1. PROJECT INFORMATION

GOA IERP Project Number:	G84
Title:	Exploring temporal and spatial variability in Gulf of Alaska groundfish dynamics with integrated biophysical models
Overall project duration	May, 2010 - February, 2015
Overall project funding	**$999,995**
Report period	May 1 2011 to Dec 1 2012
Report submission date	Nov 30, 2012
Lead Author of Report	Georgina Gibson and Sarah Hinckley (co-Lead PIs)

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

Georgina Gibson: gagibson@alaska.edu

Ken Coyle: coyle@ims.uaf.edu

Albert J Hermann: Albert.J.Hermann@noaa.gov

Carolina Parada: cparada@inpesca.cl

Sarah Hinckley: Sarah.Hinckley@noaa.gov

Carol Ladd: Carol.Ladd@noaa.gov

William Stockhausen: William.Stockhausen@noaa.gov

Kerim Aydin: Kerim.Aydin@noaa.gov

Kate Hedstrom: kshedstrom@alaska.edu

2. PROJECT OVERVIEW

A. BRIEFLY (4-5 SENTENCES) DESCRIBE THE CORE PURPOSE OF YOUR PROJECT, AND THE UNDERLYING NEED FOR THIS RESEARCH.

Groundfish recruitment in the Gulf of Alaska is thought to be controlled by physical processes (i.e. climate and transport) and biological processes (i.e. growth and predation) experienced between offshore spawning sites and the end of the young of year (YOY) stage. We will use the Regional Ocean Modeling System (ROMS), a Nutrient-Phytoplankton-Zooplankton (GOANPZ) model, and Individual-Based Models (IBMs) to examine recruitment mechanisms and derive indices related to recruitment for five ground fish species; arrowtooth flounder, walleye pollock, Pacific cod, Pacific Ocean perch, and sablefish. We will also incorporate the indices in a multispecies model (MSM) to explore the consequences of recruitment variability on the GOA ecosystem and fisheries. 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.

B. STATE THE SPECIFIC GOAIERP HYPOTHESIS OR HYPOTHESES THAT YOUR PROJECT IS ADDRESSING.

Our project will address two of the overarching GOAIERP hypotheses:

1) **The gauntlet**: The primary determinant of year-class strength for marine groundfishes in the GOA is early life survival. This is regulated in space and time by climate-driven variability in a biophysical gauntlet comprising offshore and nearshore habitat quality, larval and juvenile transport, and settlement into suitable demersal habitat.

2) **Regional comparison:** The physical and biological mechanisms that determine annual survival of juvenile groundfishes and forage fishes differ in the eastern and western GOA regions.

To achieve the objectives of our project we will address the following testable hypotheses with our suite of models:

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.*

C. LIST THE SPECIFIC OBJECTIVE(S) OF YOUR RESEARCH PROJECT.

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. 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.

- **NEP5 Regime Analysis:** Use Empirical Orthogonal Function (EOF) and other analysis tools to identify a small number (≤ 6) of distinct physical regimes that comprise the major components of environmental variability in the GOA. Categorize each year as representative of a particular regime.
- **IBM Connectivity:** Calculate the proportions of individuals that arrive at juvenile nursery areas from specific source areas (spawning regions or early larval distributions).

- **Trajectory analysis:** Examine the differences between survivors and non-survivors (or those who do not reach nursery areas) by examining correlations between physical and LTL variables and individual characteristics along individual trajectories from the IBMs through the YOY stage
- **Indices: C**alculate indices related to recruitment success from the IBM results for each of the five focal groundfish species. Transform indices into anomalies from mean recruitment biomasses.
- **MSM simulations:** Incorporate recruitment indices from the IBMs into the MSM model to test how the effects of the different environmental regimes on recruitment interact with population dynamics processes and fisheries.

3. PROGRESS SUMMARY

A. PROVIDE A TABLE SHOWING THE TIMELINE AND MILESTONES FOR THE CURRENT REPORTING PERIOD ONLY.

	2012				2013			
Research Activity Milestone	1	2	3	4	1	2	3	4
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								
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								

B. DESCRIBE REPORT PERIOD PROGRESS.

MILESTONES:

Comparison between Float Tracking Tools

During this reporting period, we finished our experiments designed to compare the skill of the offline IBM tools Ichthyop and DisMELS in tracking "floats" relative to the ROMS online float tracking. In the previous "float tracking" comparison between ROMS and the two platforms (DisMELS, Ichthyop) on which we are developing the IBMs for the 5 upper trophic level focal species, we found that the divergence between simulated floats in ROMS and DisMELS was of an acceptable order, whereas that between ROMS and Icthyop V2 was unacceptably large. These inconsistencies were associated with the way that Icthyop was dealing with particles reaching the model grid boundary. However, a new version of Ichthyop (V3.1) became available in June 2012. The new version includes a higher-order particle tracking algorithm (Runge-Kutta) and fixes a problem associated with specifying initial particle depths. The new version of the model also deals better with the grid boundary; there are now several options when a particle hits the coast: “beaching” (moving onto the land – out of the model domain), “standing still” (stopping at the coast wall) or “bouncing” (reflection back to the ocean). These options allow the possibility of continuing with the particle tracking (according with the criterion selected), even though this particle confronts a coastal/island boundary. Examples of the comparisons between ROMS and Icthyop particle tracking are shown in the results section. Now both offline IBM tools are able to reproduce the online ROMS float trajectories adequately, providing a good foundation for the development of species specific IBMs.

Construction of IBMs for the 5 target species

A number of new sub-models for various biological processes have been added by W. Stockhausen to DisMELS and made available to the IBM developers. These include functions describing swimming speed, vertical movement, growth and mortality. Swimming speed models include constant and size-based (power-law) functions with random components. Vertical movement models include diel vertical movement and buoyancy-based implementations. Growth models include linear and exponential growth functions, as well as models that depend on temperature, size, and/or consumption rates; these latter include implementations of models based on Houde and Zastrow (1993), Leising and Franks (1999), Folkvord (2005), Buckley et al. (2006), and the Wisconsin Bioenergetics Model (Hanson et al., 1997). Newly-implemented mortality models include ones based on Houde (1989), Pepin (1991), Houde and Zastrow (1993), and Lorenzen(1996).

Construction (and in the case of the pollock model, adaptation) and testing of the five target species IBMs is actively underway and first versions for most species are complete. The major additions to all of the models that we foresee for the future will be the incorporation of the habitat maps, predator maps and the prey variables from the NPZ model. Preliminary results from some of the IBMs are described in the results section, below.

.

<u>Pollock IBM</u>

The pollock IBM is a detailed model previously developed by S. Hinckley and C. Parada. This model is essentially fully developed, with only minor updates needed, which have been implemented. The original IBM pollock model (developed under NPRB#523) is being adapted to the Ichthyop 3.1. The new multi-year CGOA ROM-NPZ outputs were coupled by Parada to the new Ichthyop model and the evolved sub-models for walleye pollock are being moved to the stable version. The current pollock model considers development of eggs and temperature-dependent growth functions for yolk sac larvae.
Previously developed feeding larval and juvenile algorithms have been reviewed as well as the bioenergetic equations. Vertical and horizontal active movement methods have been reviewed for all stages. Mortality functions and superindividuals will remain in the model, but the mortality rates will be updated with data from new studies.

Cod IBM

The initial version of the Pacific cod model contains detailed algorithms for egg development, larval growth and mortality and mortality of the egg and larval stages as functions of temperature. The depth distribution of the different life stages has been included. The life stages presently incorporated in the Pacific cod IBM are egg, yolk-sac larvae, feeding larvae before diel migration begins, feeding larvae after the beginning of diel migration, epipelagic juveniles, which are individuals that are ready to settle but which have not yet found suitable nursery areas, and settled juveniles. Cod eggs were released in areas where depth is between 0 and 200 m. Juvenile settlement areas are defined as areas where the depth is 0 to 70 m. We have tested the model using some of the ROMS/NPZ output, to ensure that it is working correctly. Connectivity zones and example of connectivity analysis for the Cod IBM are illustrated in the results section.

Sablefish IBM

Due to the paucity of data and knowledge on Sablefish behavior and distribution, the Sablefish IBM is necessarily simple. The specific stages of the IBS are egg, yolk sac larvae, feeding larvae, epipelagic juveniles, juveniles and settled juveniles. The initial version of the model has constant stage dependent growth rates for each list stage. Individual stage, position and length are tracked. Transition between each stage is time and size dependent as shown in Figure 1. Examples of model output from the first iteration of the Sablefish model are shown in the results section.

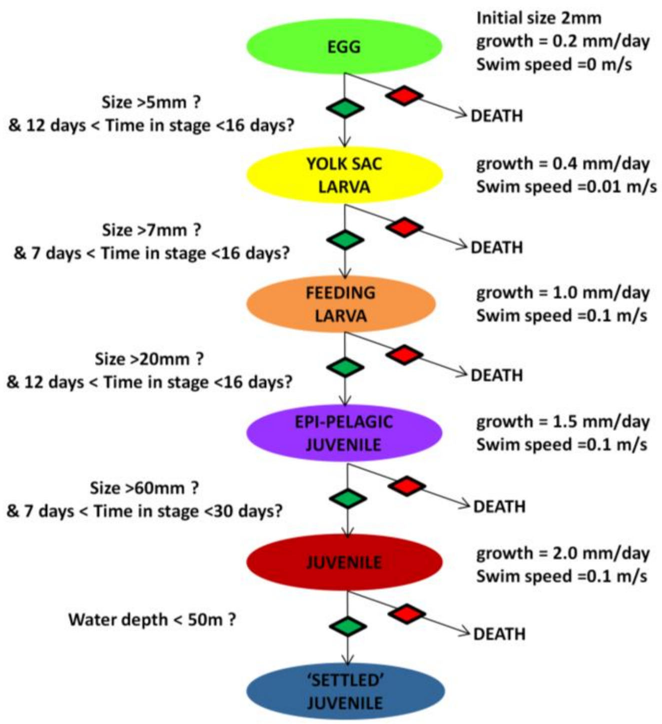

Figure 1. Illustration of the life stages in the IBM model and the rules governing the transitions between the stages.

Arrowtooth IBM

During this reporting period Generalized Additive Models (GAMs) with a temperature covariate were used to fit egg stage duration results from Blood et al. (2007) to develop a temperature-dependent function for arrowtooth flounder egg-stage development. Examples of the growth curves are shown in the Results section. These functions incorporated into the Arrowtooth IBM.

POP IBM

To date the species specific development of the POP IBM has not begun. However, due to data availability this will be a relatively simple model and now that Stockhausen has spent many hours modifying the DisMELS framework to ensure ease of adaptability with functional forms model development will be a relatively quick process.

Run ROMS/GOANPZ model on NEP grid for boundary conditions for CGOA grid

and

Run ROMS/GOANPZ on 3 km CGOA grid

Since the last progress report, Hermann's GOAIERP work has been focused on the generation of atmospheric forcing and oceanic boundary files for the 10-km resolution North-East-Pacific (NEP) model and the 3-km resolution Coastal Gulf of Alaska (CGOA) model. Output from NOAA's Climate Forecast System Reanalysis (CFSR, Saha et al., 2010) has been re-gridded for the atmospheric forcing and NEP boundary conditions. Programs were developed and executed for re-gridding of daily output for years 1996-2009, and for conversion of variable attributes to ensure compatibility with ROMS. Output from the NEP model was re-gridded to serve as boundary conditions for the CGOA model for all simulated years.

During this reporting period, using the boundary and forcing files provided by Hermann, Coyle completed the ROMS-NPZ model runs for the period 1995 – 2009. The coupled model was initially run on the NEP grid to generate boundary conditions for the CGOA grid. Model runs on the NEP grid required about 2.5 days per year, and runs have been completed through 2009. The daily average output files from the NEP runs were used to generate boundary conditions for the CGOA runs. Each year of CGOA simulation required about five days to run. CGOA runs are currently completed through 2009 and examples of the multi-year model output are shown in the results section.

Validation of 3km ROMS/GOANPZ

Data on nutrients, chlorophyll and zooplankton numbers/biomass were collected and passed on to K. Coyle for comparison with the GOANPZ model output. We are indebted to Ed Farley at the Auke Bay lab for data from the OCC program, to Peggy Sullivan (FOCI/PMEL) for extracting nutrient data from PMEL databases and to Jeff Napp and Colleen Harpold for data from the EcoFOCI databases. To facilitate validation of the NPZ model with field data, model output for the duration of the simulations has been saved to the station files during the multi-year runs on the CGOA model. While comparison between observed and modeled nutrients will be relatively straight-forward none of the zooplankton data made available from the FOCI sampling has wet weight, dry weight or carbon values – only abundance of organisms. A conversion table exists that provides some weight data for individual samples of animals (often the stages are pooled), but there is no data for individual FOCI cruises. This means that if the size, species composition or life stages are different between years, the weights calculated will not be valid. Potentially we could take the mean weight values for the GLOBEC data, where both abundance and biomass of organisms were determined simultaneously, and apply this conversion ratio to the FOCI data. This approach would assume that there are no inter-annual or regional differences in the size composition of the animals. Additionally, data from the Ocean Carrying Capacity program has no flow-meter calibration information prohibiting converting flow-meter counts to volume filtered. At the upcoming modelers PI meeting on December 19th 2012 we will have a discussion to decide whether or not to use the questionable zooplankton data for model calibration and what assumptions we are willing to make to use the data.

Preparation of ROMS/GOANPZ output for use with IBMs

Numerous test runs of the different IBMs have been successfully completed using the ROMS-NPZ model output. Output from the multi-year (1996-2008) CGOA model run has been transferred to 'Orion', our new computing platform at AFSC, as such this output is readily available for offline IBM simulations on this computer platform. Output from the coarser resolution NEP ROMS-NPZ model is in the process of being transferred to Orion. To date 1996 through 2001 is available on Orion.

Running and validation of IBMs

We have done multiple experiments and simulations with the IBMs and the results are described below and in the results section.

<u>Mesoscale Transport</u>

Parada conducted a particle tracking experiment using the ICHTHYOP 3.1, the most recent, stable version, to explore the impact of release locations on particle transport. The experiment was repeated using a stain diameter of 30 and 2 km. This experiment provided valuable insights on the sensitivity of the models particle trajectories to release location. The results of this experiment are discussed in the results section.

<u>Validation</u>

We have commenced discussions between our group about the validation approach for the IBM models and plan to spend time addressing this topic at our upcoming Modelers PI meeting on December 19th 2012. Where possible we hope to make use of the target species distribution data from the LTL, the MTL and the UTL GOAIERP components as well as historic distribution data made available by Miriam Doyle. To date, the most significant progress on IBM model validation has been made for the Pollock IBM. S. Hinckley, C. Parada and J. Horne have compared spatial distributions of pollock IBM output for 1987 with survey data for 1987. Centroid analysis, hotspot analysis , and the Syrjala test (Syrjala, 1996) have been applied to the model output and data, and we are investigating whether Lloyds patchiness index is appropriate in this context. The Getis-Ord statistic (hotspot analysis) showed both hotspots (clusters of particles/hauls with high superindividual numbers or densities), and coldspots (clusters of particles/hauls with low superindividual numbers or densities. Examination of hotspots and coldspots can tell us about areas of concentration, their sources and mortality. The Syrjala test showed no significant different difference between the pollock model output and the survey distributions for two of the three survey times in 1987, and the third was barely significantly different. Two further methods to compare model output and survey distribution data were applied, however the results have not been analyzed yet: the normalized difference index and the overlap coefficient.

Normalized difference index (NDI). We defined a costfunction to quantify the discrepancies between model and data, which is calculated by normalizing the difference between the mean field from model and measurements, respectively, with the standard deviation of observations, following Berntsen et al. (1996) and Søiland & Skogen (2000). The costfunction field NDI_i for each i bin for the modeled and data field is defined by:

$$NDI_i = (Ddata_i - Dmodel_l)/SDdata$$

where $Ddata_i$ and $Dmodel_l$ are the proportion of simulated and observed walleye pollock found in each bin at each time period, and *SDdata* is the standard deviation field. The overall costfunction NDI is the area average of the absolute values of the costfunction field and is computed as the sum over all bins. The *NDI* is always positive, while the NDI_i has both negative and positive values.

Overlap coefficient (OC). This coefficient aims to estimate the spatial overlap between simulated and data distribution of walleye pollock based on Hinrichsen et al. (2005) studies. The overlap coefficient *OC* is 0 when no overlap is apparent and 1 when the two distributions are identical (Hinrichsen et al., 2005). Hinrichsen et al (2005) applied this coefficient to determine how many larvae and prey were simultaneously present in the specified subareas of the central Baltic Sea (Hinrichsen et al., 2005). However, our application of *OC* is focused on model and data comparison which is defined by:

$$0C=2Sum(Ddata_i \times Dmodel_l)/(Sum(Ddatai^2)+Sum(Dmodeli^2))$$

This approach could potentially be used to validate the other IBMs if sufficient data is available.

IBM connectivity and trajectory analysis.

We are beginning the process of running the IBMs for the connectivity experiments. During this reporting period we have defined source and sink areas for use in the five IBMs, due to differences in spawning and settlement traits these are not necessarily the same between species. Example connectivity matrices have been produced (from the Pcod model) and have been supplied to Jocelyn for use in developing the genetics model.

Genetic Model

Dr. Jocelyn Lin was hired in the summer and started work October 1st, 2012. Code for the genetic model was obtained from Dr. Heather Galindo and converted from Matlab to Scilab (freeware platform similar to Matlab). All components of the model were run individually to check that they worked as expected. Since population sizes are a required model input, data on estimated abundances for each of the 5 species in the Gulf of Alaska were obtained from Stock Assessment and Fishery Evaluation (SAFE) reports produced by AFSC and also requested directly from authors of the SAFE reports for some species (arrowtooth flounder, Pacific Ocean perch, and sablefish). Another model input is the number of generations to run, and J. Lin consulted with Ingrid Spies (AFSC, REFM) and Nils Krueck (University of Queensland) regarding this parameter. Based on simulations in a model developed by I. Spies, neutral genetic markers in two populations connected by a 5% dispersal rate will achieve migration-drift equilibrium in approximately 25 generations. N. Krueck developed a seascape genetics model sea mullet and found that genetic differentiation stabilized in his genetic model after approximately 100 years, which is on the order of about 25 generations. Thus, our genetic model will be run for at least 25 generations for each species.

J. Lin is currently considering other components to add to the genetic model based on species biology. Development has begun for a genetic model specific to Pacific cod, which uses a preliminary connectivity matrix generated by the Pacific cod IBM. The ability to vary carrying capacities among connectivity zones has been added to this model.

Predation on the focal species

Hinckley, Kerim Aydin and Parada have had two meetings to discuss ways to incorporate groundfish data to implement predation into the IBMs. To estimate the consumption of a prey species by size group i by a groundfish predator we must calculate the:

-Daily ration. A proportion of body weight consumed daily by a predator size group i

-Number of days in the sampling period when the prey species was vulnerable to predation

-Biomass of the predator size group i

-The proportion by weight of the prey species in the diet of predator size group i.

Data on the biomass and distributions of groundfish predators on the five focal species has been located and compiled. We will be using data from the AFSC groundfish and acoustic databases, from the small-mesh trawl survey (courtesy of D. Urban and R. Foy at the Kodiak NMFS laboratory) and from the large-mesh trawl survey (courtesy of K. Spalinger at the Alaska Dept of Fish and Game) to analyze groundfish distributions. Kerim Aydin is providing diet composition data for the predators, and daily ration where it is available. Leslie Slater and Franz Mueter are aiding in the production of seabird predation maps for which the above information may or may not be available. One source of seabird distribution data is the North Pacific Pelagic Seabird Database. Jason Waite is compiling available seabird diet data. Further meetings will be organized in December 2012 to delineate the methodology to include the goundfish data and other predator sources into the IBMs.

C. DESCRIBE PRELIMINARY RESULTS.

Multi-year ROMS-NPZ model simulations

The ROMS-NPZ model has been run continuously from 1996-2009, The series of runs completed so far indicate that the ROMS model requires 2-3 years of simulation to generate upwelling in the central gyre. The upwelled nitrate in the central gyre is the source for nitrate on the shelf. Figure 2 shows that the model predicts that mean nitrate concentration in the upper 25 m on the western GOA shelf is characterized by higher minimum values in some years relative to others.

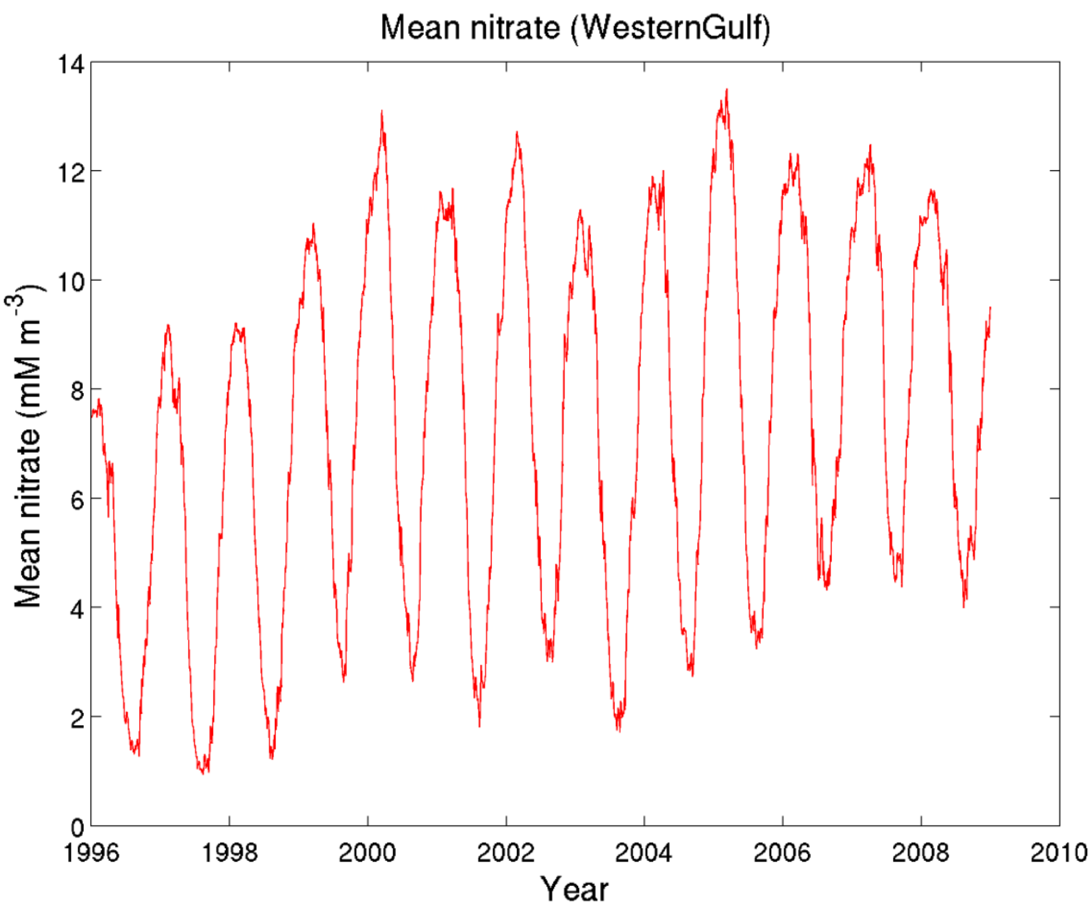

Figure 2. Simulated annual cycle of mean nitrate concentration (µM) on the western Gulf of Alaska shelf for 1996 through 2008.

Float Tracking Comparisons

Previous comparisons between Ichthyop offline particle tracking and ROMS online particle tracking had an unacceptably large divergence in trajectories (Figure 3). After re-running previous float tracking comparison using the new version of Ichthyop (V3.1) we found that the improved particle tracking algorithm in the offline IBM resulted in much improved performance, similar to that of the DisMELS model (Figure 4). Consequently, we consider the particle tracking algorithms of both DisMELS and Ichthyop 3.1 to have acceptable performance relative to online ROMS.

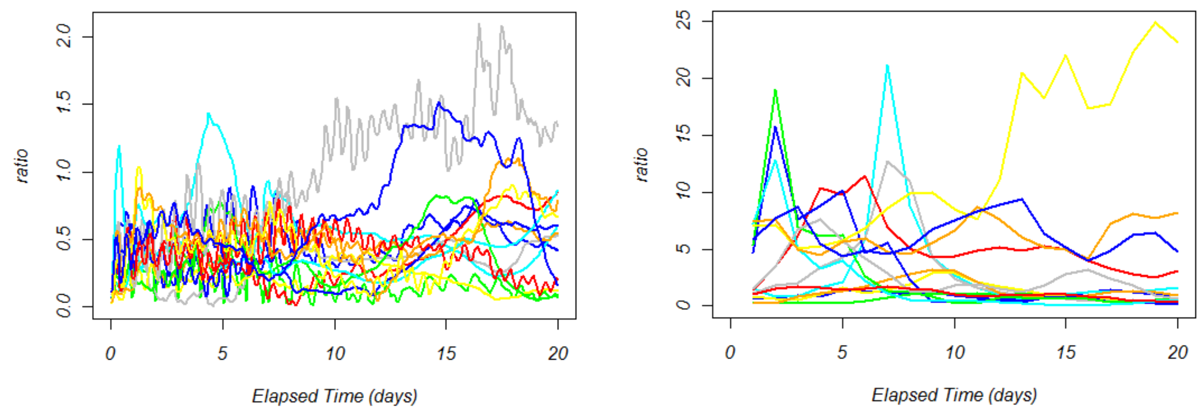

Figure 3. Comparison of the temporal evolution of $\overline{R}_{MR}/\overline{R}_{R}$ ratio for all minigrids (various colors) using the February, 2001 float release scenario. Results are shown separately for DisMELS (left plot) and Ichthyop 2.x (right plot). Ratios on the order of 1 or less are deemed acceptable.

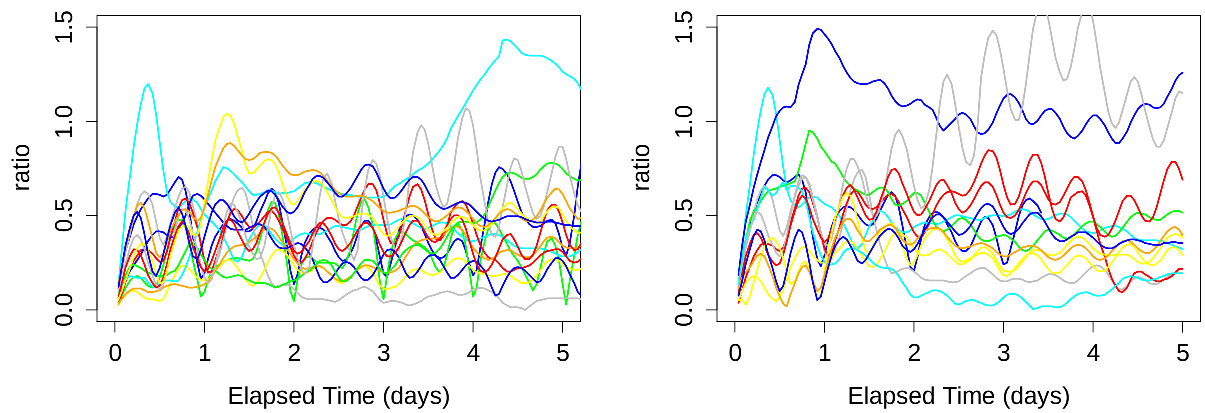

Figure 4. Comparison of the temporal evolution of the float tracking performance ratio $\overline{R}_{MR}/\overline{R}_{R}$ for all minigrids (various colors) using the February, 2001 float release scenario. Results are shown separately for DisMELS (left plot) and Ichthyop 3.1 (right plot).

<u>Particle tracking experiments to explore meso-scale features</u>

Experiments were conducted with Ichthyop 3.1 to explore the impact of release locations on particle transport. One-thousand particles were released in a radius (stain) around a given location. The simulation was initiated on Deb 3rd 2002 at 00:00 and particles were tracked for 13 days with a model time step of 1200 seconds. Model output was set to once per day. The experiment was also repeated using a stain diameter of 2 km (and several intermediate stain diameters). The results of a particle tracking experiment with Ichthyop 3.1 show that particles that are released in a diameter of 30 km (stain radius of 15 km) can be entrained in different sub-mesoescale scale eddies (<100 km) to ultimately be transported to different destinations, experiencing potentially different environment conditions and survival (Figure 5). Particles released within the tighter radius were entrained in the same sub-mesoscale eddies, with particles following a similar trajectory (Figure 6).

Figure 5. A particle tracking experiment run with ICHTHYOP 3.1 Stable version. The radius of the stain was 15 km.

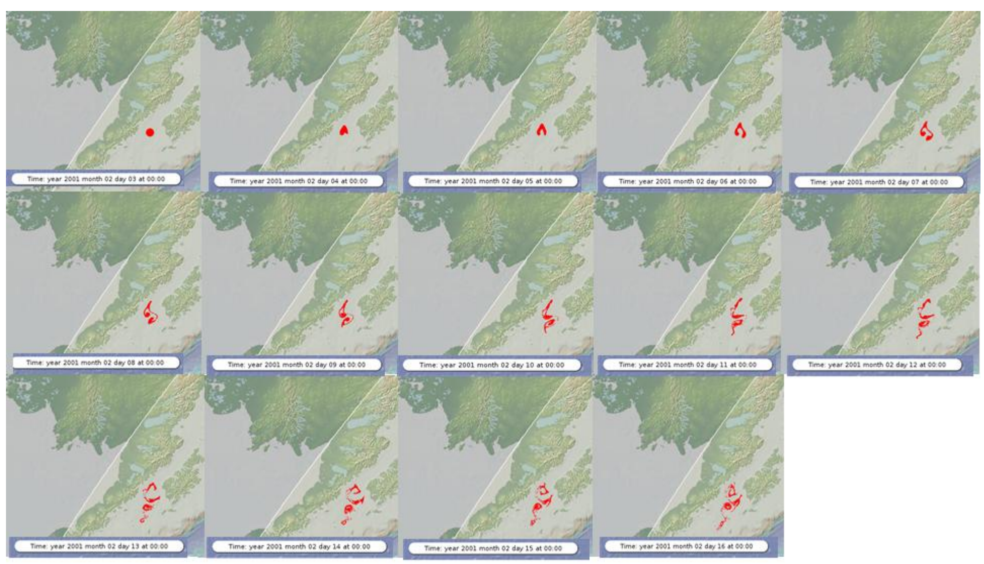

Figure 6. A tracking particle experiment run with ICHTHYOP 3.1 Stable version. The radius of the stain was 1 km.

From these experiments we can conclude that sub-mesoscale structures at <=2km resolution present in the hydrodynamics model are relatively homogeneous and produce consistent transport patterns to probable single sink regions. Using source regions larger than 2 km of diameter potentially will generate multiple connections with sink regions, with differential connectivity patterns and transport pathways.

Sub-mesoscale oceanographic structures seem important to the connectivity of source and sink areas in the GOA and the timing and location of formation of the oceanographic sub-mesoscale structures will be relevant to sustain potential connectivity pathways between sources and sinks.

IBMs simulations

Sablefish IBM

In initial simulations with the Sablefish IBM individuals were released with a 10km resolution spacing at 500m depth throughout a release zone that traversed the shelf break (Figure 7). Their transport was followed as they progressed from eggs to settled juveniles (Figure 8). Initial connectivity analysis performed on this model showed that in the absence of any additional biological movement behavior some individuals were transported to the coastal regions where they could settle. Analysis also revealed that the individual particles were failing to move 'through' the model boundaries and out of the model – essentially becoming stuck in the corner of the model grid (Figure 9). Once identified this problem was rectified in the DisMELS program code by ensuring that individuals 'die' when they get "close" (~ 0.5 grid cell spacing) to the grid boundary.

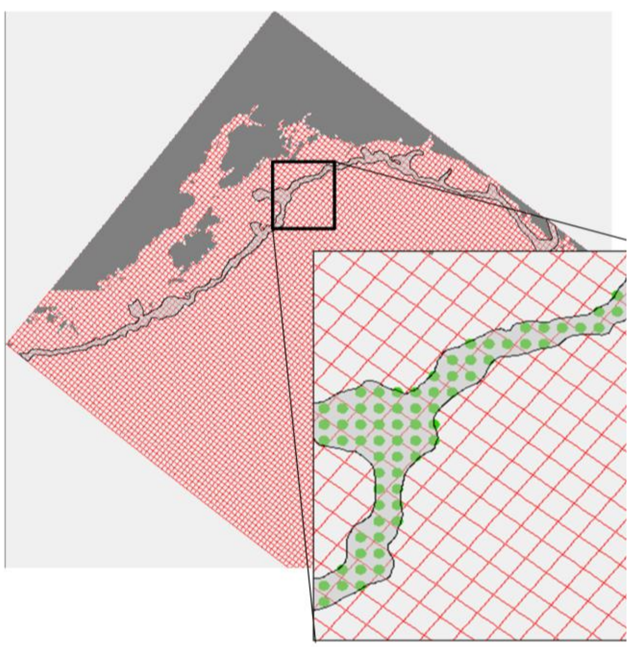

Figure 7. Source area used in the initial Sablefish IBM simulations was between 500 and 2000m along the shelf break. .

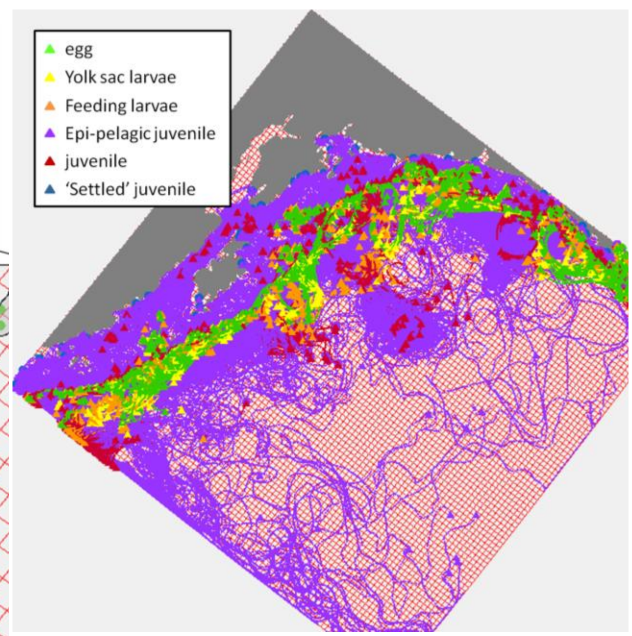

Figure 8. Trajectories of individuals in the Sablefish IBM showing the progression from eggs to settled juveniles.

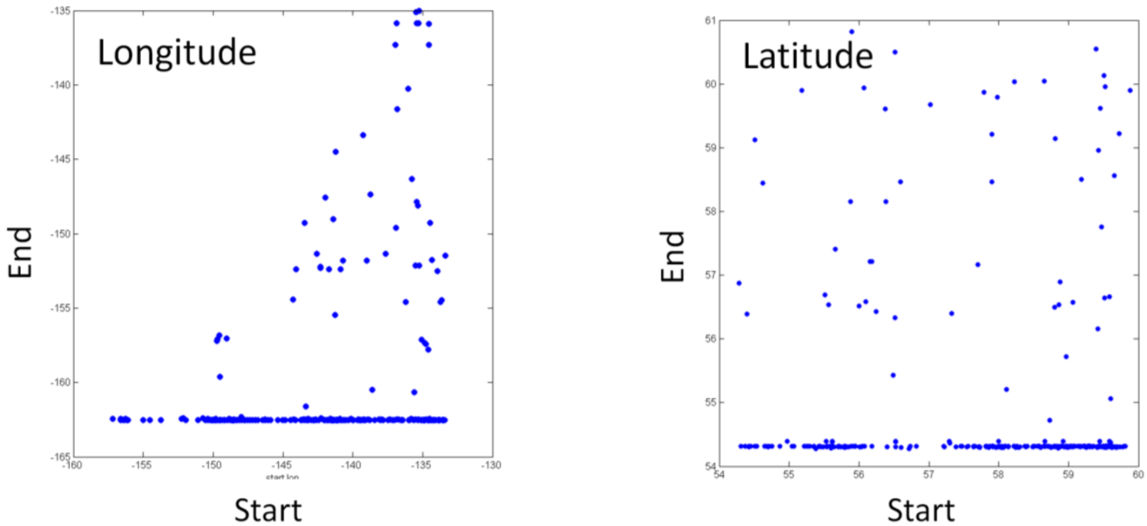

Figure 9. Initial and final latitude and longitude of individuals in the initial run of the sablefish IBM.

<u>Pacific cod IBM</u>

Connectivity zones for Pacific cod IBM are shown in Figure 10. Initial simulations were performed to determine the appropriate density of individuals to release. We examined horizontal grid spacings (as a proxy for density) of 1, 2.5, 5, 7 and 10 km, and analyzed the stability of the resulting connectivity matrices for each grid spacing. We found that the 5, 2.5 and 1 km spacing all resulted in the same set of source – sink zone pairs ranked in the top 10 of highest probabilities of connection. We therefore decided that setting the horizontal grid spacing at 5 km would be adequate.

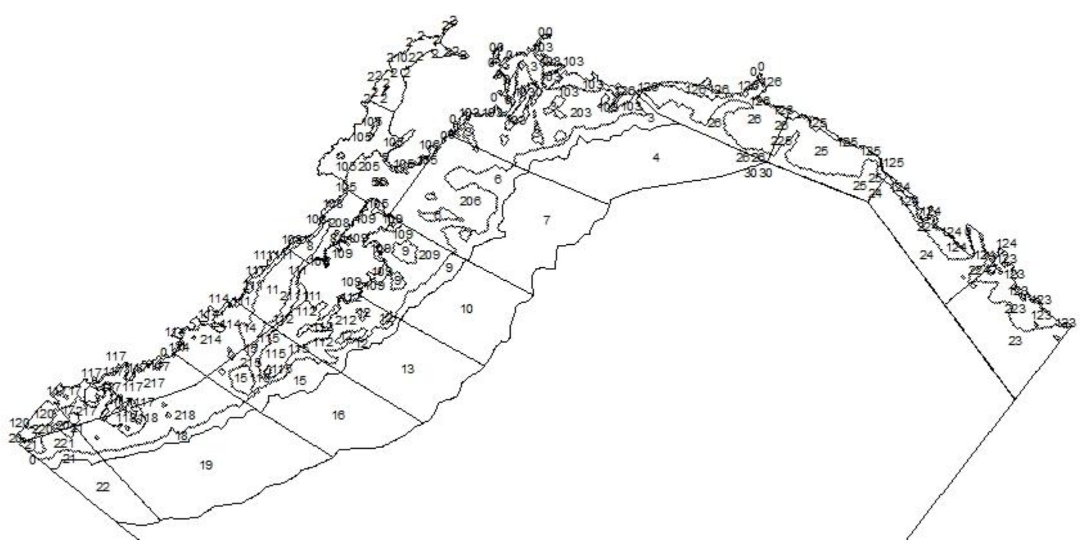

Figure 10. Connectivity zones (source and sink areas) for the Pacific cod IBM. Areas labeled in the 100's are areas where depth is between 0 and 70 m); these are defined as the preferred nursery areas. These areas, plus those labeled in the 200's (70 to 200 m deep) are used as source (spawning) areas. Individuals may be transported to any of the zones.

To test the cod IBM we released individuals in the southeast (SEAK) zones 124 (0 to 70 m) and 224 (70 to 200 m) on March 11, 2001 and ran the simulation through October 17, 2001. Figure 11 shows the trajectories for individuals released in the shallower zone (124) while Figure 12 shows the trajectories for individuals released in the deeper zone (224). The number of individuals released in each zone was proportional to the area of the zone. Thirty percent of the individuals released in zone 124 were retained within that zone, 17.6% went to zone 125 (just north of Cape Spencer), 17.6 percent went through the grid boundary towards the SEAK interior, and the remainder were dispersed more broadly. Of those individuals released in zone 224, 15% went to zone 124, 10% went to zone 125, 5% ended up in zone 126 (Yakutat area), 2.4% stayed in zone 224, and the rest dispersed more broadly. In summary, with a few exceptions, individuals released in the shallowest area, near the coast, stayed mostly in the coastal areas while only 32% of the individuals released in the deeper 70-200m zone in SEAK remained in the coastal areas.

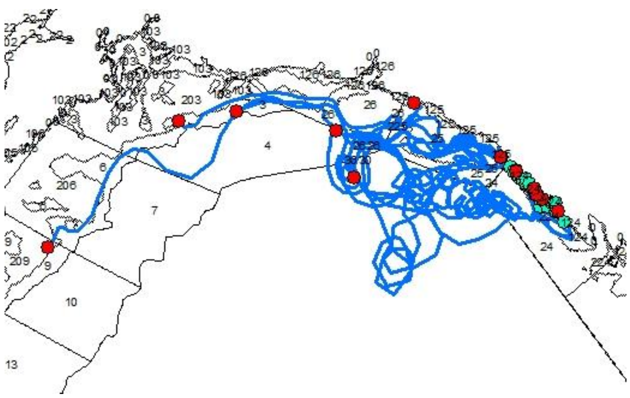

Figure 11. Trajectories of floats released in Zone 124 (0 to 70 m) in Southeast Alaska study area. Green points are Start locations, red points are End locations. Start date = March 11, 2001. End date = October 17, 2001 (n = 17).

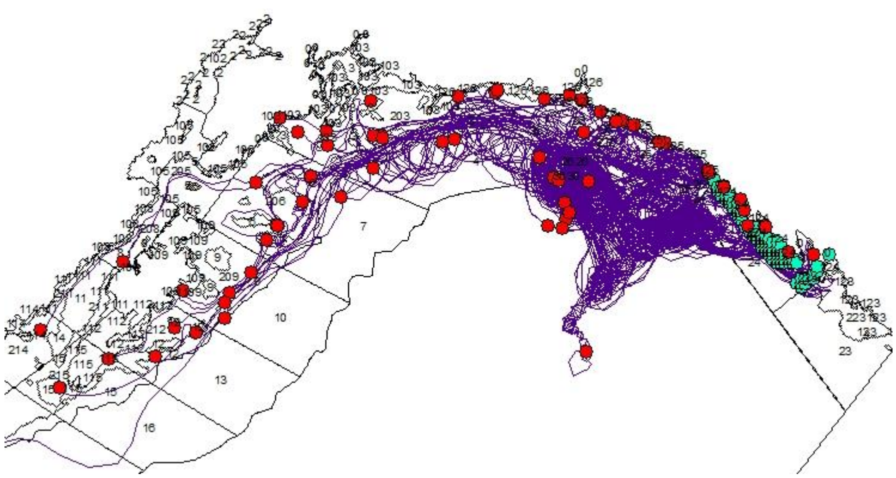

Figure 12. Trajectories of floats released in Zone 224 (70 to 200 m) in Southeast Alaska study area. Green points are Start locations, red points are End locations. Start date = March 11, 2001. End date = October 17, 2001. (n= 82)

Samples of connectivity matrices from these and other preliminary experiments were provided to Jocelyn Lin for use in her genetics model.

Arrowtooth Flounder IBM

Sixty three areas have been defined for the arrowtooth flounder IBM and connectivity analysis, based on combinations of 6 depth strata and 12 along-shelf zones (Figure 13). The depth strata were selected based on the presumed adult spawning depth range (300-600 m), previous studies of nursery habitat (0-50 m), and the distribution of small juveniles (age-1's and 2's) in the summertime groundfish surveys conducted by the AFSC since 1984 (50-150 m; see Figure 13).

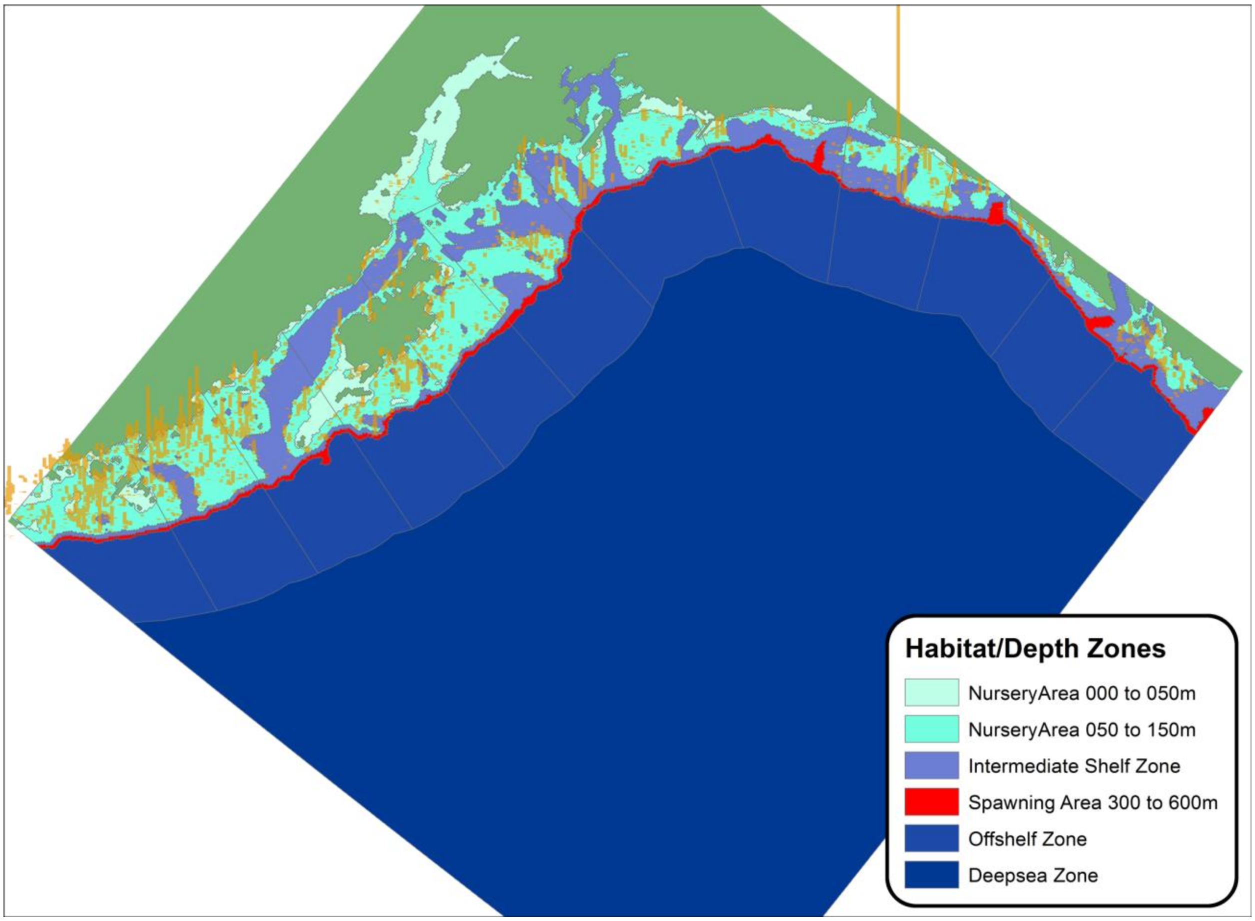

Figure 13. Spawning areas, nursery areas and other connectivity zones defined for the arrowtooth flounder IBM. The distribution of small juveniles (age-1's and -2's) in the summertime groundfish surveys (1984-2011) conducted by the AFSC is also shown (height of gold bars indicates survey CPUE at each sampling station).

Fits from the GAMs developed for egg stage duration   for arrowtooth flounder are shown in Figure 14 and 15). Although the data is noisy and sparse, the resulting fits are not bad. The results of this analysis will allow us to investigate the relative effects of advection vs. temperature (via egg stage duration) on early-stage larval distributions of arrowtooth flounder.

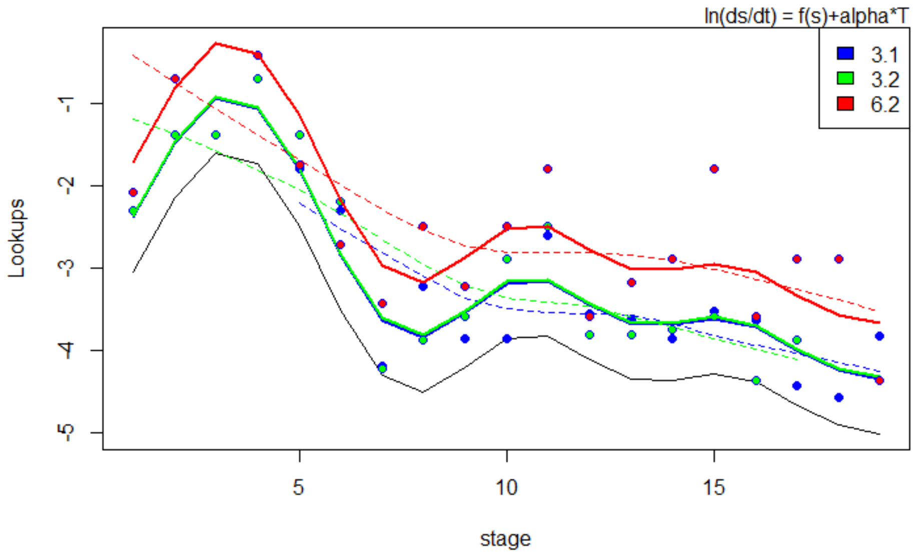

Figure 14. Fits (solid lines) of generalized additive model with temperature covariate to ln-scale development rate (inverse stage duration; points) for arrowtooth flounder at three nominal incubation temeratures (3.1, 3.2 and 6.2 °C). Data from Blood et al. (2007).

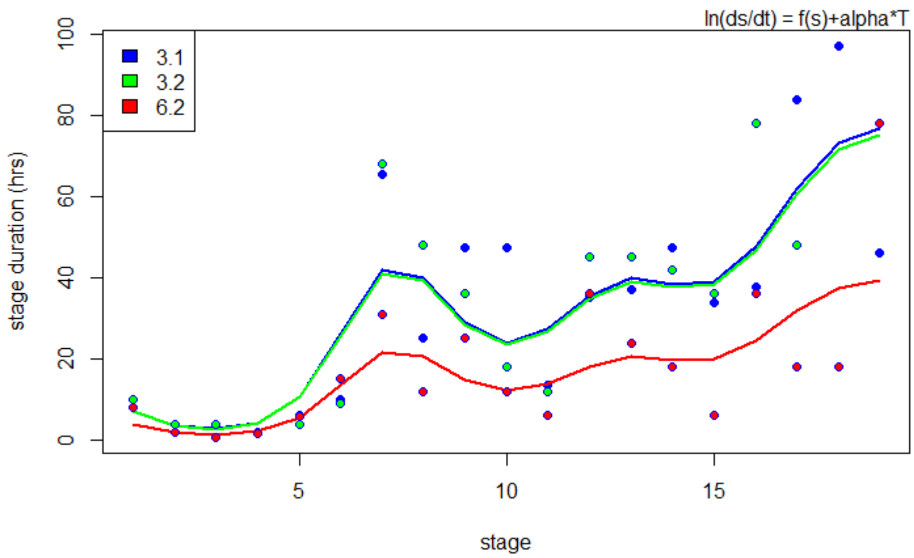

Figure 15. Predicted (lines) and observed (points) temperature-dependent egg-stage durations for arrowtooth flounder at three nominal incubation temeratures (3.1, 3.2 and 6.2 °C). Predicted durations based on the generalized additive model with temperature covariate (Fig. 1). Observations from Blood et al. (2007).

Computing Resources: Our new computing platform, Orion, is up and running at AFSC. All of the IBM modelers, plus Ken Coyle, have accounts on this machine. A large shared data area has been designated for GOAIERP work, which all modelers with accounts have access to, and this is where the ROMS/NPZ data is being put. Tests with this machine show that it is very fast and efficient running the DisMELS Pacific cod model.

Published Papers

A paper comparing the GOANPZ model being used in GOAIERP modeling work with Seward Line observational data has been published during this reporting period.

Coyle, K.O., W. Cheng, S.L. Hinckley, E.J. Lessard, T. Whitledge, A.J. Hermann, and K. Hedstrom (2012) Model and field observations of effects of circulation on the timing and magnitude of nitrate utilization and production on the northern Gulf of Alaska shelf. Prog. Oceanogr., 103, pp. 16–41.

d. Describe integration activity.

- Ken Coyle participated in the May and September Seward Line cruise during the 2011 and 2012 fields season. He is participating in processing these samples and analyze the zooplankton data.
- Carolina Parada had meetings with Kerim Aydin and Sarah Hinckley about predation maps, had discussions with S. Hinckley about connectivity analyses
- Carolina Parada and Sarah Hinckley had discussions with Jamal Moss and Ron Heintz about possible bioenergetic studies to be done on live fish collected in the fall of 2012
- Carolina Parada, Sarah Hinckley and John Horne held meetings about the validation methods to be applied to the pollock IBM output vs. survey data, and about the manuscript that is in preparation.
- Carol Ladd has been working on analysis of gap winds with the LTL component.
- Carol Ladd has participated in GABI meetings since September
- Carol Ladd has been involved in field work planning/discussions as LTL PI.
- Carol Ladd has held discussions with Jamal Moss about participating on a paper examining fish distributions in relation to eddies.
- Modelers held an in person modelers meeting in June, 2012. The GOAIERP modeler PIs regularly attend the All PI GOAIERP monthly phone meetings.
- S. Hinckley has participated in numerous discussions with PIs from the other GOAIERP components with respect to survey results (for example, fish distributions and predator stomach samples collected).
- S. Hinckley has attended the GABI through August, 2012.
- S. Hinckley has had discussions with O. Ormseth about incorporation of MTL study sites into connectivity studies.
- S. Hinckley has received data from the LTL group to aid in the validation of the GOANPZ model
- S. Hinckley has received data from the RACE groundfish and MACE groups, from personnel at the Kodiak Lab, from personnel at the Auke Bay lab and from Alaska Department of Fish and Game to assess predation on the five focal species
- S. Hinckley is working with the UTL group (Mueter and Slater) to develop a seabird predation map for the IBMs.
- Modelers have had discussions with Zimmerman and Shotwell about habitat maps

e. Describe any concerns you may have about your project's progress.

A problem was identified during test runs of the IBMs: the full output files from DisMELS (with all the data for each individual at each environmental time step – per day in this case) are extremely large. For ~10,000 individuals followed, this file was ~2.9 GB. This would necessitate the use of a limited number of software programs for the analysis. We are taking some of the variables out of these output files to try to reduce their size. We may also be able to use shell scripts and Unix editing commands, or C or Fortran code to reduce the file sizes. We are also investigating the file size limits of several software packages (R, ArcMap, etc).

Running the model for the field years, as was one of the goals of the project, has been highlighted as more challenging than anticipated. This is due to the inaccessibility of consistent atmospheric forcing data to run the models for these years; Completion of the runs for 2010 through 2012 will require identification, downloading and formatting of forcing files for 2011 and 2012. In addition, boundary conditions for the NEP and CGOA grids will have to be generated. We plan to discuss these challenges and how to tackle them at our upcoming December 19th 2012 PI meeting.

Due to very low catches of our target fish species during the 2011 and 2012 field season we anticipate that complete validation of the IBMs will be difficult, and perhaps even impossible in the case of Sablefish. IBM validation is a topic that will be under discussion at the upcoming modeling and PI meetings.

f. Poster and oral presentations at scientific conferences or seminars

A. J. Hermann, C. Ladd, W. Cheng, E.N. Curchitser and K. Hedstrom. "A model-based examination of multivariate physical modes in the eastern and western Gulf of Alaska", Eastern Pacific Ocean Congress (EPOC), 19-22 Sep 2012, Timberline Lodge, Mt. Hood, OR

J. Lin “Genetics modeling: from evolution in salmon to seascape genetics of groundfish”, EcoFOCI seminar on November 7, 2012.

g. Education and outreach

Carol Ladd has been a mentor for MPOWIR, a community-based program that provides mentoring to physical oceanographers from late graduate school through their early careers. The aim is to reduce the barriers to career development for all junior scientists in the field, with a particular focus on improving the retention of junior women.

Ladd has also hosted a high school senior for tour of lab and to discuss a career in science (June 2012)

4. PROGRESS STATUS

We are pleased with the progress of our project to date. During this reporting period it was decided that rather than running specific individual years, we could better capture the variability in the environment that may be influencing groundfish recruitment if we ran a continuous block of years. A continuous run was not within the scope of our original project as designed but the run is now near completion and we think that its analysis will greatly help us understand environmental impacts on recruitment mechanisms. Now that we have finalized the comparison of offline float tracking tools to the ROMS online model we have two offline IBM tools that perform acceptably well and we are well under-way with development of the species specific IBMs. Initial versions of all but the POP IBM have been developed and run. Due to the flexibility that has been built into DisMELS during this reporting period species specific development of POP and enhancements of the other IBMs are anticipated to be relatively straightforward.

Due the paucity of zooplankton biomass data and to the low catches of target fish species data we anticipate problems in fully validating the zooplankton component of the NPZ model and some of the IBMs.

5. FUTURE WORKPLAN and DATA DELIVERY

Workplan

What	*Who*	*Start and end dates*	*Other key dates*
Construction of IBMs for the 5 target species	Parada, Stockhausen, Gibson, Hinckley	Oct 2010-Sept 2012 (with extension to Dec 2013)	
Run ROMS/GOANPZ model on NEP and CGOA grids	Hermann, Hedstrom, Coyle, Gibson	Oct 2011-Mar 2013	
Validation of ROMS/GOANPZ	Ladd, Hermann, Coyle	June 2012 – Mar 2013	
Prepare output for IBMs PI's: Coyle	**Coyle**	July 2012 – Dec 2012 (with extension for model years past 2009)	
Run and validate IBMs Dependency: spawning locations and larval and juvenile distributions from LTL, MTL and UTL	Parada, Stockhausen, Gibson, Hinckley	October 2012 – June 2014	
IBM connectivity and trajectory analysis	Parada, Stockhausen, Gibson, Hinckley	Jan 2013 – Sept 2014	
Develop indices from all IBM models and explore regional patterns.	Parada, Stockhausen, Gibson, Hinckley	Apr 2013 – Dec 2014	
Compare model indices to recruitment	Parada, Stockhausen, Gibson, Hinckley	Apr 2013 – Dec 2014	

Data delivery.

GOAIERP Data Delivery Table		
Data type for delivery	Delivery Month & Year	Person sending data, with email address
NONE		

Literature Cited

Berntsen, J., E. Svendsen and M. Ostrowski. 1996. Validation and sensitivity study of a sigma-coordinate ocean model using the Skagex dataset. ICES CM 1996/C:5, Hydrography Committee.

Blood, D.M., A.C. Matarese, and M.C. Busby. 2007. Spawning, egg development, and early life history dynamics of arrowtooth flounder (*Atheresthes stomias*) in the Guld of Alaska. NOAA Professional Paper NMFS 7, 28 p.

Buckley LJ, E.M. Caldarone, R.G. Lough, and J.M. St. Onge-Burns.2006. Ontogenetic and seasonal trends in recent growth rates of Atlantic cod and haddock larvae on Georges Bank: effects of photoperiod and temperature. MEPS 325:205–226.

Folkvord, A. 2005. Comparison of size-at-age of larval Atlantic cod (*Gadus morhua*) from different populations based on size- and temperature-dependent growth models. CJFAS 62: 1037–1052.

Hanson, P.C., T.B. Johnson, D.E. Schindler, and J. F. Kitchell. 1997. Fish Bioenergetics 3.0. University of Wisconsin Sea Grant Institute, Madison, WI.

Hinrichsen, H-H., Schmidt, J. O., Petereit, C., and Mo¨llmann, C. 2005. Survival probability of Baltic larval cod in relation to spatial overlap patterns with its prey obtained from drift model studies. e ICES Journal of Marine Science, 62: 878e885.

Houde, E.D. 1989. Comparative growth, mortality and energetic of marine fish larvae: temperature and implied latitudinal effects. Fish. Bull. 87: 471-495.

Houde, E.D. and C.E. Zastrow. 1993. Ecosystem- and taxon-specific dynamics and energetic properties of larval fish assemblages. Bull. Mar. Sci. 53: 290-335.

Leising. A.W. and P.J.S. Franks. 1999. Larval Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) growth on Georges Bank: a model with temperature, prey size, and turbulence forcing. CJFAS 56: 25–36.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. J. Fish Biol. 49:627-647.

Pepin, P. 1991. Effect of temperature and size on development, mortality, and survival rates of the pelagic early life history stages of marine fish. CJFAS. 48:503-518.

Saha, S. and coauthors, 2010. The NCEP Climate Forecast System Reanalysis. Bull. Amer. Meteor. Soc. 91, 1015.1057. doi:10.1175/2010BAMS3001.1

Søiland, H., and Skogen, M. D. 2000. Validation of a three-dimensional biophysical model using nutrient observations in the North Sea. – ICES Journal of Marine Science, 57: 816–823.

Syrjala, S. E. 1996. A statistical test for a difference between the spatial distributions of two populations. Ecology 77(1): 75-80.