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	Dec 2 2012 to March 31 2013
Report submission date	May 23, 2013
Lead Author of Report	Georgina Gibson and Sarah Hinckley (co-Lead PIs)

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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.

	‘12		2013			
Research Activity Milestone	3	4	1	2	3	4
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						
Develop indices from all IBM models and explore regional patterns. PI’s: Parada, Stockhausen, Gibson, Hinckley						

B. DESCRIBE REPORT PERIOD PROGRESS.

Progress with respect to each of the Milestones listed in the table in 3.A is summarized below.

Construction of IBMs for the 5 target species

As of the end of this reporting period an IBM for each of the five target species has been constructed and preliminary model runs with each of these IBM models has been undertaken. During the upcoming reporting period we will continue to refine these models.

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, 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 through the end of 2012 have been generated. Output from NOAA's Climate Forecast System Reanalysis (CFSR, Saha et al., 2010), archived at CISL, was re-gridded for the atmospheric forcing and NEP boundary conditions. As had previously been done for 1996-2009, scripts were developed and executed for re-gridding of daily output for years 2010-2012, 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, ROMS-NPZ model runs for the period 2010 – 2011 were completed. The coupled ROMS-NPZ model was initially run on the NEP grid to generate boundary conditions for the finer resolution CGOA grid. Model runs on the NEP grid have been completed on through 2012. The daily average output files from the NEP runs were used to generate boundary conditions for the CGOA runs. CGOA runs have been completed through 2011. Results for 2012 will be generated upon acquisition of suitable runoff forcing for that year.

Validation of 3km ROMS/GOANPZ

During this reporting period, several recent years (2007-2011) of CGOA model output were re-gridded onto regular latitude-longitude-depth coordinates. These re-gridded products were used to generate animations of physical and biological properties, in particular for comparison with SSH data from AVISO and fish distribution data from GOAIERP. Model animations along the Seward and Cross-Sound hydrographic lines were examined in order to infer inter-annual changes in the Eastern and Western Gulf. The regridded model output has also been incorporated into 3D visualization software, for interactive display at conferences.

Computer programs were written to reformat field measurements for the 2011 field year. The reformatted data was compared to NPZ model output. Comparisons were undertaken for zooplankton and nitrate on the western grid, and iron and nitrate on the eastern grid. During this reporting period, our modeling group has been discussing the need to move away from point-to point comparisons between observations and NPZ model output. Due to the highly dynamic nature of the Gulf of Alaska, point comparisons are not very meaningful, and should be considered too strict a test of the model. We are working towards model-data comparisons with area averages over a longer time period. Primary production was computed for the entire western shelf and southeastern shelf for 1996 through 2011.

Preparation of ROMS/GOANPZ output for use with IBMs

ROM/GOANPZ model output from 1996-2011 CGOA and NEP5 model simulations has been transferred to ORION and is being used by the fish modeling group to drive the IBMs for the target fish species.

Running and validation of IBMs

During this reporting period the IBM's for all five target species were run for at least one test year. Most models were run for either 2001 or 2002, and 2011. Results are described below in the results section. During this reporting period, significant progress was made on the genetics modeling work. This genetics modeling effort should be useful for validation of IBM's once sufficient observational data is available.

Very few of some of the focal groundfish species were caught during the recent field years. For example, during the July/August cruises the UTL group caught only 2 sablefish in 2011 and only 12 in 2012. Low catch numbers are also a notable problem for P. cod. This lack of data means that it will be difficult to validate the IBMs for these species in a meaningful way. We are in the process of obtaining data from the Nearshore Fish Atlas (NMFS, Auke Bay, D. Neff) and from nearshore studies performed near Kodiak Island for the GAP project (B. Foy, NMFS, Kodiak Laboratory) to try to identify specific nearshore locations where juveniles have been found. We will attempt to use this limited data set to validate the IBMs.

IBM connectivity and trajectory analysis.

During this reporting period we developed initial connectivity matrices for all of the five target fish species. For most species these matrices were developed for multiple years so that we could begin to examine inter-annual variability in connectivity. Software functions, using both the R statistical analysis framework and Matlab, were developed to calculate and visualize connectivity matrices from IBM model runs. Example connectivity matrices can be seen in the results section.

Pollock were initialized according to observations of eggs and larvae; however there is insufficient data to use this approach to initialize the IBM for the other focal species. arrowtooth, POP and sablefish spawning in deep water along the shelf break so these generic initial conditions are relatively easy to set up and develop understanding of connectivity to recruitment sites. However, there is little information on the location of cod spawning, except that they spawn where the depth is "between 20 and 200 m", this is a zone which covers a large part of the GOA. Data from the groundfish surveys in the summer are not helpful, as these surveys take place after the main spawning season (March-June) and significant movement has probably occurred. The commercial catch between March and June occurs everywhere. We know that cod spawn in a very patchy distribution, but we don't know where these patches are. Cod eggs are not caught in ichthyoplankton surveys as they have demersal eggs. An adequate way to deal with this lack of P. cod initial conditions has not been decided upon, although some different approaches will be tried. Where possible, the EcoFOCI monthly climatology of egg/larval distributions will be used to weight the timing of spawning within the IBMs. The spatial distributions from these surveys are only of limited use as the surveys only sample the Western Gulf.

Incorporation of Predation into the IBMS:

Six data sets have been identified to be incorporated into the IBMs, these are:

1. AFSC Groundfish cruises: Stomach samples, prey length, predator length, sex, frequency, years 1981, 1984-1987,1990-2007,2009,2011. Survey catch data for identified groundfish predators on focal species.
2. Small mesh trawl databases: Survey catch data for identified predators on focal species. Forage fish collected for length, weight, catch, sex, stomachs, restricted to between Kodiak to Unimak region, years 1953,1954, 1957, 1963,1967-2010.
3. Large mesh trawl databases: Survey catch data for identified predators on focal species Total weight of fish caught, sex, length, number of fish caught, years 1988-2011.
4. MACE surveys: Catch data for identified predators on focal species from pelagic trawl catches from reference trawls during Midwater Acoustic surveys.
5. Observer data: Commercial catch data for identified predators on focal species, 1995 to present.
6. Seabird data: L. Slater will be providing distributions of seabird predators, and diet data (where available) on GOAIERP focal species.

Depending on the level of species specific information available, the incorporation of the predation products into the IBM will range from spatially explicit predation mortality estimates with inter-annual variability to relative indices indicating high, medium, low, none predation risk. Four problems and limitations associated to the integration of the predation were identified as follows:

1. Integration of data collected at different spatial scales (intensive small scale vs large scales samples)
2. Unbalanced spatial sampling across the Eastern and Western GOA
3. Unbalanced temporal sampling, mainly from summer
4. Lack of temporal resolution to appropriately represent interannual variability in most of target species

Genetic Model Development

During this reporting period the basic framework of the genetic model was completed, with the additions of age-structure and the capability for mature adults to home to natal areas. Using this framework, genetic models were created and parameterized for each of the 5 focal species. Sample connectivity matrices for each species were tested in the genetic models. Sensitivity analyses were run on two parameters that were expected to affect rates of genetic divergence between populations: 1) total population size and 2) proportion of mature adults that home to their natal areas.

Additionally, an inventory of collected genetic samples was assembled, and requests were made for additional samples to be obtained in 2013. Although sample processing is not within the scope of this project, these genetic samples will be stored and may be analyzed in the future.

Eddy identification

During this reporting period we also spent time developing analysis tools to identify and track eddies from the ROMS model output. Larvae are likely interacting with these sub-mesoscale eddies which could prove to be an important mechanism of transport. Eddy identification was performed for 2004 between 23 of February to 25 of September of 2004, a period that characterize the transport of early stages of walleye pollock in the Gulf of Alaska. Our methodology of eddy identification allows filtering of eddies according to size. Examples of eddy trajectories during this time period can be seen in the results section. In future report periods we hope to develop indices based on the eddy identification methodology for comparison with recruitment variability.

Develop indices from all IBM models and explore regional patterns

The recruitment indices for all of the five target species have been obtained from Meuter in the Retrospective group. During this reporting period we had a number of discussions with regards the indices that we plan to develop. At the 'GOAIERP All PI' meeting in March, our discussion got down to a species specific level and involved members of the Retrospective group. Following our timeline, this activity is expected to be ongoing for the remainder of the year.

C. DESCRIBE PRELIMINARY RESULTS.

<u>NPZ Model Results:</u>
Production was computed for the western shelf and southeastern shelf for 1996 through 2011 from the CGOA NPZ model output. In conformity with field observations for 2011, simulated production on the southeastern shelf was notably lower than for all other years simulated in the sixteen year simulation (Figure 1). The low production in the southeastern grid in spring 2011 may be related to physical factors (wind and runoff) affecting the water column circulation, stability and iron concentration. Examination of the runoff forcing files indicated that runoff for the recent cold period (about 2006 to present) was depressed in April-May relative to earlier years (2000 – 2005), resulting in lower iron concentrations during spring. Examination of wind data revealed that the v (north-south) wind component was strongly negative in February – March 2011 compared to strongly positive the previous year when production was higher.

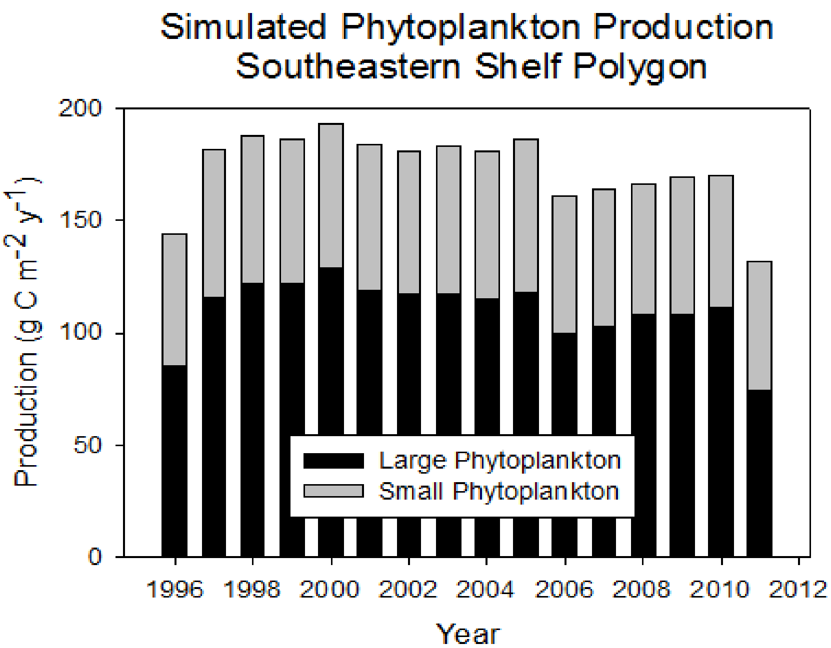

Figure 1. Simulated primary production in the upper 30 m for the Southeastern polygons for 1996 through 2011.

IBM Model Results:

Differences between years in patterns of simulated trajectories indicate moderate variability in transport patterns and connectivity between spawning areas along the shelf break and inshore nursery areas (i.e. arrowtooth flounder, Figure 2).

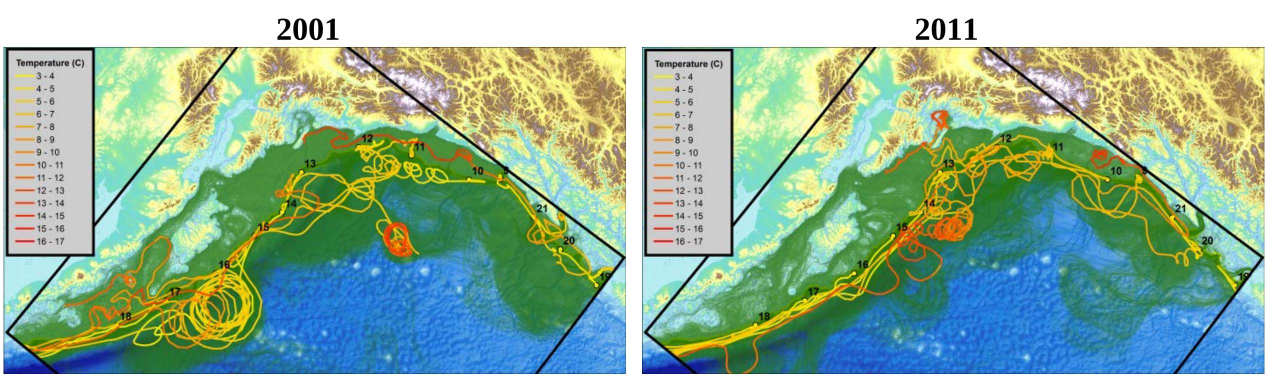

Figure. 2. Comparison of simulated trajectories for arrowtooth flounder pelagic eggs and larvae for 2001 (left) and 2011 (right). Trajectories of selected individuals for each year are highlighted and the trajectories colored according to in situ temperature.

The regions that are being used to explore the spawning-recruitment connectivity will likely be species specific, and will depend on the individual species life-history characteristics. Figure 3 illustrates the regions that were used during this reporting period to develop connectivity matrices for arrowtooth, POP and sablefish. Examples of connectivity matrices that have been developed for sablefish (Figure 4) illustrate that despite some inter-annual differences in connectivity there are some common patterns that are emerging i.e. areas west of Kodiak (region 7) appear to be unlikely spawning areas and settlement in central CGOA (region 6) appears to be consistently high each year. The connectivity matrix developed for pollock (Figure 5) show that in 2002 there was strong retention in Areas 5, 11 and 14 (Shelikof Strait region). The highest connectivity was observed between region 15 (offshore Shelikof region) and nursery region 21 (Shumagin region). In 2011 these relationships were much weaker and there was a higher retention and transport in the EGOA (region 3), a higher transport to Shumagin regions (region 21 and 22) and also advection to the basin (region 25). The connectivity zones and general movement of P.cod is summarized in Figure 6. Generally, P. cod either were retained in the region they were released, or moved to the shallower (<70 m) directly inshore of the region they were released. Some were transported somewhat "downstream" (or to the west) of the area of release. A few individuals released in the 70-200 m depth zone off southeast AK ended up in the mid-GOA gyre, and some individuals released in the same locations and from the 70-200 m zones south of the Kenai and off northeast Kodiak were transported (probably in the Alaska Stream) past the Shumagin Islands.

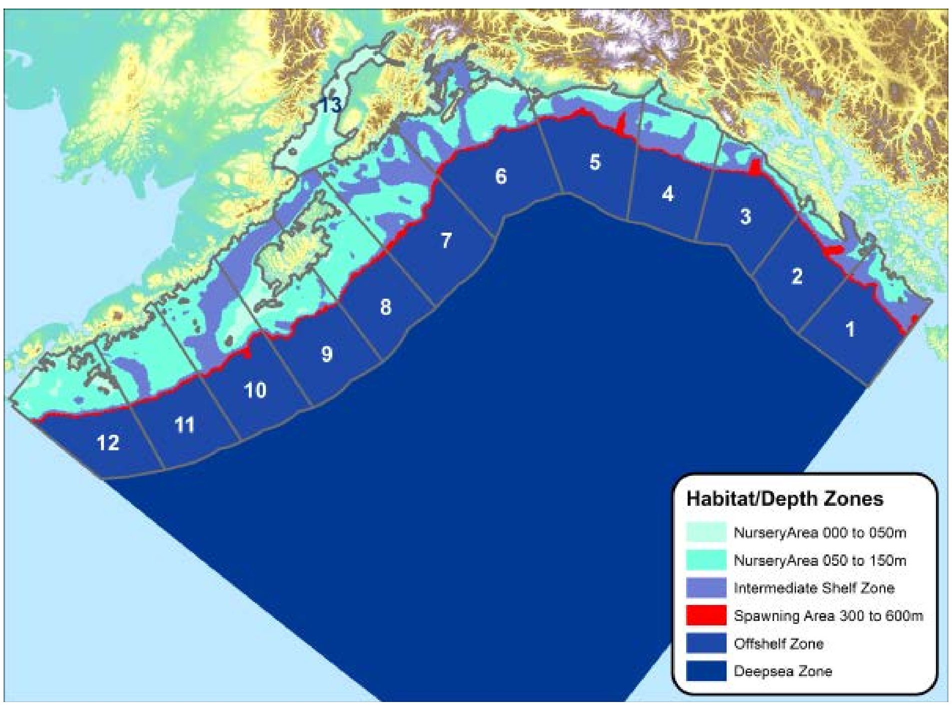

Figure. 3. Spawning and nursery regions used in the connectivity analysis of arrowtooth, POP and sablefish.

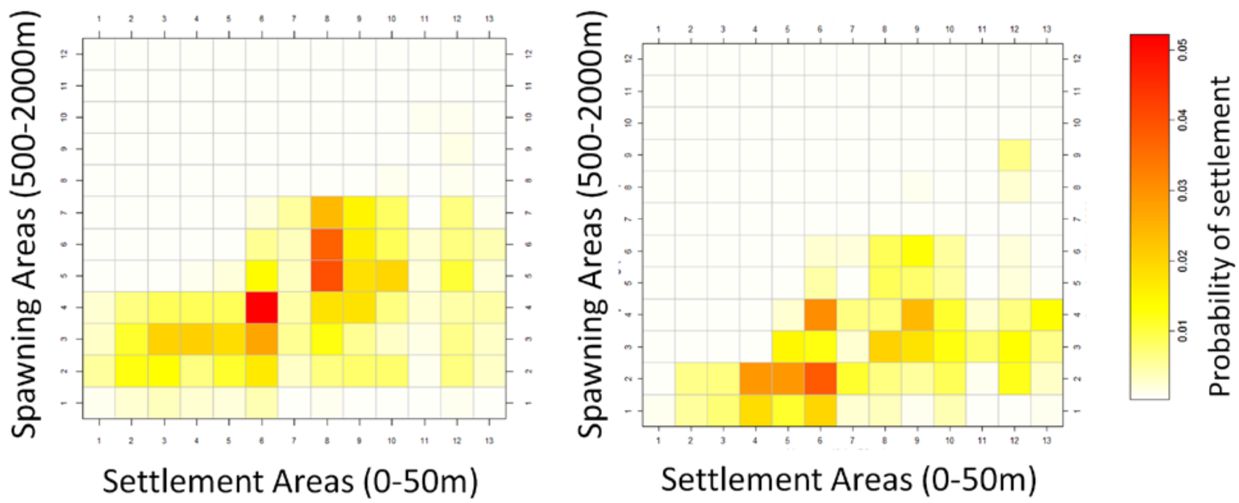

Figure. 4. The estimated connectivity matrix for sablefish from 2001 (left) and 2011 (right), based on potential spawning and nursery areas shown in Figure X. The matrix indicates the fraction of individuals from each spawning area (a row in the matrix) that settle in a potential nursery area (a column in the matrix). The 'hotter' the color, the higher the connectivity between a spawning region and a settlement region.

Figure 5. Connectivity matrices for pollock in 2002 (left) and 2011 (right).

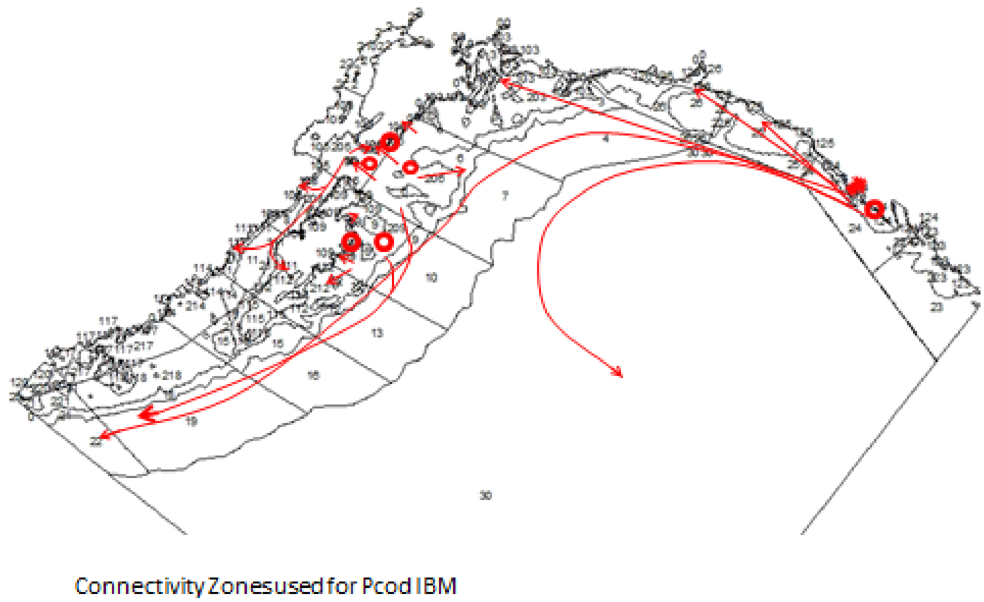

Figure 6. Cartoon representation of transport and connectivity of P. cod in the GOA for 2011. Red circles represent retention of P. cod in spawning areas.

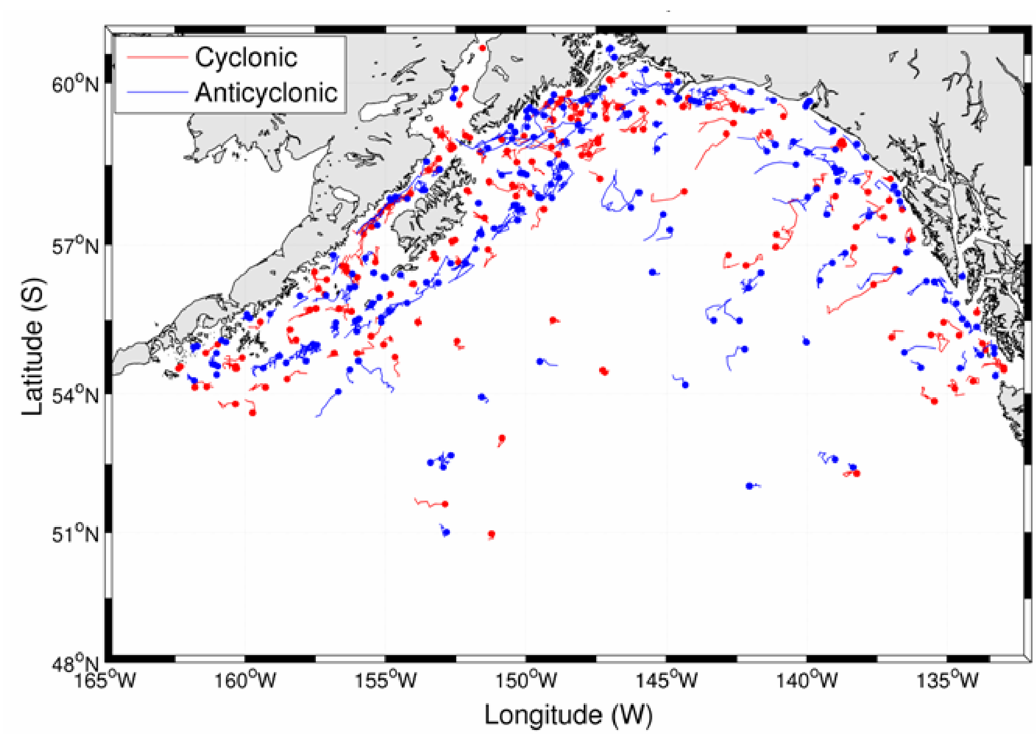

Figure 7. Submesoscale eddies trajectories in The Gulf Of Alaska year for 23 Feb -25 Sept.2004.

Eddy identification

Figure 7 shows the location of eddies in the Gulf for the model year 2004. Submesoscale eddies (<20 km) tend to be present mostly on the shelf, while large scale eddies are mostly found in the basin.

Genetics Model Results

Results from preliminary genetics model runs were consistent with expectations from population genetic theory; genetic differentiation between populations decreased as population sizes increased (Figure 8), whereas genetic differentiation increased as the proportion of homing individuals increased (Figure 9).

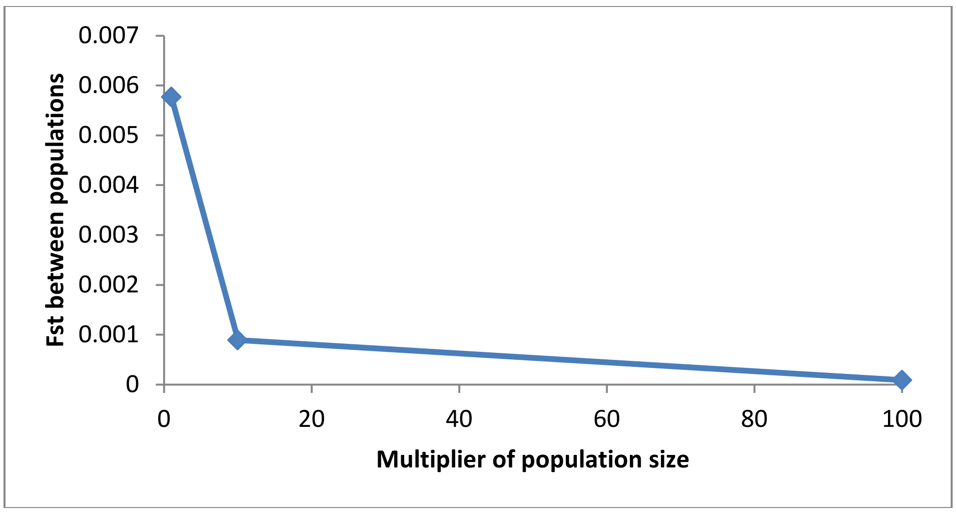

Figure 8. Decrease in genetic differentiation between populations (estimated as F_{ST}) as population sizes were multiplied by factors of 10 and 100.

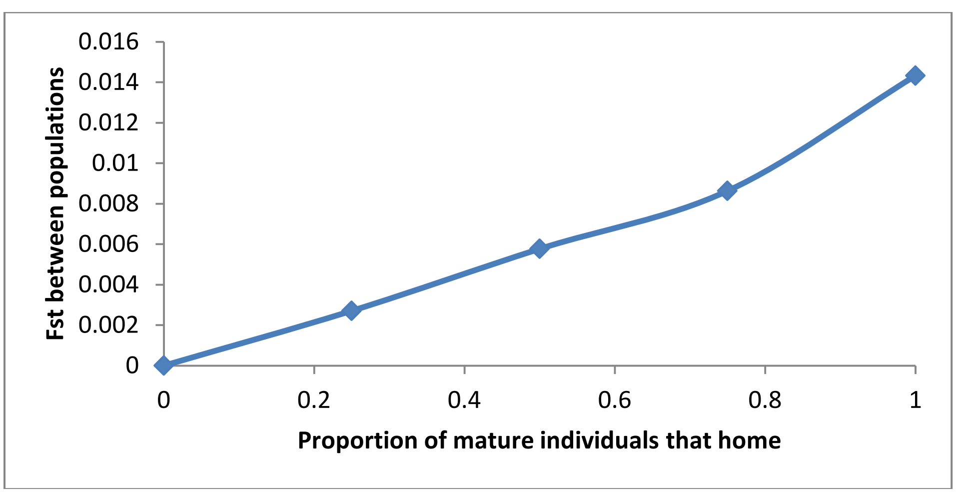

Figure 9. Increase in genetic differentiation between populations (estimated as F_{ST}) as the proportion of mature individuals that homed to natal areas increased.

D. DESCRIBE INTEGRATION ACTIVITY.

As a modeling group we made a very conscious effort to integrate our modeling work into the work of the other GOAIERP groups proceeding the March ‘All PI meeting’. This effort was continued at this meeting in the form of multiple one-on-one and inter-group talks addressing questions of concern to the modeling group, including predation, habitat mapping, and indices for correlation with recruitment.

E. DESCRIBE ANY CONCERNS YOU MAY HAVE ABOUT YOUR PROJECT’S PROGRESS.

During this reporting period the output file size issue previously identified with the DisMELS output was addressed. During simulation setup a user of the DisMELS code now has the ability to select from various outputs in order to produce smaller, more manageable, output files with only the variables needed. Post-processing scripts were also developed in Fortran to further reduce the file sizes.

Also during the past reporting period we reported that we were concerned with being unable to run the models for 2010-2012. We have now been able run the ROMS and NPZ model through 2011, so have covered 2011, the first of the field years. To date we have been unable to run the model for 2013 due to the lack of available forcing products.

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.

We had anticipated that the habitat maps and habitat preference data that are being developed by the UTL group would be available in time for incorporation into the IBMs by now. As time progresses it is looking more unlikely that we will receive these products within a time frame that would allow us to incorporate them into online versions of our models. We will have to continue IBM model development and simulation in accordance to the time-line we developed so that we meet our target deadlines. If this habitat data becomes available at a later date we will attempt to incorporate it into the IBMs in a post-processing fashion. We have a similar concern with timeline of availability for some of the predation data that we had planned to incorporate into the IBMs.

F. POSTER AND ORAL PRESENTATIONS AT SCIENTIFIC CONFERENCES OR SEMINARS

The presentations listed below were made during the past reporting period:

A. J. Hermann, C. Ladd, W. Cheng, E. Curchitser and K. Hedstrom. A model-based examination of multivariate physical modes in the eastern and western Gulf of Alaska. Poster presentation at Alaska Marine Science Symposium, Anchorage, Jan 21-25, 2013.

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.

Stockhausen, W., G. Gibson, S. Hinckley, C. Parada. Modeling the "Gauntlet" from Spawning Grounds to Juvenile Nurseries: Individual-Based Models for the Early Life Stages of 5 Focal Fish Species in the Gulf of Alaska. Alaska Marine Science Symposium, 2013, Anchorage, AK.

Stockhausen, W., S. Hinckley, G. Gibson, C. Parada, K. Coyle, A. Hermann. Modeling the "Gauntlet" from Spawning Grounds to Juvenile Nurseries: Preliminary Estimates of Dispersal Pathways for the Early Life Stages of 5 Focal Fish Species in the GOA. Alaska Marine Science Symposium, 2013, Anchorage, AK.

Stockhausen, W., S. Hinckley, G. Gibson, C. Parada, K. Coyle, A. Hermann. Modeling the "Gauntlet" from Spawning Grounds to Juvenile Nurseries: Preliminary Estimates of Connectivity between Spawning and Nursery Grounds for 5 Focal Fish Species in the GOA. Alaska Marine Science Symposium, 2013, Anchorage, AK.

G. EDUCATION AND OUTREACH

During this reporting period we provided figures and text to NPRB for inclusion in education/outreach brochures describing the GOAIERP project.

4. PROGRESS STATUS

We are pleased with the progress of our project to date which is progressing in accordance to the timeframe we had initially proposed. We have initial working versions of all five IBMs and have developed initial connectivity matrices. We will continue to refine the models during the next reporting period, prior to conducting 'production' runs. Quite a bit of validation has been undertaken for the NPZ model, however, as a group we recognize the need to extend our point-to point validation efforts to a comparison of broader regions and time periods where possible. These comparisons would be a more meaningful validation for a region that is so heterogeneous in time and space.

5. FUTURE WORKPLAN and DATA DELIVERY

Workplan

What	*Who*	*Start and end dates*	*Other key dates*
Validation of	Ladd, Hermann,	June 2012 – Mar	

ROMS/GOANPZ	Coyle	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		