of the order of 100's). Each IBM simulation will use alternate values for key
 799 IBM parameters, such as those determining growth and movement rules. The range of potential values for
 800 the key IBM parameters will be selected following discussions with the field scientists. Model output
 801 following each simulation will be assessed and error bars for the IBM model predictions (a measure of
 802 forecast uncertainty) will be derived. Contributing factors to model forecast uncertainty will be compared;
 803 for example, among-regime physically driven variability vs. among-individual variability driven by
 804 stochasticity in the IBM model.

805 The probabilistic nature of the effects of the different regimes on recruitment, and how this affects
 806 ecosystem and population trajectories will be explored by incorporating the uncertainty in base food web
 807 parameters and time series used to drive the MSM model. Presentations of results will include depictions
 808 of uncertainty so that managers may assess the relative utility of the predictions. The multispecies model
 809 incorporates uncertainty in its base food web parameters using the EcoSense method described in Aydin
 810 et al. 2007. Briefly, thousands of alternative food web realizations are generated using prior distributions

811 on all base model parameters which are broader for more uncertain parameters and narrower for better
 812 known parameters. Then, any perturbation or alternative forcing time series is implemented for each
 813 alternative food web realization and run forward in dynamic mode to create a distribution of trajectories
 814 and endpoints of future projections.

815

816 ***C6l. What is the schedule for providing NPRB with specified data files of observations and model***
 817 ***output fields, and how does this set of observations and outputs ensure transparency and verifiability?***

818 Model simulations of a few recent years of hydrography and LTL dynamics will be provided to the
 819 observational field scientists and NPRB prior to the planned 2011 field year. By December 2011 we will
 820 provide NPRB with results from the regime analysis. Prior to March 2013 we provide field scientists and
 821 NPRB our initial simulation of 2011 hydrographic, LTL and juvenile fish dynamics in addition to our
 822 prediction of recruitment strength for each of the five target species. Following the 2013 field year we
 823 will be able to use observations of recruitment for species that recruit within two years (from the 2011
 824 year class) to test the accuracy of our predictions. In 2014, at the end of the project we will provide NPRB
 825 with LTL dynamics for the selected 10-20 simulation years, the resultant distributions of target species,
 826 results of the connectivity analyses, indices of recruitment and MSM results. In each instance, in addition
 827 to model output files NPRB will be provided with the pertinent version of model source code and the
 828 parameter input files for each model used to produce the predictions. If necessary, NPRB will also be
 829 provided with the climate forcing files. This suite of files will allow complete reproduction of each model
 830 experiment.

831

832 **D. Project Responsiveness:**

833

834 **D1.** Our proposed project is responsive to the following data and information needs of the UTL
 835 component as outlined in Table 3 of the UTL proposal:

836 1. Biophysical model (ROMS/GOANPZ). Our model will be run for hindcast years showing (a) examples
 837 of the different physical regimes, (b) extremes of recruitment, and (c) extremes of factors correlated to
 838 recruitment (as determined by UTL retrospective component). We do not feel that multi-decadal
 839 simulations with this model are the best use of limited computer resources. We feel that the identification
 840 of the different regimes and factors useful in identifying them will allow managers to quickly identify the
 841 presence of a new regime and understand how different regimes affect recruitment and respond
 842 accordingly.

843 2. and 3. In addition to receiving observation-based indices of zooplankton abundance for the eastern and
 844 central GOA from the LTL component we will provide the UTL component with model-based indices of
 845 physical and lower trophic level variability that will help identify regimes and may help predict
 846 recruitment.

847 4. We will utilize ichthyoplankton distributions of eggs and larval stages to initialize and/or groundtruth
 848 our IBM models.

849 5. We will utilize habitat maps from the UTL component as input to our IBMs. We will use information
 850 on juvenile nursery areas, including habitat maps to groundtruth our IBM models.

851 6. We will develop individual based transport models (IBMs) for the five UTL target species to assess
 852 connectivity (the connections between spawning and nursery areas), and to derive transport-related
 853 recruitment indices. The models will also provide indices related to survival along various larval
 854 trajectories. We will derive indices of recruitment success for inclusion in the MSM. If the UTL
 855 component provides us with specific (East vs. West) stock assessment estimates of recruitment for some
 856 of the target species we will produce separate recruitment predictions for the East and West, making it
 857 possible to make region specific comparisons between stock assessment estimates and model recruitment
 858 estimates and inter-region comparisons of IBM recruitment predictions.

859 7. We will use available genetic information on POP (Garrett's NPRB Projects 420, 512 and 908, and
 860 any further genetic analyses) to corroborate model results. Funding of the genetic work itself under this

861 proposal is not financially possible. If further genetic work is funded under GOAIERP program, we will
862 be able to use this information.

863
864 One of the goals of the UTL component is to assess the effects of environmental variability, habitat,
865 competition and predation on juveniles, and various fisheries management strategies in a multispecies
866 context. We will provide a pre-existing MSM of the western and central GOA which will use output from
867 ROMS/GOANPZ and IBMs, for this purpose.

868
869 **D2.** Discussions with PIs from the LTL and MTL GOAIERP components indicates that in addition to the
870 indices relating to recruitment we will develop, the field scientists are interested in the mechanistic
871 understanding of the GOA ecosystem that the model will provide and in the predicted seasonal
872 distributions of ecosystem components, particularly in regions that they are unable to sample. Further
873 details of anticipated model products are provided in section D1 and E4.

874
875 Elements of this work that are innovative include the analysis of the physical model simulation time
876 series to identify different regimes, the development of recruitment indices from connectivity and
877 longitudinal analyses of IBM output, the use of the genetic model to begin to validate connectivity, and
878 identification of variables which can be monitored to enable identification of regimes.

879
880 Funding from this project will allow Hinckley, Stockhausen and Gaichas to extend their previous
881 NOAA research to four groundfish species in the GOA that have not been studied using IBMs feeding
882 into MSMs. It will allow further runs of the ROMS/GOANPZ and IBM models to evaluate the effects of
883 physical and biological factors on recruitment of important groundfish species, and to evaluate indices of
884 recruitment and fishing strategies in the context of a MSM. None of this work can be funded with present
885 NOAA resources.

886 **E. Program Management, Timeline and Milestones**

887 **E1. Management**

888
889 **E1a. Research team.** Drs. Hinckley and Gibson will be responsible for overall project execution,
890 oversight and management, including writing reports, and coordinating activities among modeling PIs
891 from all institutions and with the other GOAIERP components. The project lead PIs will ensure that
892 communications and information sharing occurs in a timely manner among all PI's. Drs. Ladd and
893 Hermann will perform the analysis of the NEP5 output to identify the regimes and will validate the
894 physical model output. Dr. Coyle and Dr. Gibson will update, run and validate the GOANPZ model. Drs.
895 Hinckley, Gibson, Stockhausen and Parada will update or develop the IBMs for each of the five focal
896 species, produce the connectivity matrices, and the indices of recruitment. These four PIs will also
897 transform indices into recruitment biomass for the MSM model. Dr. Parada will develop the longitudinal
898 analysis methods. Dr. Galindo, a collaborator on this project, will use her genetics model to predict which
899 juvenile nursery areas are likely to be genetically differentiable and will begin the process of validating
900 the connectivity matrices. Dr. Gaichas will update and run the MSM model. All PIs will work together to
901 analyze and interpret results. Dr. Hedstrom is not a PI on this project but she will provide ROMS model
902 expertise for debugging, problem solving and technical assistance.

903
904 We will use a web tool ("Basecamp") for information sharing; This will be set up in 2010 and
905 maintained by Dr. Coyle to ensure all personnel have access to all information required to perform their
906 tasks. Skype, WebEx, telephone and videoconferencing will be used on an as-needed basis. Information
907 will also be passed among PI's at the annual all-GOAIERP meeting and at two meetings per year of the
908 modeling group. Dr. Coyle will be responsible for communication between the modeling component and
909 the GOAIERP data manager.

911 General computer support will be supplied by the respective institutions. The ROMS/GOANPZ
912 model will require supercomputing resources. The Arctic Region Supercomputing Center will supply
913 support for ROMS/GOANPZ runs and data storage (see Letter of Support from ARSC); additional
914 supercomputing time is available at the Forecast Systems Laboratory in Boulder, CO under the account of
915 A. Hermann.

916

917 Below is a summary of the expertise of each PI and collaborator:

918 *Co-Lead PI: Dr. Sarah Hinckley, NOAA/AFSC.* Hinckley is a fisheries oceanographic modeler in the
919 FOCI program studying recruitment and physical/biological interactions in Alaskan ecosystems. She
920 (along with Al Hermann and Bern Megrey) is experienced using IBMs to study recruitment mechanisms
921 and dynamics. She has been lead PI on NPRB-funded (#523, #624) and NOAA-funded projects using
922 IBMs to study connectivity and recruitment dynamics of pollock and snow crab in Alaska, and the
923 invasive potential of green crab along the West Coast. She is the creator of the GOANPZ model under
924 GLOBEC funding, and has collaborated with Ken Coyle in its further development, refinement and
925 tuning (NPRB Project 614).

926 *Co-Lead PI: Dr. Georgina Gibson, UAF.* Gibson has been intimately involved with the development of
927 the GOANPZ model that is at the core of our proposed research. She has working knowledge of the
928 coupled ROMS/GOANPZ model, the FORTRAN code in which it is written, and experience displaying
929 three-dimensional model output (vis5D, GoogleEarth). Through the BEST-BSIERP program (NFS
930 Award Id: 0732538) Gibson has adapted the GOANPZ model to the Bering Sea through re-
931 parameterization and the addition of benthic infauna and jellyfish components. Gibson has experience
932 with IBM type modeling through an ongoing NPRB research project (#805) in which, she, in
933 collaboration with Coyle, is exploring mechanisms controlling the transport of mesozooplankton onto the
934 shelves of the Bering Sea and GOA.

935 *Co-PI: Dr. Kenneth Coyle, UAF.* Coyle has a long history as a zooplankton observational biologist in
936 both the Gulf of Alaska and the Bering Sea, participating in the majority of the GLOBEC LTOP cruises
937 in the GOA and numerous cruises in the Bering Sea. He has extensive knowledge of the regional
938 oceanographic literature in English and Russian, and has a long publication record, both as principal and
939 contributing author. Coyle has played a key role in documenting the distribution and biomass of oceanic
940 zooplankton across both the Bering Sea and Gulf of Alaska continental shelves. He has many years of
941 experience with FORTRAN programming and has participated in optimizing and refining the GOANPZ
942 model for application in the GOA (NPRB project # 614). Coyle will aid in further refining and running
943 the GOANPZ model.

944 *Co-PI: Dr. Sarah Gaichas, NOAA/AFSC.* Gaichas has worked as a Research Fishery Biologist at the
945 Alaska Fisheries Science Center since 1997 on ecosystem modeling, stock assessment, and fisheries
946 monitoring. She serves on the North Pacific Fishery Management Council's Gulf of Alaska Groundfish
947 Plan Team and Aleutian Islands Fishery Ecosystem Plan Team. She earned a Ph.D. from the University of
948 Washington's School of Aquatic and Fisheries Science in 2006, and an M.S. from the College of William
949 and Mary's Virginia Institute of Marine Science in 1997.

950 *Co-PI: Dr. Albert J. Hermann UW/JISAO.* Hermann has over 17 years experience as an oceanographic
951 modeler with the Joint Institute for the Study of the Atmosphere and the Oceans (JISAO), and is
952 supported by EcoFOCI, BEST, BSIERP, and other interdisciplinary programs. He has adapted several
953 hydrodynamic models (SPEM, SCRUM, ROMS) to sub-regions of the North Pacific, and collaborates
954 with the PIs of this proposal on the development and interpretation of biological NPZ and fisheries
955 models using hydrodynamic output. He will contribute to the development and implementation of
956 relevant Lagrangian and Eulerian simulations for this project, and will assist in the interpretation and
957 publication of results. His ongoing modeling activities with colleagues (under GLOBEC, BEST, and
958 NPRB-funded projects) include multi-decadal modeling of Northeast Pacific physical fields at 10-km
959 resolution, and modeling of the Coastal Gulf of Alaska at 3-km resolution (including tides).

960 *Co-PI: Dr. Carol Ladd.* NOAA/PMEL. Ladd is a physical oceanographer at the Pacific Marine
 961 Environmental Laboratory, NOAA, Seattle. Her research focuses on the influence of physical
 962 oceanography on ecosystems in the Bering Sea and GOA. She has more than 8 years of experience in the
 963 physical oceanography of Alaskan waters. She will analyze hindcast runs and historical data to determine
 964 which years or scenarios to use as boundary conditions/forcing for the 3-km CGOA model.

965 *Co-PI: Dr. Carolina Parada, UW/JISAO.* Parada is a fisheries oceanographer with the University of
 966 Washington Joint Institute for the Study of the Atmosphere and Ocean (JISAO) and the University of
 967 Concepcion, Chile, working in conjunction with NOAA scientists on EcoFOCI and U.S. west coast
 968 research. She has developed IBMs coupled to the ROMS model for anchovy in the Benguela ecosystem,
 969 pollock in the GOA, snow crab in the Bering Sea and green crab off the west coast of the U.S., and has
 970 published papers on the results. She will aid in development of IBMs and do connectivity and trajectory
 971 analyses.

972 *Co-PI: Dr William Stockhausen.* NOAA/AFSC: Stockhausen is a research fisheries biologist and stock
 973 assessment scientist with NMFS at the AFSC. He has developed several biophysical models to simulate
 974 the dispersal of early life stages of marine species, including DisMELS, a model that couples individual-
 975 based sub-models of early life history characteristics (e.g., larval behavior, growth rates) with output from
 976 ROMS oceanographic models to simulate dispersal trajectories of eggs and larvae. He will adapt and run
 977 the DisMELS simulation model to produce and subsequently analyze dispersal trajectories for POP and
 978 arrowtooth flounder under the IBM component of this project.

979 *Collaborator: Dr Kate Hedstrom, Oceanographic Specialist, Arctic Region Supercomputing Center*
 980 *(ARSC):* Hedstrom has worked with the ROMS model for over 20 years, and is one of the most
 981 knowledgeable experts on coding, debugging, and running ROMS. She will derive initial and boundary
 982 conditions, and aid in debugging, code updates, implementation of ROMS on ARSC super computers.

983 *Collaborator: Dr. Heather Galindo, UW.* Dr. Galindo has worked on coupled oceanographic-genetic
 984 models to predict population structure of marine species for over five years. She will run her genetic
 985 model to validate connectivity in the five IBMs.

986
 987 ***E1b. Federal Employees.*** Drs. Stockhausen, Gaichas and Hinckley are Federal employees at
 988 NOAA/NMFS/AFSC. Dr. Hinckley's time commitment to this project, if funded, will fill in her time
 989 from the recently completed NPRB Projects #523 and #614 and the soon to be completed NPRB project
 990 624. Dr. Hinckley's activities during this time period will be part of her overall performance plan. Dr.
 991 Stockhausen will be supported by matching contributions from NOAA/NMFS/AFSC. No current duties
 992 will be reassigned or backfilled; instead, his time commitment to this project, if funded, represents a
 993 "rollover" in commitment from his recently-completed FATE-funded project (FATE Project #07-05). Dr.
 994 Stockhausen's activities on the proposed project will be part of his overall performance evaluation in
 995 2010, as well as in subsequent project years. Dr. Gaichas will be allowed two weeks per year for activities
 996 related to the GOAIERP and will not have any of her current duties reassigned or backfilled.

997

998 **E2. Research Platforms.**

999

1000 If one were to identify models as research platforms as well as essential elements we would like to note
 1001 that the development and running of all of these models are dependent on NPRB funding. No external
 1002 institutional support is provided.

1003

1004 **E3. Timeline and Milestones**

1005 A chronological description of our proposed research activities and anticipated timeline for completion of
 1006 each milestone is outlined in Table 1.

1007

1008

1009 Table 1. Outline of research activities and projected timeline.

Research Activity Milestone	'10		2011				2012				2013				2014				'15		
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	
Run 3km ROMS/GOANPZ for prior years PI's: Coyle																					
NEP5 Regime Analysis PI's: Ladd & Hermann.																					
Comparison between Float Tracking Tools PI's: Parada, Stockhausen, Gibson																					
Construction of IBMs for the 5 target species Dependency: LTL, MTL and UTL information PI's: Parada, Stockhausen, Gibson, Hinckley																					
Develop experimental design for model runs Dependency: Regime Analysis, Recruitment timeseries, UTL retrospective analysis PI's: All PIs																					
Run ROMS/GOANPZ model on NEP grid for boundary conditions for CGOA grid PI's: Hermann, Hedstrom, Coyle, Gibson																					
Run ROMS/GOANPZ on 3 km CGOA grid PI's: Coyle, Gibson																					
Validation of 3km ROMS/GOANPZ Dependency: LTL information PI's: Ladd, Hermann, Coyle																					
Prepare output for IBMs PI's: Coyle																					
Run and validate IBMs Dependency: spawning locations and larval and juvenile distributions from LTL, MTL and UTL PI's: Parada, Stockhausen, Gibson, Hinckley																					
IBM connectivity and trajectory analysis. PI's: Parada, Stockhausen, Gibson, Hinckley																					
Develop indices from all IBM models and explore regional patterns. PI's: Parada, Stockhausen, Gibson, Hinckley																					
Compare model indices to recruitment PI's: Parada, Stockhausen, Gibson, Hinckley																					
MSM simulations Dependency: UTL and MLT information PI's: Gaichas																					
Draft manuscripts and final report PI's: All PI's																					
Prepare Metadata and ready data for submission to NPRB database PI's: All PI's																					

1010
 1011 **E4. Products:** We will supply ROMS model physical output fields, GOANPZ biological and chemical
 1012 fields, and IBM trajectories and other output derived from our model experiments, hindcasts and
 1013 scenarios to the appropriate data repository. We will provide metadata using the Metavist programs to

1014 comply with NPRB requirements. Results will also be delivered to NPRB in Progress and Final Reports,
1015 in a timely manner. Papers in peer-reviewed journals will also be produced. We will produce indices from
1016 the ROMS, GOANPZ and IBM models. Table 1 indicates the expected timeline for product development.
1017 Information on mechanisms underlying recruitment variability and how they interact with other
1018 ecosystems components and fisheries, seasonal and spatial distributions, indices related to recruitment
1019 will be provided to the UTL component. These products are attainable with the requested research funds
1020 within the project time period. These products will enhance future research by identifying physical
1021 regimes, by identifying processes and forcing that influence year class strength, and by providing indices
1022 which can be monitored to detect signals of upcoming recruitment strength. Results from this work will
1023 give managers the ability to evaluate fishing strategies and management alternatives dependent on regime
1024 and predicted recruitment strength. Model output can be used for survey and sampling designs targeted on
1025 areas and timeframes or processes of specific interested, or to potentially detect climate change using
1026 IPCC scenarios. Please refer to section C6h and the timeline in Table 1 for data needs. Research results
1027 will be disseminated by peer reviewed published manuscripts, by presentations at scientific conferences,
1028 and through workshops with stake holders.

1029
1030 **F. Data Management Plan:** Data management for the entire vertically integrated module is included as
1031 part of the UTL component responsibilities. Coyle will be responsible for getting data from the Modeling
1032 component to the GOAIERP data manager. We anticipate needing 200,000 cpu hours on ARSC
1033 supercomputers per year of this project for completion of the ROMS/GOANPZ simulations. This will be
1034 enough for 10 simulations of both the 10-km and the 3-km models, for each year of the project. Based on
1035 model output files sizes we estimate that we will require 10 terabytes of storage during the lifetime of this
1036 project. ARSC has pledged us sufficient hours for completion of this project and the required space on
1037 their storage silos. See the accompanying Letter of Support from ARSC. Additionally, we will need
1038 approximately 12 terabytes of data storage at the appropriate data storage repository for project products.
1039 Dates when information from other components of the GOAIERP program are needed, are specified in
1040 the Timeline, above. Dates when information from the modeling work will be available are noted in the
1041 Timeline section, above. All data and metadata will be delivered to the appropriate data repository within
1042 the time frames required by project management upon completion of the project.

1043
1044 **G. Outreach and Education Plan:** NOAA/AFSC and UAF/IARC have outreach and education
1045 specialists, who will be available for consulting on E&O, and who can incorporate results of this work
1046 into ongoing outreach activities with the public.

1047
1048 **H. Coordination Strategy:** This project will build upon developments of the ROMS model made under
1049 NOAA, NSF, and NPRB funding over many years. The GOANPZ model was initially developed with
1050 NOAA and NSF GLOBEC NEP funding. We will build on results of NPRB 614, which has refined and
1051 tuned the GOANPZ model for the Seward Line, and has been run for 2001-2003. The pollock IBM was
1052 initially developed with NOAA/FOCI funding, and has been further developed with NPRB funding. We
1053 will use the updated pollock model and connectivity matrix database from NPRB Project 523 to inform
1054 our pollock modeling work. We will use the model interface developed by Parada et al. (NPRB 523, 624)
1055 for some of the IBMs. We will utilize the DisMELS interface developed under NOAA/NMFS funding by
1056 Stockhausen. We will use information from Dr. A. Gharrett's work on POP genetics done under NPRB
1057 funding (Projects 420, 512, 908) in our POP IBM. We will use FOCI ELH databases in our IBM work.
1058 We will collaborate on model development with BSIERP PI's. We will interact with LTOP program at
1059 the Seward Line, if funding for this continues. The ROMS/GOANPZ model will be run for GLOBEC's
1060 PanSynthesis and GOA LTL Synthesis programs. Results from NPRB Project 805 exploring zooplankton
1061 transport will also be useful to this study. PI's of this project are participants in all of these other
1062 programs, which will facilitate coordination and cooperation.

1063 Table 2. Historical and future data sources and products that will be used for model validation, initialization and parameterization.

Variable	Historical Data		Expected Future Data		Application
	Source	Years	Source	Years	
Physical Data for ROMS model					
<i>Temperature and Salinity</i>	GLOBEC LTOP EcoFOCI SECOM transect	1998-2004 1974-date 1997-date	GOAIERP LTL	2011+2013	Validation.
<i>Climate Indices</i>					
Aleutian Low North Pacific Index	NCAR	1899-date			Validation.
PDO	JISAO	1900-date			Validation.
<i>Stratification/MLD</i>	GLOBEC LTOP EcoFOCI	1998-2004 1974-date	GOAIERP LTL	2011+2013	Validation.
<i>Currents</i>	1998 –2004 EcoFOCI Moorings	1998-2004 1974-date	GOAIERP LTL	2011+2013	Validation.
Lower Trophic Level Data for GOANPZ					
<i>Nutrients</i>					
Nitrate	GLOBEC LTOP	1998-2004	GOAIERP LTL	2011+2013	Tuning and Validation.
Ammonium	GLOBEC LTOP	1998-2004	GOAIERP LTL	2011+2013	Tuning and Validation.
Iron	Seward Line. Wu et al. (2009)	2004			Parameterization and tuning.
<i>Phytoplankton</i>					
Biomass	GLOBEC LTOP	1998-2004	GOAIERP LTL	2011+2013	Tuning and Validation.
Surface Chl-a	SeaWifs	1997-date	SeaWifs	Uncertain	Validation.
Primary Production	GLOBEC PROCESSES	2002,2004			Validation.
Phytoplankton Rates	GLOBEC PROCESSES Literature	2002,2004 To date			Parameterization.
<i>Zooplankton</i>					
Biomass	GLOBEC LTOP	1998-2004	GOAIERP LTL	2011+2013	Validation.
Zooplankton Rates	GLOBEC PROCESSES Literature	2002,2004 To date			Parameterization.
Focal Fish Data					
<i>Eggs: Distribution and Abundance</i>	ecoFOCI Ichthyoplankton Database	1972-2008	GOAIERP LTL	2011+2013	Initialization.
<i>Larvae</i>					

Distribution and Abundance	ecoFOCI Ichthyoplankton Database NMFS Sablefish survey SECOM transect	1972-2008 May 1990 1997-date	GOAIERP LTL	2011+2013	Initialization or validation.
length-weight relationships	Literature	To Date	GOAIERP LTL	2011+2013	Model development.
<i>YOY Juveniles</i>					
Distribution and Abundance	ecoFOCI Ichthyoplankton Database ADF&G LMT biennial survey Shellfish Assessment Program ADF&G SMT Survey AFSC GOA Groundfish Survey AFSC GOA EIT Survey SECOM transect	1972-2008 1988-date 1971-date 1971-date 1984-2008 1980-date 1997-date	GOAIERP MTL	2011+2013	Historic data will be used for tuning and model fitting. Data collected in 2011 and 2013 will be used for validation of IBM trajectory analysis. Fitting of the MSM. Validation.
Growth rates and diet. Competitors overlap Predator Distributions Mortality rates	Literature	To date	GOAIERP MTL+UTL	2011+2013	IBM development. MSM development.
Region specific stock assessment estimates			GOAIERP UTL	2013	Region specific validation of model recruitment indices.
<i>Spawning Adults</i>					
Distribution and Abundance	AFSC GOA Groundfish Survey Observer Program AFSC GOA EIT Survey CECOM	1984-2008 1996-2009 1980-date	GOAIERP UTL	2011+2013	IBM initialization.
Upper Trophic Level Data					
Groundfish biomass			NMFS groundfish survey	2011+2013	Extend the biomass time series for many species in the model.
UTL Diet			NMFS diet studies		Development and fitting of the MSM.

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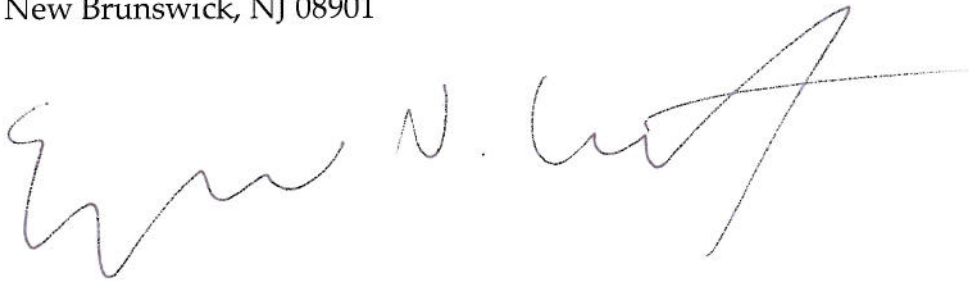
Dr. Sarah Hinckley
Alaska Fisheries Science Center
NOAA
Seattle, WA.

Dear Dr. Hinckley,

This letter is to support your request to use model data for your proposal titled. "Exploring temporal and spatial variability in Gulf of Alaska groundfish dynamics with integrated biophysical models". In particular, we will make available to you and your collaborators any model results from our ongoing hindcast simulations in the North Pacific ocean using ROMS that are relevant to your proposed work. Please be aware that some of this data is only recently been generated and under usual data-sharing protocols should not be further disseminated until it becomes part of the public domain.

With warm wishes,

Enrique Curchitser
Institute of Marine and Coastal Sci.
Rutgers University
71 Dudley Rd.
New Brunswick, NJ 08901

A handwritten signature in blue ink, appearing to read "Enrique N. Curchitser", written over a light blue horizontal line.



Arctic Region Supercomputing Center

NPRB
1007 W. 3rd Avenue, Suite 100
Anchorage, AK 99501

September 29, 2009

Dear review committee

The Arctic Region Supercomputing Center (ARSC) at the University of Alaska Fairbanks is pleased to write in support of Dr. Georgina Gibson and Dr. Sarah Hinckley's NPRB proposal, "Exploring temporal and spatial variability in Gulf of Alaska groundfish dynamics with integrated biophysical models."

We have worked with Dr. Gibson and colleagues for several years, and understand the computational needs of the proposed project. These needs are at a level that is consistent with our ability to support academic research at UAF, and we anticipate being able to provide all the required computational cycles, storage, and support services required for success of the project. The Gulf of Alaska ecosystems and related physical oceanography are of great importance to the University and the State. The proposed research is leading edge, and promises discoveries significant to understanding of complex ecosystems and their ties to fishery production.

ARSC currently operates two large supercomputers, and will introduce two new supercomputers in 2010. Storage capability is on a similar growth track, with over 6,400 terabytes (6.4PB) of capacity using existing equipment. As an UAF faculty member, Dr. Gibson has access to ARSC's systems, storage, networking and expertise.

We are enthusiastic about working with Drs. Gibson and Hinckley on this important research, and anticipate a successful research program, meeting the goals of the her proposed work and of NPRB.

Sincerely,



Dr. Frank Williams
Director



Dr. Gregory B. Newby
Chief Scientist

Sarah Kathleen Gaichas
NOAA Fisheries Service, Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle WA 98115

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Education

2006	Ph.D. in Aquatic and Fisheries Science	University of Washington, SAFS, Seattle, WA
2001	Complex Systems Summer School	Santa Fe Institute, Santa Fe, NM
1997	M.S. in Marine Science (Fisheries)	College of William & Mary, VIMS, Gloucester Point, VA
1991	B.A. w/Distinction in English Literature	Swarthmore College, Swarthmore, PA

Experience

Research Fishery Biologist NOAA/NMFS Alaska Fisheries Science Center, Seattle, WA
Ecosystem Modeling June 2006 - present
Establishing an ecosystem context for fishery management through analysis of food web, fishery, and research survey data combined with ecosystem modeling.

Research Fishery Biologist NOAA/NMFS Alaska Fisheries Science Center, Seattle, WA
Stock Assessment November 1998 – June 2006
Assessed the condition of commercially exploited fish stocks through analysis of fishery and research survey data combined with population dynamics modeling.

Working Group Participant NCEAS (National Center for Ecological Analysis and Synthesis)
December 2001-December 2004
Primary analyst and author for the Gulf of Alaska ecosystem model, one of five models compared during the project "Models of Alternative Management Policies for Marine Ecosystems."

Research Fishery Biologist NOAA/NMFS Alaska Fisheries Science Center, Seattle, WA
Observer Program March 1997-October 1998
Conducted statistical analyses of fishery observer data, evaluated present and proposed data collection methods through directed research, and examined uses of observer data in multiple fisheries resource management and stock assessment applications.

Selected Peer-Reviewed and Management Publications

Gaichas, S., G. Skaret, J.Falk-Petersen, J.S. Link, W. Overholtz, B.A. Megrey, H. Gjoesaeter, W. Stockhausen, A. Dommasnes, K. Friedland, and K. Aydin. 2009. A comparison of community and trophic structure in five marine ecosystems based on energy budgets and system metrics. *Progress in Oceanography* 81: 47–62.

Gaichas, S.K. and R.C. Francis. 2008. Network models for ecosystem-based fishery analysis: A review of concepts and application to the Gulf of Alaska marine food web. *Canadian Journal of Fisheries and Aquatic Sciences* 65: 1965-1982.

Gaichas, S.K. 2008. A context for ecosystem based management: developing concepts of ecosystems and sustainability. *Marine Policy* 32: 393–401.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-178, 298 p.

Gaichas, S.K. 2006. Development and application of ecosystem models to support fishery sustainability: A case study for the Gulf of Alaska. University of Washington Ph.D. Dissertation.

Recent management documents for the North Pacific Fishery Management Council:

September 2009: Ecosystem Assessment coauthor: ftp://ftp.afsc.noaa.gov/afsc/public/Plan_Team/ecosystem.pdf

September 2008: Arctic Fishery Management Plan Environmental Analysis; contributed Arctic Ecosystem Description, Chapter 8, Section 1: http://www.fakr.noaa.gov/analyses/arctic/ArcticFMP_EA1108.pdf

December 2007: Aleutian Islands Fishery Ecosystem Plan; Ecosystem Plan Team member, contributed food web analyses: http://www.fakr.noaa.gov/npfmc/current_issues/ecosystem/AIFEPbrochure1207.pdf

Current Involvement in Research, Science, and Management Organizations

- Member of the Aleutian Islands Fishery Ecosystem Plan Team (2007-present) and the Gulf of Alaska Fishery Management Plan Team (2000-present) for North Pacific Fishery Management Council. Co-authored the Aleutian Islands Fishery Ecosystem Plan (2007) and regularly co-author the Stock Assessment and Fishery Evaluation introduction and summary for the Gulf of Alaska. Authored Ecosystem Description and contributed analyses for management alternatives for the draft Arctic Fishery Management Plan (2008).
- Investigator with 22 others on the interdisciplinary "Collaborative Research: GLOBEC Pan-Regional Synthesis: End-to-end Energy Budgets in US-GLOBEC Regions" project comparing four marine ecosystems in the Southern Ocean, in the Pacific off Alaska and the U.S. West Coast, and in the Atlantic off the U.S East Coast (began 2008).
- Co-organizer of the symposium "Bridging the gap between fisheries and marine conservation to advance ecosystem-based management", for the Society for Conservation Biology's International Marine Conservation Conference (IMCC) in May 2009.
- Invited participant in Asia-Pacific Economic Cooperation International workshop on developing a network for deep sea research in Lima, Peru (2007). Presented information on North Pacific ecosystems, fisheries, and management, and helped develop a preliminary framework for an information-sharing network.
- Invited participant in Society for Conservation Biology symposium on ecosystem consequences of fishing in Port Elizabeth, South Africa (2007) and collaborator on an associated review of fishing-induced trophic cascades for Ecology Letters (review proposal accepted December 2007, manuscript submitted July 2008).
- Participant in the Marine Ecosystems of Norway and the U.S. (MENU) workshop in Bergen, Norway (2007). Compared energy budget models and trophic network attributes for five high-latitude marine ecosystems, presented results at 2007 ICES and PICES meetings, and collaborated on three manuscripts.
- Co-organized "Ecosystem modeling applications in fishery management" symposium at the 2007 American Fisheries Society annual meeting.
- Regular participant in Alaska Fisheries Science Center scientific education and outreach activities, including Pacific Science Center programs, Minorities in Marine Science Undergraduate Program presentations, elementary, secondary, and college educator workshops, internship application review and placement.

Collaborators

Collaborators (last 48 months):

V. Agostini (TNC), K. Aydin (NMFS), S. Barbeaux (NMFS), J. Bisagni (UMass), S. Bograd (NMFS), F. Bowers (ADF&G), R. Brodeur (NMFS), V. Byrd (USFWS), J. Cahalan (NMFS), M. Canino (NMFS), V. Christensen (UBC), J. Collie (URI), M. Connors (NMFS), S. Cox (Simon Fraser U), K. Coyle (UAF), L. Crowder (Duke), K. Daly (USFla), A. Dommasnes (IMR, Norway), M. Dorn (NMFS), J. DiCosimo (NPFMC), T. Essington (UWash), D. Evans (NPFMC), J. Falk-Petersen (UTromso, Norway), J. Field (NMFS), D. Fluharty (UWash), K. Friedland (NMFS), R. Foy (NMFS), S. Gaines (UCSB), C. Gburski (NMFS), D. Gifford (URI), H. Gilroy (IPHC), H. Gjoesaeter (IMR, Norway), J. Hinke (NMFS), J. Hoff (NMFS), E. Hofmann (ODU), A. Hollowed (NMFS), J. Ianelli (NMFS), O. Jensen (UWash), I. Kaplan (NMFS), W. Karp (NMFS), J. Kitchell (UWisc), C. Ladd (NOAA PMEL), J. Link (NMFS), J. Little (UWash), T. Loomis (Cascade Fishing), S. Lowe (NMFS), S. Martell (UBC), B. Matta (NMFS), B. Megrey (NMFS), J. Olsen (NMFS), R. Olson (IATTC), I. Ortiz (NMFS), W. Overholtz (NMFS), R. Reuter (NMFS), J. Ruzicka (OSU), A. Salomon (UCSB/Simon Fraser U), J. Sepez (NMFS), G. Skaret (IMR, Norway), N. Sloan (Parks Canada), P. Spencer (NMFS), J. Steele (WHOI), D. Stevenson (NMFS), W. Stockhausen (NMFS), S. Strom (UWestWA), R. Swanson (NMFS), T. TenBrink (NMFS), C. Walters (UBC), J. Watson (NMFS), G. Watters (NMFS), F. Weise (NPRB).

Graduate Advisors:

M. Sc. Advisor: Mark E. Chittenden, Jr. (College of William and Mary). Committee members: David A. Evans (College of William and Mary), John A. Musick (College of William and Mary), S. Laurie Sanderson (College of William and Mary)

PhD advisor: Robert C. Francis (University of Washington). Committee members: Brian Bershaw (University of Washington), Anne Hollowed (NMFS), Garret Odell (University of Washington), Julia Parrish (University of Washington)

Curriculum Vitae

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Academic Training:

June 1998 B. S. University of Wales, Bangor, UK, Marine Biology & Oceanography (jnt. hrs.)
May 2004 Ph. D. University of Alaska Fairbanks, Biological Oceanography.
Thesis title – Nonlinear Dynamics of Marine Ecosystem Models

Professional Experience:

April 2009-Present Postdoctoral Associate; Cooperative Institute for Alaska Research/Institute of Arctic Research, University of Alaska, Fairbanks, AK.
April 2006-April 2009 Postdoctoral Associate; Arctic Region Supercomputing Center, Fairbanks, AK.
Summer 2001 Computer Laboratory Assistant; Arctic Region Supercomputing Center, Fairbanks, AK.
2000 Research Assistant; School of Fisheries and Ocean Science, University of Alaska, Fairbanks, Fairbanks, AK.
1999-2000 Teaching Assistant; School of Fisheries and Ocean Science, University of Alaska, Fairbanks, Fairbanks. AK.
1998-1999 Research Scientist; Water Research Centre, Swindon, U.K.

Awards Received:

2001-2004: Rasmuson Fisheries Research Center Fellowship.
2000: UAF Presidents Special Project Award

Research Topics of Interest:

My interests concern computational approaches to explore marine ecosystem dynamics in an effort to improve our ability to rapidly detect changes in marine ecosystems and predict future change in marine productivity in response to climatic variability. I specialize in lower trophic level food web models and particle tracking models.

Selected Publications:

Gibson, G., Coyle, K.O., and Johnson, M. (In Prep) The BEST NPZ model. A lower trophic level model for the South East Bering Sea.
Gibson and Spitz (In Prep) Parameter Sensitivity and Uncertainty of the BEST Ecosystem model.

Hinckley, S., K.O. Coyle, G. Gibson, A.J. Hermann and E.L. Dobbins. 2009. A biophysical NPZ model with iron for the Gulf of Alaska: Reproducing the differences between an oceanic HNLC ecosystem and a classical northern temperate shelf ecosystem. Deep-Sea Research II, DOI: 10.1016/j.dsr2.2009.03.003.).

Gibson, G. A., Musgrave, D. L. Hinckley, S. (2005) Non-Linear Dynamics of a Pelagic Ecosystem Model with Multiple Predator and Prey Types. Journal of Plankton Research, vol. 27, pp.427-447

Journals Reviewed for:

Deep Sea Research II

Journal of Plankton Research

Ecological Modelling

Collaborators in past 48 months:

K. Aydin, NOAA; N. Bond, JISAO/Univ. of Washington; K. Coyle, UAF; A. J. Hermann, JISAO; Hinckley, NMFS; K. Hedstrom, ARSC, Y. Spitz, OSU.

Advisors:

Ph.D Advisor: D. L. Musgrave, School of Fisheries and Ocean Science, University of Alaska Fairbanks

Postdoctoral Advisors: M. A. Johnson, Institute of marine Science, University of Alaska Fairbanks.

J. Walsh, Institute of Arctic Research, University of Alaska Fairbanks

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ACADEMIC TRAINING

Cornell University	Ecological Modeling	B.Sc.Eng.	1977
University of Florida	Systems Ecology	M.Sc.	1980
University of Washington	Physical Oceanography	Ph.D.	1988
Woods Hole Oceanographic Institution	Physical Oceanography	Postdoctoral Investigator	1989-1991

PROFESSIONAL APPOINTMENTS AND EXPERIENCE

Affiliate Associate Professor, School of Oceanography, University of Washington, 10/03 – present.

Research Oceanographer, Joint Inst. for the Study of the Atmos. and the Oceans, U Washington, 02/91-present.

Activities: Development and testing of physical models and their coupling with biological models for application to fisheries oceanography in the Gulf of Alaska and the Bering Sea. 3D visualization of model output.

Postdoctoral Investigator, Woods Hole Oceanographic Institution, Dept. of Physical Oceanography, 01/89-01/91.

Activities: Development and testing of oceanic circulation models. Numerical modeling of gravitational adjustment related to deep convection in the coastal and open ocean.

Pre-doctoral Research Associate, University of Washington, School of Oceanography. 09/82 - 12/88.

Activities: Interpretation and synthesis of physical and biological data from upwelling experiments in the Pacific Northwest. Numerical modeling of geophysical fluid phenomena near boundaries. Three months of cumulative seagoing experience.

Faculty Research Assistant, University of Maryland, Center for Environmental and Estuarine Studies, 03/80 - 08/82.

Activities: Numerical modeling of estuarine ecosystems and coastal plain hydrology.

FIVE RELEVANT PUBLICATIONS

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

Hermann, A.J., S. Hinckley, E. L. Dobbins, D. B. Haidvogel, N. A. Bond, C. Mordy, N. Kachel and P. J. Stabenon. 2009. Quantifying cross-shelf and vertical nutrient flux in the Gulf of Alaska with a spatially nested, coupled biophysical model. *Deep Sea Research II*, doi:10.1016/j.dsr2.2009.02.008.

Hermann, A.J. and C. W. Moore. 2009 Visualization in fisheries oceanography: new approaches for the rapid exploration of coastal ecosystems. In: B.A. Megrey and E. Moksness (eds.), *Computers in Fisheries Research*, 2nd ed., DOI 10.1007/978-1-4020-8636-6_10, Springer Science and Business Media B.V.

Stockhausen, W. T., and A. J. Hermann. 2007. Modeling larval dispersion of rockfish: A tool for marine reserve design? In: J. Heifetz, J. DiCosimo, A.J. Gharrett, M.S. Love, T. O'Connell, and R. Stanley (eds.), *Biology, assessment, and management of North Pacific rockfishes*. Alaska Sea Grant College Program, University of Alaska Fairbanks, in press. AK-SG-07-01.

Curchitser, E. N., D. B. Haidvogel, A. J. Hermann, E. L. Dobbins, and T. M. Powell, 2005. Multi-scale modeling of the North Pacific Ocean I: Assessment and analysis of simulated basin-scale variability (1996-2003). *J. Geophys. Res.*, 110, C11021, doi:10.1029/2005JC002902.

FIVE OTHER SIGNIFICANT PUBLICATIONS

Williams, W, T. Weingartner, and A. Hermann. 2007. Idealized Modeling of Seasonal Variation in the Alaska Coastal Current *J. Geophys. Res.*, 112, C07001, doi:10.1029/2005JC003285.

Stabeno, P. J., N. A. Bond, A. J. Hermann, C. W. Mordy and J. E. Overland. 2004. Meteorology and Oceanography of the Northern Gulf of Alaska. *Prog. Oceanog.* 24: 859-897.

Hermann, A.J., D. B. Haidvogel, E. L. Dobbins, and P. J. Stabeno. 2002. Coupling Global and Regional Circulation Models in the Coastal Gulf of Alaska. *Prog. Oceanog.* 53: 335-367.

Hermann, A. J., S. Hinckley, B. A. Megrey and J. M. Napp. 2001. Applied and theoretical considerations for constructing spatially explicit Individual-Based Models of marine larval fish that include multiple trophic levels. *ICES J. Mar. Sci.* 58: 1030-1041.

Hermann, A. J., P. B. Rhines and E. R. Johnson. 1989. Nonlinear Rossby adjustment in a channel: beyond Kelvin waves. *J. Fluid Mech.* 205: 469 - 502.

SELECTED TECHNICAL REPORTS

Brand, E. J., I. C. Kaplan, C. J. Harvey, P. S. Levin, E. A. Fulton, A. J. Hermann, J. C. Field. 2007. A spatially explicit ecosystem model of the California Current's food web and oceanography. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-84, 145 p.

Hermann, A. J. and D. L. Musgrave. 2006. Evaluation of ocean circulation models for the Bering Sea and Aleutian Islands Region. North Pacific Research Board Project 402 Final Report

PROFESSIONAL SERVICE

- President, Eastern Pacific Ocean Congress (EPOC), 09/08-present
- Review panelist for National Science Foundation and Alaska Sea Grant
- Session Chair for annual meetings of PICES, EPOC and AGU
- Member American Geophysical Union and American Meteorological Society
- PhD Students Advised: Dr. William J. Williams, University of Alaska Fairbanks (co-advisor with Dr. Tom Weingartner UAF); Elaina Jorgensen, University of Washington (committee member)

COLLABORATORS AND OTHER AFFILIATIONS

Recent Collaborators

J. Allen (OSU), D. Armstrong (UW-SAFS), H. Batchelder (UC-Berkeley), N. Bond (UW-JISAO), W. Cheng (UW-JISAO), K. Coyle (UAF), E. Curchitser (Columbia-LDEO), E. DiLorenzo (GaTech), E. Dobbins (UW-JISAO), B. Ernst (UC, Chile), J. Fiechter (UCSC), D. Haidvogel (Rutgers), K. Hedstrom (ARSC), S. Hinckley (NMFS), N. Kachel (PMEL), A. Kurapov (OSU), G. Kruse (UAF), C. Ladd (UW-JISAO), B. Megrey (NMFS), A. Moore (UCSC), C. Moore (UW-JIASO), C. Mordy (UW-JISAO), J. Napp (NMFS), J. Overland (PMEL), L. Orensanz (UW-SAFS), C. Parada (UW-JISAO), T. Powell (UC-Berkeley), P. Rand (Wild Salmon Center), N. Soreide (PMEL), P. Stabeno (PMEL), W. Stockhausen (NMFS), M. Wang (UW-JISAO), T. Weingartner (UAF), W. Williams (U Victoria)

Graduate Advisors

PhD co-chairs: Drs. Barbara M. Hickey and Peter B. Rhines, University of Washington

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Education:

University of Alaska Fairbanks, Ph.D. Oceanography, 1997
 University of Alaska Fairbanks; M.S. Oceanography, 1974
 University of Washington; B.S. Oceanography, 1972

Positions Held:

Research Associate, Institute of Marine Science, University of Alaska Fairbanks, 1988–present
 Oceanographic Technician, University of Alaska, 1974–1988
 Graduate Research Assistant, IMS, University of Alaska, January 1972–June 1973
 Graduate Teaching Assistant, Microbiology, University of Alaska, September 1971–December 1971

Experience:

Zooplankton and acoustic studies, Bering Sea and Gulf of Alaska (GLOBEC), 1997 - present
 Scientific exchange: Murmansk Marine Biological Institute, November 1989; Marine Biological Institute, Vladivostok, June–July 1990
 Amphipod energetics, sample collection and processing, data processing, publications, 1986–1994
 Seabird studies with G. Hunt, U.C. Irvine: Zooplankton collections, hydroacoustic data collection and processing, northern Bering Sea and Pribilof Islands, Aleutian Islands, Bristol Bay, 1985–present
 Zooplankton collections, sample processing, data processing, publications, APPRISE project, 1985–1992
 Bering Sea Ice Edge Ecosystem, sample collection, sample processing, data processing, publications, 1976–1978 (BLM, NOAA, OCS), 1981–1982 (Polar Programs)
 Zooplankton and microplankton studies in the Bering, Chukchi and Beaufort Seas (BLM/NOAA, OCS), 1975–1977
 Phytoplankton studies, sea ice and marginal ice zone, Beaufort and Chukchi Seas, 1972–1974

Translator: Russian-English translations:

Russian-English translation of articles from Voprosy Ikhtiologii, Gidrobiologicheskii Zhurnal and Okeanologiya for Scripta Publishing Co., 1985–1995

Thesis:

Coyle, K. O. 1974. The ecology of the phytoplankton of Prudhoe Bay, Alaska, and the surrounding waters.

Dissertation

Coyle, K. O. 1997. Distribution of large calanoid copepods in relation to physical oceanographic conditions and foraging auklets in the western Aleutian Islands.

Relevant Publications:

Coyle, K. O., Konar, B., Blanchard, A., Highsmith, R. C., Carroll, J., Carroll, M., Denisenko, S. G., Sirenko, B. I. 2007. Potential effects of temperature on the benthic infaunal community on the southeastern Bering Sea shelf: Possible impacts of climate change. Deep-Sea Research II, doi:10.1016/j.dsr2.2007.08.025
 Coyle, K. O., Pinchuk, A. I., Eisner, L. B., Napp, J. M. 2008. Zooplankton species composition, abundance and biomass on the eastern Bering Sea shelf during summer: the potential role of

water column stability and nutrients in structuring the zooplankton community. *Deep Sea Res. II.* 55: 1775 – 1791

- Coyle, K. O., Bluhm, B., Konar, B., Blanchard, A., Highsmith, R. C. 2007. Amphipod prey of gray whales in the northern Bering Sea: comparison of biomass and distribution between the 1980s and 2002 - 2003. *Deep Sea Res. II* doi:10.1016/j.dsr2.2007.08.026
- Coyle, K. O. 2005. Zooplankton distribution, abundance and biomass relative to water masses in eastern and central Aleutian Island passes. *Fish. Oceanogr.* 14(Suppl. 1): 77 – 92.
- Coyle, K. O. and P. I. Pinchuk. 2005 Seasonal cross-shelf distribution of major zooplankton taxa on the northern Gulf of Alaska shelf relative to water mass properties, species depth preferences and vertical migration behavior. *Deep Sea Res. II.* 52: 217 – 245.

Recent Publications:

- Coyle, K. O. and P. I. Pinchuk. 2003. Annual cycle of zooplankton abundance, biomass and production on the northern Gulf of Alaska shelf, October 1997 through October 2000. *Fish. Oceanogr.* 12: 327-338
- Coyle, K. O. and P. I. Pinchuk. 2002. The abundance and distribution of euphausiids and zero-age pollock on the inner shelf of the southeast Bering Sea near the Inner Front in 1997-1999. *Deep Sea Res. II*, 49: 6009-6030.
- Coyle, K. O. and P. I. Pinchuk. 2002. Climate-related differences in zooplankton density and growth on the inner shelf of the southeastern Bering Sea. *Prog. Oceanogr.* 55: 177-194.
- Coyle, K. O. and G. L. Hunt. 2000. Seasonal differences in the distribution, density and scale of zooplankton patches in the upper mixed layer near the western Aleutian Islands. *Plankton. Biol. Ecol.*, 47: 31-42.
- Coyle, K. O., V. G. Chatur, and A. I. Pinchuk. 1996. Zooplankton of the Bering Sea: a review of the Russian-language literature. *In: Mathisen, O. A. and K. O. Coyle (eds.). Ecology of the Bering Sea: A review of the Russian Literature.* University of Alaska Sea Grant College Program Report No. 96-01.

Synergistic Activities: Translation of Russian scientific articles and books into English; Development of database of software for analysis of BASIS Bering Sea fisheries and oceanographic data.

Collaborators:

Bodil Bluhm, University of Alaska, Fairbanks
 Ray Highsmith, University of Mississippi, University, MS
 George Hunt, School of Aquatic and Fishery Sciences, University of Washington
 Evelyn Lessard, Dept of Oceanography, University of Washington
 Sue Moore, National Marine Mammal Laboratory, NOAA, Seattle
 Jeff Napp, National Marine Fisheries Service, Seattle
 Phyllis Stabeno, Pacific Marine Environmental Lab, NOAA, Seattle
 Suzanne Strom, Western Washington State University, Bellingham, Washington
 Gordie Swartzman, Applied Physics Laboratory, University of Washington.
 Tom Weingartner, University of Alaska, Fairbanks
 Steve Zeeman, University of New England, Biddeford, Maine

Graduate Advisors: Rita Horner, M.S., R. T. Cooney, Ph.D.

Graduate Student Advisor: C. Adams (PhD 2007), L. DeSousa (PhD, expected 2009)

Sarah Hinckley

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Education

B.S. College of the Atlantic, Ecology, June 1977
M.S. University of Washington, Fisheries, June 1986
Ph.D. University of Washington, Fisheries, June 1999

Professional Experience

Fisheries Research Biologist, Subtask Leader, Ecological and Ecosystem Modeling, FOCI, AFSC: 1999-present
Fisheries Research Biologist, Ecological and ecosystem modeler, FOCI, AFSC: 1991-present
Fisheries Research Biologist, Data analyst, Northwest and Alaska Fisheries Science Center: 1980-1991

PI or Co-PI on research programs including:

2007-2009: Modeling the spread of green crab (Fiest *et al.*)
2006-2010: Optimization of a NPZ model, NPRB (Coyle *et al.*)
2006-2010: Modeling snow crab transport using IBMs, NPRB (Hinckley *et al.*)
2005-2008: Modeling the GOA, NP GLOBEC (Hermann *et al.*)
2005-2008: Pollock Recruitment and Stock Structure using IBMs, NPRB (Hinckley *et al.*)
2004-2006: Multidecadal simulations of circulation and pollock in the GOA, FATE (Hermann *et al.*)
2003-2005: Biophysical Models of Pollock Recruitment in the GOA, NOAA SSLRI (Hinckley *et al.*)
2001-2005: Modeling the GOA, NP GLOBEC (Haidvogel *et al.*)

Relevant Present Research Activities

- Green crab modeling – Use of ROMS/IBMs to study the invasive spread of green crab up the West Coast of the US.
- Snow crab modeling (NPRB funded) – Use of ROMS/IBMs to study larval transport of snow crab in the Bering Sea.
- Optimization of ROMS/GOANPZ model (NPRB funded).
- Pollock recruitment and stock structure using ROMS/IBMs (NPRB funded).
- Member of ICES Working Group on Physical-Biological Interactions.
- Preparation of book prospectus on biophysical IBM models.
- Research into transport of young pollock from the GOA into the BS using ROMS/IBM.
- Use of IBMs to study feeding processes of larval pollock.

5 Relevant Modeling Publications:

Hinckley, S., K.O. Coyle, G. Gibson, A.J. Hermann and E.L. Dobbins. 2009. A biophysical NPZ model with iron for the Gulf of Alaska: Reproducing the differences between an oceanic HNLC ecosystem and a classical northern temperate shelf ecosystem. *Deep-Sea Research II*, DOI: 10.1016/j.dsr2.2009.03.003.

- Hinckley, S., Napp, J.M., Hermann, A.J., and Parada, C. 2009. Simulation of physically-mediated variability in prey resources for larval fish: a three-dimensional NPZ model. *Fisheries Oceanography*, 18:4, 201-223.
- Hermann, A.J., S. Hinckley, E. L. Dobbins, D.B. Haidvogel, N.A. Bond, C. Mordy, N. Kachel and P J. Stabeno. 2009. Quantifying cross-shelf and vertical nutrient flux in the Coastal Gulf of Alaska with a spatially nested, coupled biophysical model. *Deep Sea Research II*, DOI: 10.1016/j.dsr2.2009.02.008)
- Hinckley, S., Megrey, B.A. and Miller, T. 2009. Recruitment prediction. In: *Manual of Recommended Practices for Modelling Physical-Biological Interactions During Fish Early Life*. E. North, A. Gallego, and P. Petitgas (eds.). ICES Cooperative Research Reports, No. 295.
- Gibson, G.A., D.L. Musgrave and S. Hinckley. 2005. Non-linear dynamics of a pelagic ecosystems model with multiple predator and prey types. *J. Plankton Res.*

5 Other Publications

- Hinckley, S., A.J. Hermann, K.L. Mier and B.A. Megrey. 2001. Importance of spawning location and timing to successful transport to nursery areas: a simulation study of Gulf of Alaska walleye pollock. *ICES J. Marine Sci.* 58(5): 1042-1052
- Hermann, A.J., S. Hinckley, B.A. Megrey and J.M Napp. 2001. Applied and theoretical considerations for constructing spatially explicit, individual-based models of marine larval fish that include multiple trophic levels. *ICES J. Marine Sci.* 58(5): 1030-1041
- Megrey, B.A. and S. Hinckley. 2001. The effect of turbulence on feeding of larval fishes: a sensitivity analysis using an individual-based model. *ICES J. Marine Sci.* 58(5): 1015-1029
- Hinckley, S., A.J. Hermann and B.A. Megrey. 1996. Development of a spatially-explicit, individual-based model of marine fish early life history. *Mar. Ecol. Prog. Ser.* 139:47-68.
- Hermann, A.J., S. Hinckley, B.A. Megrey and P.J. Stabeno. 1996. Interannual variability of the early life history of walleye pollock near Shelikof Strait as inferred from a spatially explicit, individual-based model. *Fish. Ocean* 5(Suppl 1): 39-57.

Recent Collaborators

C. Alvarez (Consultant, Mexico), D. Armstrong (UW), J. Burgos (UW), W. Cheng (NOAA/PMEL), K. Coyle (UAF), E. Dobbins (NOAA/PMEL), M. Dorn (NOAA/AFSC), B. Ernst (U. Concepcion, Chile), B. Feist (NOAA/NWFSC), L. Fritz (NOAA/NMML), G. Gibson (UAF), A. Hermann (UW/PMEL), J. Horne (UW), G. Kruse (UAF), B. Megrey (NOAA/AFSC), J. Napp (NOAA/AFSC), L. Orensanz (Cenpat, Argentina), C. Parada (UW), A. Parma (Cenpat, Argentina), S. Salo (NOAA/PMEL), K. See (UW), P. Stabeno (NOAA/PMEL), W. Stockhausen (NOAA/AFSC)

Graduate and Postdoctoral Advisors

Dr. Robert C. Francis (PhD chair): School of Ocean and Fisheries Science, University of Washington, Seattle

Dr. Barbara Hickey: School of Oceanography, University of Washington, Seattle

Dr. Donald Gunderson: School of Ocean and Fisheries Science, University of Washington, Seattle

Dr. Kenneth Rose: Coastal Fisheries Institute, Louisiana State University, Baton Rouge

Dr. Bernard Megrey: Alaska Fisheries Science Center, Seattle

Thesis Advisees and Postgraduate-Scholars

Georgina Blamey-Gibson: Doctoral committee. University of Alaska, Fairbanks (Grad. 2004)

Dr. Carlos Alvarez: Postgraduate Scholar. University of Washington, Seattle

Dr. Carolina Parada: Postgraduate Scholar. University of Washington, Seattle.

Dr. Julian Burgos: Postgraduate Scholar. University of Washington, Seattle.

Carol Ladd

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Education

B. S. California State University, Sacramento, Finance, December 1986
M. S. University of Washington, Seattle, Physical Oceanography, June 1996
Ph. D. University of Washington, Seattle, Physical Oceanography, June 2000

Professional Experience

Oceanographer, NOAA/Pacific Marine Environmental Laboratory (PMEL), 2005-present
Oceanographer, Joint Institute for the Study of Atmosphere and Ocean, University of Washington
2002-2005.
Postdoctoral Research Associate, National Research Council, NOAA/PMEL, 2001-2002
Scientific Programmer, University of Washington, Seattle, 2000-2001
Research Assistant, University of Washington, Seattle, 1993-2000

Relevant Publications

Ladd, C., W. R. Crawford, C. E. Harpold, W. K. Johnson, N. B. Kachel, P. J. Stabeno, and F. Whitney (2009), A synoptic survey of young mesoscale eddies in the Eastern Gulf of Alaska, *Deep Sea Res. II*, doi:10.1016/j.dsr2.2009.02.007.

Ladd, C., C. W. Mordy, N. B. Kachel, and P. J. Stabeno (2007), Northern Gulf of Alaska eddies and associated anomalies, *Deep Sea Res. I*, 54, 487-509, doi:10.1016/j.dsr.2007.01.006.

Ladd, C. (2007), Interannual variability of the Gulf of Alaska eddy field, *Geophys. Res. Lett.*, 34, L11605, doi:10.1029/2007GL029478.

Ladd, C., P. Stabeno, and E. D. Cokelet (2005), A note on cross-shelf exchange in the northern Gulf of Alaska, *Deep Sea Res. II*, 52, 667-679.

Ladd, C., and N. A. Bond (2002), Evaluation of the NCEP-NCAR Reanalysis in the Northeast Pacific and the Bering Sea, *J. Geophys. Res. - Oceans*, 107, 3158, doi:10.1029/2001JC001157.

Other Publications

Ladd, C., and P. J. Stabeno (2009), Freshwater transport from the Pacific to the Bering Sea through Amukta Pass, *Geophys. Res. Lett.*, *36*, L14608, doi:10.1029/2009GL039095.

Ladd, C., N. B. Kachel, C. W. Mordy, and P. J. Stabeno (2005), Observations from a Yakutat eddy in the northern Gulf of Alaska, *J. Geophys. Res. - Oceans*, *110*, C03003, doi: 03010.01029/02004JC002710.

Ladd, C., G. L. Hunt, Jr., C. W. Mordy, S. A. Salo, and P. J. Stabeno (2005), Marine environment of the eastern and central Aleutian Islands, *Fish. Oceanogr.*, *14*, 22-38.

Ladd, C., J. Jahncke, G. L. Hunt, Jr., K. O. Coyle, and P. J. Stabeno (2005), Hydrographic features and seabird foraging in Aleutian Passes, *Fish. Oceanogr.*, *14*, 178-195.

Ladd, C., and L. Thompson (2002), Decadal variability of North Pacific central mode water, *J. Phys. Oceanogr.*, *32*, 2870-2881.

Synergistic Activities:

Mentor for undergraduate student intern, summer 2004.

Reviewer for several oceanography journals (*Deep Sea Research, Dynamics of Atmospheres and Oceans, Geophysical Research Letters, Journal of Geophysical Research – Oceans, Journal of Physical Oceanography, Progress in Oceanography*)

Collaborators in past 48 months

N.A. Bond, UW/JISAO; W. Cheng, UW/JISAO; E. Churchitser, Columbia/LDEO; E. Cokelet, NOAA/PMEL; K. Coyle, UAF; W. Crawford, IOS, Canada; E. Dobbins, UW/JISAO; A.J. Hermann, UW/JISAO; G.L. Hunt, UW; J. Jahncke, Point Reyes Bird Observatory; N.B. Kachel, UW/JISAO; F.J. Meuter, NOAA/NMFS; S. Moore, NOAA/NMML; C. Mordy, UW/JISAO; D. Musgrave, UAF; J. Napp, NOAA/NMFS; S. Salo, NOAA/PMEL; P.J. Stabeno, NOAA/PMEL; F. Whitney, IOS, Canada

Thesis Advisor: L. Thompson, University of Washington

RESEARCHER CURRICULA

1. PERSONAL, ACADEMIC AND PROFESSIONAL BACKGROUND

Name: Carolina Eugenia Parada Véliz
Country of Nationality: CHILE
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PhD in Oceanography, University of Cape Town, South Africa, 2003.
Specialization: **Post-Doc**, Joint Institute for the Study of the Atmosphere and Ocean & NOAA and University of Washington. US. 2003-2007.
Appointment: **Research associate**, School of Aquatic and Fisheries Sciences, University of Washington, Seattle.US. 2007-2008.
Appointment: **Research Scholar**, School of Aquatic and Fisheries Sciences, University of Washington, Seattle. US. 2008-2009.

Research associate, Departamento de Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Concepción, Chile. 2009-

2. CURRENT ACTIVITIES RELEVANT TO THE PROPOSED PROJECT

My current research activities are related to finish running IBM model simulation and write manuscripts for snow crab¹ in the Bering Sea and understand biophysical interaction for green crab² in California Current system in the framework of current projects. In addition, I am involved in analyzing walleye pollock connectivity patterns between GOA and BS through IBM results from previous NPRB project funded³. Currently, we are writing and reviewing IBM manuscripts for walleye pollock NPRB results³.

¹Modeling transport and survival of larval crab: Investigating the contraction and variability in snow crab stocks in the Eastern Bering Sea using individual-based models. **Funding Source:** North Pacific Research Board, United States. **Role** : PI. **Period:** 2007-extended 2009.

²Biophysical model of Green Crab larvae: Invasive species. **Funding Source:** National Oceanographic Atmospheric Administration, United States. **Role:** Co-PI. **Period:** 2008-2009. Biophysical Models of Pollock Recruitment Processes in the Western Gulf of Alaska. **Funding Source:** Stellar Sea Lion, Consortium, United States. **Role:** Co-PI (PI: principal investigator). **Period:** 2003-2005.

³Walleye Pollock Recruitment and Stock Structure in the Gulf of Alaska: An investigation using a suite of biophysical and individual-based models. **Funding Source:** National Pacific Research Board, United States. **Role** : PI. **Period:** 2005-2007

3. FIVE RECENT/RELEVANT PUBLICATIONS

Hinckley, S., J.M. Napp, A.J. Hermann, C. **Parada**. 2009. Simulation of physically mediated variability in prey resources of a larval fish: a three-dimensional NPZ model. (p 201-223) **Fisheries Oceanography**, 18(4):201-223. DOI: 10.1111/j.1365-2419.2009.00505.x (**NPRB**).
Parada, C, Armstrong, D, Ernst, B, Hinckley, S, Orensanz, J.M. (Lobo). 2008. Spatial dynamics of snow crab (*Chionoecetes opilio*) in the Eastern Bering Sea-Putting together the pieces of the puzzle. **Bulletin of Marine Sciences**. In press (**NPRB**).

Lett, C., Verley, P., Mullon, C., **Parada**, C., Brochier, T., Penven, Blanke, B., **2008**, A Lagrangian tool for modelling ichthyoplankton dynamics. **Environmental Modelling & Software**. Vol 23, 1210, 1214.

Parada, C., Ernst, B., Hinckley, S., Orensanz, J.M. (Lobo), Armstrong, D., Curchitser, E., Hermann, A. Patterns of Connectivity and Potential Settlement Regions of Snow Crab (*Chionoecetes opilio*) Larvae in the Eastern Bering Sea. **Submitted** to Progress in Oceanography (July 2009). (**NPRB**).

Parada, C., Hinckley, S., Horne, J., Dorn, M., Hermann, A., Megrey, B. Comparing simulated walleye pollock recruitment indices to data and stock assessment models from the Gulf of Alaska. **Submitted** to Marine Ecology Progress Series. (**NPRB**).

4. FIVE OTHER SIGNIFICANT PUBLICATIONS

Parada, C., Mullon, C., Roy, C., Freon, P., Hutchings, L., Van der Lingen, C. **2008**, Does vertical migratory behaviour retain fish larvae inshore in upwelling ecosystems? A modeling study of anchovy in the southern Benguela, **African Journal of Marine Science**, 18(3): 437-452(16).

Mullon, C., Fréon, P., **Parada**, C., van der Lingen, C., and Huggett, J, **2003**, From particles to individuals: modeling the early stages of anchovy in the Southern Benguela, **Fisheries Oceanography**, Vol. 12. No. 4, 396-406.

Parada, C., van der Lingen C.D., Mullon C., Penven P, **2003**, Modelling the effect of buoyancy on the transport of anchovy (*Engraulis capensis*) eggs from spawning to nursery grounds in the southern Benguela: an IBM approach. **Fisheries Oceanography**, Vol 12, No. 3, 170-184.

Brickman, D., Adlandsvik, B., Thygesen, U.H., **Parada**, C., Rose, K., and Hermann, A., **2008**, Manual for recommended practices: Best Practices for particle tracking. Workshop on advances in modeling physical-biological interactions in fish early-life history: recommended practices and future decisions (the WKAMF Manual of Recommended Practices (MRP). Editors: North E., Gallego, A., Petigas, P. **ICES Working Group on Modeling Physical-Biological Interactions (WGPBI) members** http://northweb.hpl.umces.edu/wkamf/WKAMF-MRP_FinalDraft_24March08.pdf

Ernst, B., Manríquez, P., Orensanz, J.M. (Lobo), Roa, R., Chamorro, J., **Parada**, C. **2008** Strengthening of traditional territorial tenure system through protagonism in monitoring activities by Lobster fishermen from Juan Fernandez Islands (Chile). **Bulletin of Marine Science**. In press.

5. COLLABORATION LAST FOUR YEARS

Dr. David Armstrong:	SAFS, University of Washington (UW)
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Dr. Francois Colas:	Institute of Geophysics and Planetary Physics, University of California
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Dr. Pierre Freon:	IRD, France.
Dr. JM(Lobo) Orensanz :	SAFS, UW and CENPAT, Argentina.
Dr. Samuel Hormazabal:	Departamento Geofísica, Universidad de Concepcion, Chile
Dr. Albert Hermann:	PMEL, NOAA.
Dr. Sarah Hinckley:	AFSC, EcoFOCI, NOAA.
Dr. John Horne:	SAFS, UW.
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Dr. Christopher Lett:	IRD, France
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 The College of William and Mary
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1984 MS, College of Letters and Science
 University of California, Davis
 Davis, CA
 Physics

1982 BS, College of Science and Mathematics
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 double major: Physics and Mathematics

RECENT PROFESSIONAL EXPERIENCE

2004-Present **Research Fisheries Biologist**
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2002- 2004 **Guest Investigator**
 Marine Policy Center
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1995–2002 **Senior Marine Scientist**
 Department of Fisheries Science
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CURRENT RELEVANT ACTIVITIES

Developed DisMELS individual-based biophysical model to provide quantitative annual recruitment indices for flatfish in the Eastern Bering Sea based on dispersal trajectories of eggs and larvae as a follow-on to OSCURS. Co-PI on NPRB-funded project investigating slope/shelf use for spawning and nursery areas by Greenland turbot and Pacific halibut.

RELEVANT PUBLICATIONS

- 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 modeling fish and shellfish responses to future climate change. *ICES Journal of Marine Science*, 66: 1584-1594.
- B. Megrey, J. Hare, **W. Stockhausen**, A. Dommasnes, H. Gjøsæter, W. Overholtz, S. Gaichas, G. Skaret, J. Falk-Petersen, J. Link, K. Friedland. 2009. A cross-ecosystem comparison of spatial and temporal patterns of covariation in the recruitment of functionally analogous fish stocks. *Progress in Oceanography* 81:63-92. doi:10.1016/j.pocean.2009.04.006
- Stockhausen, W.** and A. Hermann. 2007. Modeling larval dispersion of rockfish: A tool for marine reserve design? In: J. Heifetz, J. DiCosimo, A.J. Gharrett, M.S. Love, T. O'Connell, and R. Stanley (eds.), *Biology, assessment, and management of North Pacific rockfishes*. Alaska Sea Grant College Program, University of Alaska Fairbanks.
- Stockhausen, W.** and R. Lipcius. 2003. Simulated effects of seagrass loss and restoration on settlement and recruitment of blue crab postlarvae and juveniles in the York River, Chesapeake Bay. *Bulletin of Marine Science*, 72:409-422.
- Stockhausen, W.**, R. Lipcius and B. Hickey. 2000. Joint effects of larval dispersal, population regulation, marine reserve design and exploitation on production and recruitment in the Caribbean spiny lobster. *Bulletin of Marine Science*, 66(3):957-990.

OTHER SIGNIFICANT PUBLICATIONS

- Link, J., **W. Stockhausen**, G. Skaret, W. Overholtz, B. Megrey, H. Gjøsæter, S. Gaichas, A. Dommasnes, J. Falk-Petersen, J. Kane, F. Mueter, K. Friedland and Jon Hare. 2009. A comparison of biological trends from four marine ecosystems: synchronies, differences, and commonalities. *Progress in Oceanography* 81:29-46. doi:10.1016/j.pocean.2009.04.004
- Gaichas, S., G. Skaret, J. Falk-Petersen, J. Link, W. Overholtz, B. Megrey, H. Gjoesaeter, **W. Stockhausen**, A. Dommasnes, K. Friedland, and K. Aydin. 2009. A comparison of community and trophic structure in five marine ecosystems based on energy budgets and system metrics. *Progress in Oceanography* 81:47-62. doi:10.1016/j.pocean.2009.04.005
- Lipcius, R., D. Eggleston, S. Schreiber, R. Seitz, J. Shen, M. Sisson, **W. Stockhausen** and H. Wang. 2008. Importance of metapopulation connectivity to restocking and restoration of marine species. *Reviews in Fisheries Science*, 16(1-3):101-110.
- Steele, J.H., J.S. Collie, J.J. Bisagni, D.J. Gifford, M.J. Fogarty, J.S. Link, B.K. Sullivan, M.E. Sieracki, A.R. Beet, D.G. Mountain, E.G. Durbin, D. Palka and **W.T. Stockhausen**. 2007. Balancing end-to-end budgets of the Georges Bank ecosystem. *Progress in Oceanography*. 74:423-448.

RECENT COLLABORATORS

Z. A'mar¹, T. Auth¹², R. Beamish¹⁶, A. Beet⁶, J. Bisagni⁸, N. Bond², R. Brodeur¹⁴, M. Busby¹, L. Ciannelli¹², J. Collie⁷, M. Doyle², K. Drinkwater⁵, J. Duffy-Anderson¹, E. Durbin⁷, D. Eggleston¹⁰, M. Fogarty³, S. Gaichas¹, D. Gifford⁷, H. Gjøsæter⁵, V. Guida³, J. Hare³, Albert Hermann², J. Link³, R. Lipcius⁴, M. Martin¹, A. Matarese¹, B. Megrey¹, W. Melle⁵, E. Methratta³, K. Mier¹, D. Mountain³, D. Nichol¹, J. Overland¹⁵, D. Palka³, M. Schirripa¹⁶, S. Schreiber¹¹, R. Seitz⁴, M. Sieracki⁹, A. Shanks¹³, J. Shen⁴, M. Sisson⁴, P. Spencer¹, J. Steele⁶, B. Sullivan⁸, B. Turnock¹, H. Wang⁴, T. Wilderbuer¹, M. Wilkins¹

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