I. FY07 Invitation: Narrative Forms for Proposals

PROPOSAL SIGNATURE FORM

THIS FORM MUST BE SIGNED BY THE PROPOSED PRINCIPAL INVESTIGATOR AND SUBMITTED ALONG WITH THE PROPOSAL. If the proposal has more than one investigator, this form must be signed by at least one of the investigators, and that investigator will ensure that Trustee Council requirements are followed. Proposals will not be reviewed until this signed form is received by the Trustee Council Office.

> By submission of this proposal, I agree to abide by the Trustee Council's data policy (*Trustee Council Data Policy**, adopted July 9, 2002) and reporting requirements *(Procedures for the Preparation and Distribution of Reports***, adopted July 9, 2002).

PROJECT TITLE: **An Ecosystem Model of Prince William Sound Herring: A Management & Restoration Tool**

Printed Name of PI: Dr. Dale A. Kiefer ______________________________
Signature of PI: ______________________________ Date 7/31/2006

Printed Name of co-PI: Dr. Evelyn Brown ______________________________
Signature of co-PI: ______________________________ Date 1/8/2006

Printed Name of co-PI: Dr. Vardis M. Tsontos ______________________________
Signature of co-PI: ______________________________ Date 7/31/2006

* **www.evostc.state.ak.us/Policies/data.htm**
** **www.evostc.state.ak.us/Policies/Downloadables/reportguidelines.pdf**

Trustee Council Use Only Project No.070810 Date Received: _________

FY07 INVITATION
PROPOSAL SUMMARY PAGE

Project Title: An Ecosystem Model of Prince William Sound Herring: A Management & Restoration Tool

Project Period: Jan.1, 2007 to Dec.31, 2009 (3 years total: 1 year initially, with possibility of renewal for 2 additional years)

Proposer(s): Drs. Dale A. Kiefer & Vardis M. Tsontos (System Science Applications, Inc)
Dr Evelyn Brown (Flying Fish Ltd).

Study Location: Analysis/Modeling of data from Prince William Sound & Gulf of Alaska

Abstract:

Over a three-year period, we propose to develop a life-stage specific, ecosystem based model of the Prince William Sound (PWS) herring that will aid in the integration ecological data that has been gathered on herring over the last 2 decades, evaluation of proposed restoration activities, and attempt to simulation of the processes that cause the chronic decrease in herring stocks since the 1989 spill. More specifically, it will be used to test the unresolved hypotheses of why the herring have not recovered to pre-spill densities. The model and associated data will be housed in a geographic information system that we have developed specifically for marine applications. The geo-spatial information from field surveys and simulations with the model will available for interactive viewing and downloading of files over the Internet.

The model will provide a mathematical description of the population dynamics of annual herring cohorts as they mature through their life stages. In particular we will focus on arrival of larvae to the Bays of PWS, the maturation and survival of juveniles in these bays, and the survival and reproductive success of adults as they move seasonally from spawning grounds, feeding grounds and wintering grounds. The system of coupled differential equations that describe these processes will be tuned to prove a best fit between model calculations and field and laboratory measurements. In its final form the model will consist of 3 sets of such equations that will simulate the unique conditions found in herring habitats of the eastern, northern and southwestern regions of PWS. Most importantly, the model will be formulated according to the principals of the trophic trap in which 2 metastable states for herring exist, low-density and high-density. We propose that a sequence of events following the spill drove the herring from high-density to low-density and a trophic trap prevents stocks from recovering. Thus, we will tune our model to both high-density and low-density states and then run the tuned models in the forward or backward direction to identify both the most probable causes of the injury and the most promising approaches to restoration.

Our team has the scientific and technical experience to succeed, and we will work closely with researchers from the other herring projects, especially those working on larval drift, disease, otolith marking, and intervention. Our web-based system will promote such collaboration particularly with such groups as PWSFRAP and with the PWS Science Center.

FUNDING:

Total EVOS funding requested for FY 2007 – FY 2009 = $752.4K

FY 2007 = $250.8K FY 2008 = $250.8K FY 2009 = $250.8K

Non-EVOS funding being contributed during FY 2007 – FY 2009 = $0.0K

Date: 8/3/2006

Project Plan

II. Statement of the Problem

Pacific herring (*Clupea pallasi*), an ecological and economically important forage fish in Prince William Sound (PWS), continues to remain at low population levels following the disease event in 1993 (EVOS solicitation). This problem is best presented in terms of three questions:

- What factor or factors caused the initial decline in PWS herring following the 1989 spill?
- What factor or factors have caused herring stocks to remain in low densities to present and prevented recovery to pre-spill levels?
- What management procedures if any can be implemented to help drive the stocks towards stable pre-spill densities?

Answers to these three questions are not easily answered both because of the spatial and temporal complexity of herring life history and the extensive research conducted since the spill has indicated that population dynamics of the species is subject to many environmental variables including predation, disease, food availability, and passive transport and active migration of life stages. One of a very limited number of approaches to understanding such a multivariate system is to develop ecological models that are spatially explicit and tuned to time series observations of population and related environmental variables. We propose here to develop such a model.

In April of this year EVOSTC hosted a herring workshop that gathered a large group of herring researchers, resource users, agency managers, and other concerned members of the public. The list of prioritized research categories in Appendix A from the FY07 solicitation were identified and outlined as a result of that meeting. It was clear from the meeting that further research into this problem will require will require a team of multi-disciplinary scientists, local experts and local involvement. Optimal results can best be derived from a team that can communicate, cooperate, and integrate their findings and actions in an iterative, flexible process. In addition, building upon past research and local knowledge will make the process more efficient and prevent "re-inventing the wheel". For this reason, it will be desirable to involve scientists and local people that have been involved in the past, who may have worked together previously, who are invested in the results, and who therefore possess motivation to produce comprehensive and applicable results. Because the research needs have broadened to include intervention and possibly enhancement, new ideas and new tools are need. Our research team consists of scientists who have been integrally involved in past herring research and who are connected locally to involved community members, as well as scientists who developed models and tools with broad applications in fisheries science and oceanography.

Our model will draw upon the ideas and analyses of Dr. Evelyn Brown, a Co-PI in our project, and her associates. This work is fully described in her doctoral dissertation (2003), a short analysis paper, and several articles that she has co-authored in scientific journals. She has hypothesized that the lingering low populations of herring in PWS is a result of a two factors that occurred during the years of 1989-1993. The first factor was the oil spill itself that impacted the population directly through the local mortality eggs, larvae, juveniles, and adults. Exposure to oil and surfactants used during the cleanup also impacted the population by weakening the health and fitness of surviving individuals. The second factor was a regime shift in the early 90s that led to decreases within the Sound of the concentration of zooplankton, the key food supply for the herring. The combined effects of diminished food and exposure to oil, compromised the immune system of the populations, and in 1993, an epidemic of Hemorrhagic Septicemia virus (VHSV) broke out. The disease is largely limited to PWS and has persisted through the 90s. By further diminishing depleted stocks the disease as well as the prolonged warm period has made recovery that much more difficult. Dr. Brown has hypothesized that the populations had been reduced to such low levels in the early 90s that they cannot return to pre-spill levels because predation on the reduced population by seabirds, larger fish and marine mammals prevents recovery.

Dr. Brown's analysis is based upon historic studies, field surveys, and modeling exercises. She states that the link between the oil spill and the population crash hangs on two main pieces of evidence. The first piece of evidence is the link between PWS and other herring populations in the Gulf of Alaska. Because some environmental factors that affect herring growth and survival occur on a large scale, there is often coherence between herring populations occurring within this region (Williams and. Quinn, 2000a and b). Sitka Sound, Southern Southeast Alaska, and PWS are three coherent populations that show similar recruitment, age structure, and population trends. The correlation of recruitment between any two of the three is highly significant (Williams and. Quinn, 2000a). Prior to 1989, Sitka Sound was most closely correlated to PWS with a squared correlation coefficient (R^2) of 0.94. This correlation was used to predict recruitment in PWS for 1989 through 1993. Since 1991 the actual PWS recruitment has fallen well below the predicted recruitment (Figure 5). Although recruitment in PWS has fallen well above (e.g. 1972) or below Sitka (e.g.1980) in the past, it has never done so for more than a single year. The drop in expected recruitment in PWS is a three-year trend and continues to the present. In addition, the coherence among other Pacific Herring populations continues and only PWS seems to diverge. The lower than expected recruitment may help to explain why the PWS population has not recovered after the disease crash in 1992.

The second piece of evidence is based upon the historic relationship of the PWS herring population to trends in climate. As with many other herring populations in the Pacific, the PWS population appears to track trends in climate. Especially significant are the relationships of the herring population trend to the Atmospheric Forcing Index (AFI), the Aleutian Low Pressure Index (ALPI), and the winter months of the Pacific Decadal Oscillation (PDO). Figure 1 displays the time series from 1964 to 2000 of the Pacific Decadal Oscillation for winter months and the normalized annual herring spawn in PWS (in mile-days as obtained from aerial surveys. While the two parameters track each other well prior to 1989-1990, the relationship has diverged thereafter. Such divergence has not been observed in Sitka Sound or along the southeastern coast.

The breakdown in the relationships between climate indices and recruitment that has occurred since the spill was not caused by a prolonged decrease in the availability of food to the herring.

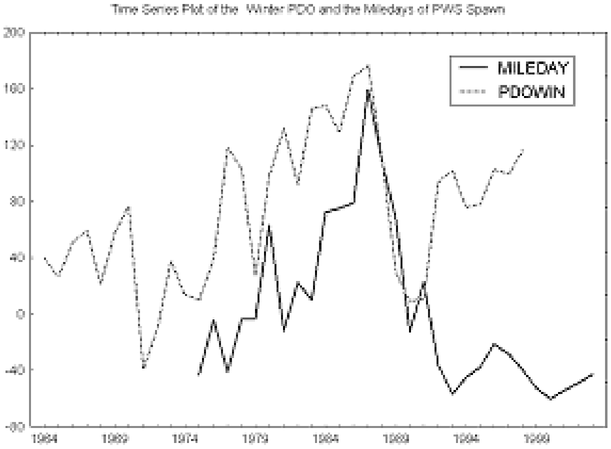


Figure 1. Time series of spawning in PWS and the Pacific Decadal Oscillation that were correlated between 1973 and 1993, but now appear to have deviated.

This figure displays a time series from 1973 to 1999 for the size at age anomaly of PWS herring for age classes and from 1979 to 1999 of the peak zooplankton concentration. The size-at-age of PWS herring has been found to be cyclic over approximately 14 years. Data gathered by the plankton watch program of the PWS Aquaculture Corporation, suggests strongly that size-at-age of PWS herring are highly correlated with the annual index of zooplankton biomass (Brown, 2003).

One notes from this figure is that the herring in PWS faced declining concentrations of food immediately after the spill, but since 1992 food availability has increased as has the size-of-age of herring. The failure of recovery into the 2000s does not appear to be the result of a climate change that has reduced the availability of food. Some other factor in the life history of PWS herring has suffered long term alteration. It has been determined that recruitment remains a problem, and therefore early and possibly adult life history mortality must continue to remain high.

III. Responsiveness to Trustee Council Strategies

The relevance and utility of an integrative modeling and mapping exercise to the herring research objectives listed in the solicitation that reflect EVOSTC Restoration Plan Strategies has been discussed in the previous section. This proposal directly addresses two complementary research categories, web based GIS/geospatial analysis and modeling, and indirectly addresses five others (predation, disease, oceanographic characteristics, marking studies and intervention). Because two members of or team have worked directly with the local agencies, fishermen, and scientists of PWS, we are acutely aware of the need for comprehensive tools that can be used to monitor and restore herring. We propose to work closely with the locally formed citizen's group PWSFRAP to ensure that our product helps identify the most promising methods for managing and restoring PWS herring. We will closely with other scientists selected by EVOSTC part of the working "team".

IV. Objectives

The main goal of this project is to produce a spatially-explicit, life-stage compartmentalized, and ecosystem-based herring model that will simulate intrinsic and extrinsic effects on herring survival and mortality that is sufficiently robust that provide reliable guidance to both future fishery management and ecological intervention. The data and model will be fully housed in a dynamic, web-based GIS (called EASy) that we have developed specifically for marine applications. The main herring model will actually be a series of life-stage sub-models that are connected by state variables and processes. This will be a 3-year, iterative effort with measurable products at the end of each year.

The objectives for this project center on producing a series of connected life-stage submodels that can address 4 overarching hypotheses concerning limitations to herring recovery:

1) A climate shift has impacted regional production by changing circulation patterns and temperature that directly affects larval drift and prey resources for herring;
2) Hemorrhagic Septicemia virus (VHSV) continues to limit growth rate and increase mortality rates of adult fish;
3) A change in community structure has created a "predator" that has caught herring in a low-density state, that acts to limit herring recovery (interaction of predation, prey, competition in relation to abundance of the species involved);
4) Contamination from EVOS continues to limit the herring's habitat;

We will see below that all four of these hypotheses can best understood in terms of models that are structured around the concept of a "trophic trap" (See section IV). We will construct the life-stage submodels to specifically test these hypotheses. The specific objectives for the project are given below (respective task numbers in brackets), and the timetable for task implementation is given in the Schedule section (VII):

Year 1

- Create spatial and temporal database of ecological information on herring within the GIS system EASy as a precursor to analysis and modeling. [1.1-1.2]. The database will include relevant ecosystem datasets for PWS listed in Table 1 of the Appendix.
- Develop a project website providing descriptive information on the project and access to project products (eg. web-based GIS). [1.3]
- Update the historic stochastic analyses (GLIM/GAMs applied mainly to time series datasets) to include recent years (2000-2006) and to include the disease time series that is now available (1993 to present) in order to detect changes in functional relationships between and among variables. [1.4]
- [1.5-1.7] Formulate a 1-dimensional, time-series simulation for juvenile and adult submodels to include representation of disease processes (hypotheses 2) and predator/prey/competitor dynamics (hypothesis 3). This model, which provides a generic simulation of herring population dynamics will be structured according to the "trophic trap" scheme that is described in section IV. The development of these models will be guided by the Evolutionary Equations that have been developed for PWS by Dr. Patricks and his co-workers. The 1-d model will be tuned using the search routines (Newton, Levenberg-Marquardt, and binary) that are already available within the EASy GIS to provide a best fit to the metastable states that characterize pre-spill and post-spill conditions of herring population size and temporal variability.

- Install a web-enabled version of the GIS on the EVOS server so that the data, maps, and outputs of the model can be viewed and downloaded over the Internet. [1.8-1.9]
- [1.10] Interface the GIS with output from the circulation models that have been developed for PWS and examine the possibility of obtaining a monthly climatology of circulation within the 3 regions that are thought to contain the PWS subpopulations. The circulation climatologies will include provide a time series of fields for flow velocity, temperature and salinity that are among the inputs to the spatially explicit model that will be developed in years 2 and 3. We are particularly interested in characterizing the flow responsible for the transport of herring larvae emerging from attached embryos to their destination as juveniles in the nursery grounds of PWS bays.

Year 2

- Extend the dynamics population model to a spatially-explicit, metapopulation model formulation accounting for climatology of ecological conditions within each region. Furthermore, the population dynamics of herring within each region will be subject to exchange of herring between subunits and differential population rate processes between regions. [1.11]
- The climatologies of variations in the circulation within PWS caused by regime shifts or extremes in seasonal conditions will be collected and introduced into the GIS as described in Year 1. The metapopulation model will be tuned our search routines to provide a best fit to the two metastable states that characterize pre-spill and post-spill conditions of herring population size, and temporal variability. [1.12]
- We will run preliminary tests with the model to explore which of the intervention methods that have been proposed appears most promising. Run spatial simulation and evaluations for enhancement or intervention scenarios, for effects of disease or pollution, and for variations in larval drift. [1.13]
- The metapopulation model and associated data will be interfaced via EASy API with the GIS application developed for this project, such that users will be able to view both Herring model outputs and compiled data layers via the GIS over the Internet. [1.14]

Year 3

- The metapopulation model will be further refined and tested by comparing its predictions with the short term simulation predictions calculated with the Evolution Equation Model that has been developed by Patrick and colleagues for pink salmon and subsequently applied to herring. [1.15]
- The metapopulation model will be iteratively to determine it sensitivity to differing values for coefficients within the system of the coupled differential equations. Based upon this sensitivity analysis, confidence limits will be placed upon model predicts of the outcome of intervention schemes. [1.16]
- Deliver finalized and functional, web-based GIS tool to local entities (EVOSTC, PWSFRAP, ADFG, and PWSSC). [1.17

We will undertake all required reporting and write scientific articles describing our work. [1.18]

V. Procedural & Statistical Methods

Project Website and Web-based GIS

A key deliverable of this project will be a Web-based GIS system, accessible via a project Website also to be developed, that will provide an interactive, public medium for viewing project data as well as the results of calculations with the Prince William Sound (PWS) herring model. As described above this model will simulate seasonal variations in the distribution and associate population dynamics of life stages of PWS herring metapopulations and in relation to topographic and relevant oceanographic variables. In addition to incorporating herring aerial survey data, habitat information and other herring-related data for overlay and synthesis, this GIS tool will also integrate the spatially explicit population dynamics (metapopulation) model developed as part of this project (section IV), thus providing a means of geospatial analysis, synthesis and comparison of both model outputs and field observations. The GIS system proposed will be an application of EASy/Netviewer, an advanced oceanographic GIS software package that is already hosted on EVOS and NPRB servers and providing online access to Alaskan fisheries and oceanographic datasets via the AFSC Trophic habits and Alaskan Marine Information System (AMIS) applications respectively. Specific technical features of this software relevant for this application are summarized in the appendix. A general description of the overall structure of the proposed herring information system follows.

The components and flow of information within the proposed EVOS Herring Web-based GIS (EHGIS), that we suggest should ultimately reside on the EVOSTC server(s), are summarized in Figure 2. The overall implementation model proposed is closely comparable to that for the AFSC trophic application, that is being successfully served by EVOS. At the top level are the application source data, including PWS herring survey datasets, oceanographic observations, and satellite imagery, that will be assimilated into the GIS as relational databases or in the case of imagery as raster/vector files in their native format (details of specific PWS herring and ecosystem datasets to be used are described in Table 1, Appendix). Metalite will be used to document the metadata of all datasets employed in the application according to FGDC standards, and all metadata will be accessible via the EHGIS system. The system will

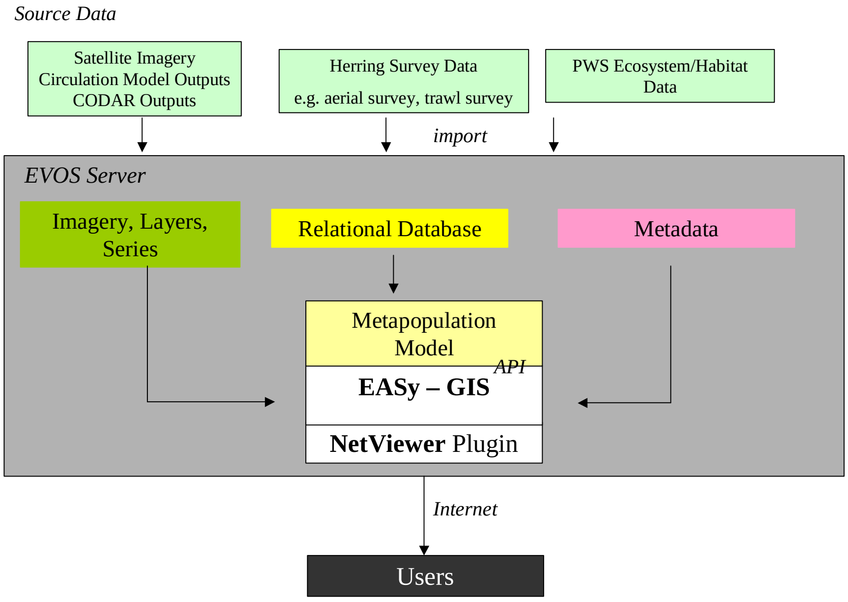


Figure 2. Components of EVOS GIS

also be coupled, via EASy GIS's API (applications programming interface), to the spatially explicit population dynamics model developed as part of this project. EASy's Netviewer plug-in allows the fully integrated application to be deployed across the Internet via hosting on a PC/Windows Server running MS-IIS and SQLserver. By using Netviewer's intuitive Graphic User Interface (GUI), users will be able to easily and interactively overlay, browse or step through time-series of synthetic maps and other graphical representations of observed and modeled data comprising the Herring application. If the maps or source data of interest in making assessment of recovery, the information can be downloaded directly via the system to the user's computer. The point of entry to the Web-based Herring GIS will be via the project Website that in turn will be linked to the EVOSTC Website. The project site will serve as a public information/outreach tool, documenting project objectives, key activities, status of the work component packages, while also functioning as a home for project products, such as the Web-based PWS Herring GIS application.

Data Analysis, Statistical Methods, and Models

Previous Modeling Efforts & Herring Life History Aspects

During the EVOSTC project 00375, *Effect of Herring Egg Distribution and Ecology on Year-Class Strength and Adult Distribution*, Dr. Brown developed a life-history model that summarizes the processes regulating survival, year-class formation, and distribution of Pacific herring. An extensive literature review was conducted as a part of this project. The model was formulated from that extensive ecological database on Pacific herring including recent research conducted in PWS by the Sound Ecosystem Assessment (SEA) program (see Norcross et al. 2001) and the Alaska Predator Ecosystem Experiment (APEX) project, both funded by EVOSTC. Framed as a simulation model, the form is spatially explicit, dynamic and ecologically based. Using the conceptual model, observed temporal events, and observed and modeled spatial distributions, a stock structure is proposed for the Prince William Sound (PWS), Alaska herring population based on metapopulation theory (Levins 1968; Hanski, 1999). The conceptual model comprises four life-stage submodel consisting of adults, embryos, larvae, and juveniles (Figure 3); each stage the population dynamics of each of these stages is determined by the

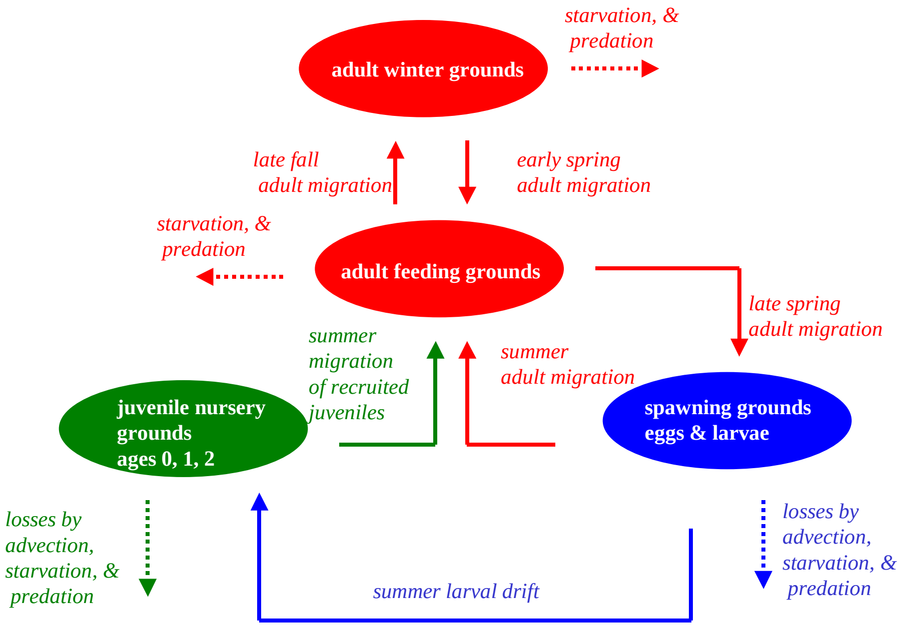


Figure 3. Spatial domains, life history stages, and processes of herring model

behavioral and physiological properties of the population and the ecological conditions within the habitats that each stage occupies. Sections of model components can be represented using existing herring models that will be described here.

Brown's study included two separate stochastic modeling exercises to examine 1) the effects of climate on long-term changes in the herring population, and 2) the effects of intrinsic and extrinsic forces within the ecosystem that drive large oscillatory fluctuations in recruitment. These analyses identified key components of the conceptual model subcomponents that appear to cause much of the variability in year-class strength. Fortunately, many of the environmental model inputs were basic oceanographic and atmospheric variables easily obtained from routine observational measurements or from the gridded physical models. The biological state variable inputs were data monitored by Alaska Department of Fish and Game (e.g. spawn magnitude and location, egg or spawner density, and age composition). The recruitment models produced by Brown (2003) explained up to 90% of the variability, a significant improvement over past models. In addition, the models identified eight critical life history periods within which year-class strength (survival to adult recruitment) was determined. This identification helps focus our modeling efforts.

The relationship between the life cycle shown in figure 3 and habitat of the stages is shown in figure 4. Life begins in the late spring (blue oval) in the subtidal regions of adult spawning grounds where embryos attached to substrate mature to larvae after an incubation period of 1-2 months. The larvae then drift with the coastal currents for approximately 3 months until they become sufficiently strong to maintain their position relative to currents. Planktonic predation is intense. Those juveniles finding bays (green oval) have the greatest chance of survival, they reside in the bays for over 1.75 years. Prior to the spill the populations of mature juveniles within the bays achieved breakout densities every 4 years; the breakouts were always followed by a 2-year decline in adult recruitment and then recovery. The mature juvenile join the adults as they return from spawning grounds and migrate to summer feeding grounds (lower red oval). Finally in late fall the adults migrate to wintering grounds (upper red oval). According to this cycle herring have 5 quite distinct "stage habitats", the subtidal shore of spawning grounds, the region of larval drift, nursery bays and inlets, adult feeding grounds, and adult wintering grounds. The maximum longevity of adults is 8 years. The ecological diversity of these habitats adds complexity to the simulation model.

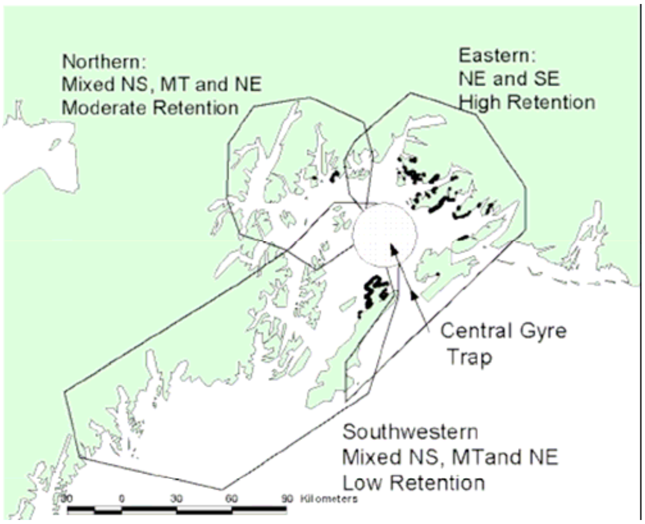


Figure 4. Proposed Herring metapopulation structure (from Brown, 1993)

Formulation of the Model

As indicated above we will develop a herring model will be a spatial, simulation of metapopulation dynamics of the latter 3 stages in the life history of herring as determined by conditions found in the associated 4 associated stage habitats. We will focus our efforts on the juvenile and adult submodels as well as the trophic alteration model with minimal attention to the embryonic or larval submodels. Embryonic survival and mortality has been modeled effectively by former studies (McGurk and Brown 1996; Rooper et al. 1996; Norcross and Brown 2001). Other researchers (Wang and Norcross, this solicitation) are proposing to complete a larval drift model; we propose coupling larval stage model to this effort during the second year of the project. Our development will attempt to incorporate the key features the pink salmon foraging model described in Willette et al. 2001 and formulated by Vince Patrick. We will also include disease terms that will generate direct removals (disease mortality) and affect condition and thereby predation rates. However, we expect to formalize quantification of the disease processes after conferring with researchers from the pathology study (see Kocan and Herschberger, this solicitation) and will be completed in year 2.

We describe in a general way the movement of cohorts through a given life stage j within a closed and uniform habitat as a differential equation consisting of three basic processes:

$$\frac{\partial \mathrm{N_j}}{\partial \mathrm{t}} = \mathrm{g_{i\to j}}\,[\Delta \mathrm{t_i},\ \Delta \mathrm{tm_i},\ \mathrm{N_i}] * \mathrm{N_j} - \mathrm{g_{j\to k}}[\Delta \mathrm{t_j},\ \Delta \mathrm{tm_j}] * \mathrm{N_j} -$$
$$\left\{\mathrm{mpred_j}\left[\gamma_{\mathrm{j,i}}\left(\bar{\mathrm{X}}_\mathrm{i}\right),\ \sigma_{\mathrm{j,i}}\left(\mathrm{N_j}\right)\right] * + \mathrm{mstarve_j}\left[\gamma_{\mathrm{j,i}}\left(\bar{\mathrm{F}}_\mathrm{i}\right),\ \sigma_{\mathrm{j,i}}\left(\bar{\mathrm{F}}_\mathrm{i}\right),\ \mathrm{T}\right] + \mathrm{minfect_j}[\mathrm{Finfect_j}]\right\} \mathrm{N_j}$$

1. $g_{i->j}$ $[\Delta t_i, \Delta tm_i, N_i]*N_j$ describes the addition of new recruits to the stage j caused by maturation of the previous life stage i. $g_{i->j}$ $[\Delta t_i, \Delta tm_i, N_i]$ is the specific rate of recruitment, i.e. the rate of recruitment divided by the population of stage j. $g_{i->j}$ $[\Delta t_i, \Delta tm_i, N_i]$ is itself a function whose value will be determined by the time the cohort has spent at stage i, Δt_i, the time required for stage i to reach maturity, and the population of stage i, N_i . A detailed description of this and the other functions in the equation above will not be given here for two reasons. There is insufficient space here, and the final derivation of the function is among our tasks. In the case of the adult stage we define $g_{i->j}$ $[\Delta t_i, \Delta tm_i, N_i]$ is the specific rate of production of the herring population. We will see that in section below, **The Trophic Trap**, that this function is a defining feature of the trap that we propose has prevented PWS herring from returning to pre-spill densities.

2. $g_{j->k}$ $[\Delta t_j, \Delta tm_j]*N_j$ is the loss of members of the population of stage j caused by their maturation and recruitment into the population of stage k. Again $g_{j->k}$ $[\Delta t_j, \Delta tm_j]$ is the specific rate of recruitment to stage k and is itself a function whose value will be determined by the time the cohort has spent at stage j, Δt_j and the time required for stage j to reach maturity.

3. The third process is the loss of members of the population of stage j caused by predation, starvation, and disease. As indicated by the brackets the total, rate of mortality of the

population of stage j is simply the product of the sum of the functions for specific mortality for each of the 3 types of mortality and the population of stage j. We will see in the "Trophic Trap" section that the sum of the specific rates of mortality for predation, starvation, and infection for the adult population will be called the specific mortality rate. It is a defining feature of the trap.

- The specific mortality rate at which stage j individuals are consumed by its predators is $\text{mpred}_j[\gamma_{j,i}(X_i), \sigma_{j,i}(N_j)]$. Following the development of Kiefer and Berwald (1992), this function is itself a function of the rate at individuals of stage j encounter in their search for food each of their predators, $\gamma_{j,i}(X_i)$, where X_i is the vector of predator species populations. mpred_j is also a function of $\sigma_{j,i}(N_j)$, predator i's selectivity for killing an encountered individual of stage j. As indicated this function will depend upon the population of stage j. According to optimal foraging theory, when the density of prey species is low relative to alternative prey species, selectivity on the low-density species drops. This theory also predicts that when there is an abundance of food, the predator will become sated and selectivity will decrease. We will see that such responses are a critical feature of the trophic trap.

- The specific mortality rate at which stage j individuals starve is $\text{mstarve}_j[\gamma_{j,i}(F_i), \sigma_{j,i}(F_i), T]$. This function is a physiological description of the difference between the rate of supply of food to individuals of stage j and their rate of respiration. The rate of supply is once again a function of encounter rates between predator and prey and the selectivity of ingesting and assimilating the prey. $\gamma_{j,i}(F_i)$ is the rate at which an individual of stage j encounters its prey, where F_j is the vector of the population of stage j, prey species. $\sigma_{j,i}(F_i)$ is the selectivity with which an individual of stage j ingests and assimilates prey of species i that it has encountered. Again, optimal foraging theory provides the basis for formulating this function. T is temperature that determines the specific respiration rate of individuals of stage j, i.e. the rate at which assimilated food is lost from the individual. The Pink Salmon model of Patrick and co-workers will help guide the formulation of both the predation and starvation functions.

- The specific mortality rate at which stage j individuals die from VHSV infection is $\text{minfect}_j[\text{Finfect}_j]$. This function is itself a function of the fraction of the population of stage j that is infected, Finfect_j. Furthermore, Finfect_j is a function that will likely depend upon several factors including rates of encounter between infected and uninfected individuals, the selectivity of transmission during encounter that will depend upon the fitness of the uninfected individuals. We will work with the PWS herring hemorrhagic septicemia virus team to derive this function.

As stated above there is insufficient space here to discuss these functions, but we note that these functions and all other discussed in this proposal will draw upon the published research and in particular the mathematical insights that have resulted from the pink salmon model of Patrick and co-workers. Furthermore, while these functions have a well defined mathematical form, they will include variables whose values will be determined by tuning to field and laboratory measurements and observations; thus, these functions are a type of phenomenological description- as reliable as both the fit between model calculations and field measurements and that the fidelity to which field and laboratory measurements provide a complete and accurate description in time and space of relevant ecological conditions.

We wish to point out three additional features of the formulation that we will develop. First, we note that for the sake of simplicity the equation above refers to the population dynamics of a single annual cohort. In fact the cohorts of differing years for juveniles and adults will compete with each other for food resources and sites for egg deposition, infect each other with VHSV, and although evidence is sparse may even prey upon earlier life-stages. For example the large, 4-year oscillations in herring recruitment prior to the spill may be an expression of such interactions between cohorts. These interactions will be included in the model.

Second, we note that the functions for specific productivity rate and the specific mortality rate for the adult stage described above are key emergent features of our model since they define the existence and properties of the trophic trap. (See figure 7). We have made preliminary simulations with functions of the type described above and found that both the specific production rate and mortality rate will depend not only upon the population of prey and predators, but also upon the population of adult herring. In fact and as described by Bakun (2006) specific rates of production and mortality vary in characteristic ways with the size of the adult population. *We believe that the failure of the recovery of PWS herring is most easily explained by this density dependence of the mortality and productivity functions; we call this condition the "trophic trap".*

Third, we note that the equation above is limited in it applicability since it describes the dynamics of a herring stage in terms of the ecological characteristics of a single habitat. However, the equation can be easily extended to a description of the dynamics of a metapopulation, which consists of several subpopulations from spatially distinct habitats. This is achieved by including terms for immigration and emigration between habitats and introducing appropriate values for model variables of the subpopulations within their respective (sub)habitats. The development of such a metapopulation model is important for developing a strategy for intervention, more effective management of a herring fishery should it recover, as well as a better understanding of the factors that drove the population to chronic low-density.

Our metapopulation model will describe three herring subpopulations that inhabit the eastern, northern and southwestern regions of PWS (Figure 4). These three regions are distinguished by their climatological patterns of circulation. According to Brown (2003) subpopulations with each regional population have adapted unique strategies to meet the challenges of successful recruitment. Regional differences range from high retention of larval stages within the eastern region to low retention but high rates of migrants arriving from other regions within the southwestern region. Likewise herring life stages will have varying survival probabilities in each region because of differences in food supplies and competing and predatory species. Within any one region, populations will be treated as uniformly distributed within the habitat occupied by a given life-stage. For example, young juveniles tend to congregate nearshore within PWS bays while adults range more widely in summer months, out to the inner continental shelf adjacent to PWS. Local concentration factors will generally depend on both life stage and season.

The Trophic Trap.

Figure 5 illustrates the "trophic trap" in which the shapes of the density dependent curves for the specific productivity rate and the specific mortality rate creates two metastable states for a fish population a metastable low population density state and a metastable high population density state. As indicated dual states exist with the model of population dynamics because the density-dependent function for specific mortality rate is unimodal while the density-dependent function for specific productivity is a monotonic curve. The unimodal shape of predation is an emergent feature of optimal foraging theory. The monotonic shape of production is on the other hand an emergent feature of resource limitation that is a feature bottom-up regulation.

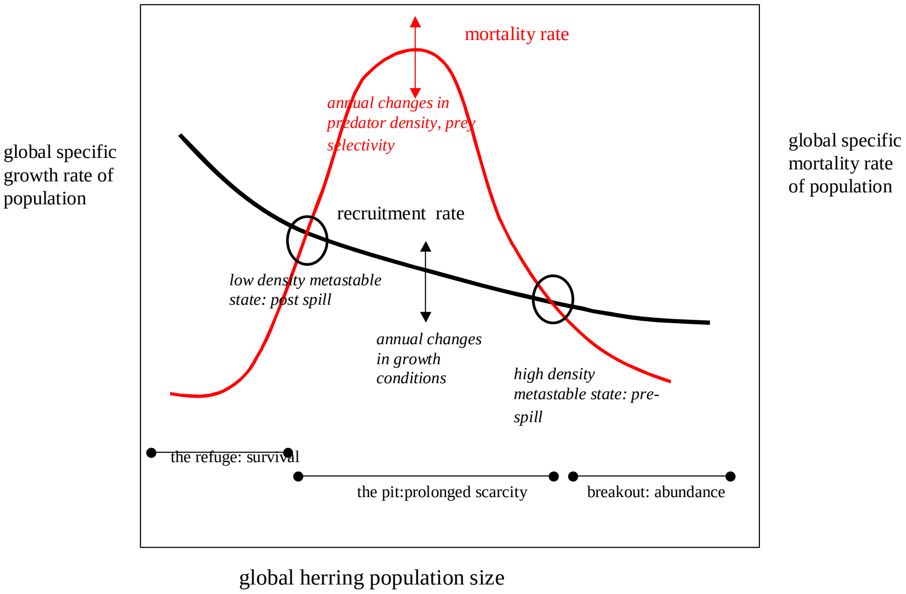


Figure 5. Schematic illustrating how the Trophic Trap mechanism may give rise to the observed metastable states in the PWS Herring population.

Bakun (2006) first called this a predator trap, but we prefer to label it a "trophic trap" since it provides room for control by disease, habitat loss, reduced production, and fishing, as well as predation. From such perspective the PWS herring were driven by the time series of events during and after the spill from a high-density state to a low-density state. As indicated by the diagram, each of the two metastable states is characterized by a steady state in which the specific mortality rate of the adult herring population (shown in red) is equal to the specific production rate (shown in black) of the adult population. Both rates were defined and described mathematically above. Because the two metastable conditions are steady states around which populations oscillate, they serve as anchor points for formulating, tuning, and testing our model.

Although the mortality and recruitment curves in the figure are only illustrative, the shapes of the curves are critical to the hypothesis. Following the terms and arguments of Bakun 2006, at population densities below the low-density metastable state, herring "find" a refuge in which predator selectivity for prey is much reduced for herring because their infrequent encounters with potential predators force their predators to focus on alternate prey. Within the refuge, the herring population is always forced towards the low-density metastable state because the specific recruitment rate always exceeds the specific mortality rate. The "trophic trap" is found between the low density and high density metastable states where specific mortality rates always exceed specific rates of recruitment. Such a condition is called a trap since herring populations are forced towards the state of low density. Within the trap and to the left of maximal mortality rate, specific mortality rates increase with increases in the density of herring because increasing rates of encounter between herring and their predators cause increases in predator selectivity of herring relative to other species of their predators prey. At the peak of the specific mortality rate predators are not only fully selective of herring but are also sated; thus, to the right of the maximum increases in herring density are paralleled by a predictable (inverse density squared) and rapid decrease in specific mortality rate that can drive the population towards the high-density, metastable state. Oscillations around the low-density metastable state are strongly dampened because the forces of population dynamics on either side of the state always drive the population towards that state. The "breakout" condition occurs at population densities that exceed that of the high-density metastable state; here specific rates of recruitment exceed specific rates of mortality, a condition that allows transient, dramatic increases in population size. Thus, oscillations around the high-density, metastable state are expected to be large since restorative forces are lacking to the right of the steady state.

As implied by the vertical arrows in the diagram the position and shape of the two curves may change stochastically largely because of annual variability in external environmental forces. They may also change because of changes within biological community itself. The trap may be deep and wide making it unlikely those stochastic variations in herring density will release the population from the trap with the new attraction of the high-density state. Of course the trap may also be shallow and narrow making escape more likely. We argue that the time-series of ecological and fisheries information on herring from PWS and other locations fits well the trophic trap shown figure 5 and that the simulation equation presented above fully provides the detailed ecological functions and variables to create a model that will reveal the emergent features shown in the diagram.

1. Prior to the oil spill, PWS herring were in a protracted high density state in which annual recruitment of adults oscillated with an extremely large amplitude with are remarkably consistent 4 year period. Such large and regular oscillations are consistent with "breakouts" from a high-density metastable state. Currently the herring are in a protracted low-density state in which the oscillations in recruitment are much reduced and lacking in clear periodicity.
2. The spill itself directly increased mortality rates for many of the age classes of herring and thus temporarily drove the herring population to lower densities- away from the high-density state and towards the low-density state.

3. Following the spill, at least two events lowered the specific production rate of the herring, and thereby increased the depth and width of the trophic trap. During the early 90s, a regime shift in the Gulf of Alaska caused decreases in zooplankton concentrations in the offshore waters of the Sound. In addition the VHSV infection through the 90s and to present may also have driven the specific production rate down. These two events could also have been compounded by increased competition by planktivores such as juvenile Pollock.

Finally, it is possible that the regime shift and decrease in herring population provided an opportunity for more effective predators of herring to become more prominent part of PWS pelagic community.

Model Analysis

Figure 6 describes our logic in searching for the factors that have caused the current, low-density state of herring in PWS and examine intervention measures for restoration to the prior, high-density state. The initial trophic-trap, simulation model that provides a description of herring population dynamics in a closed region will be expanded to accommodate a metapopulation for the subpopulations of herring within PWS. After the metapopulation model is completed it will be tuned to the ecological surveys on herring and environmental conditions for the high-density state prior to the spill as well as the surveys of the low-density state following the spill. The tuning will be achieved by importing the databases and the model into the PWS herring GIS that we will develop (figure 2) and then apply the search routines that currently exist in EASy to obtain values for unknown variables in the model (see equation above) that provide the best fit to field data. The model tuned to the pre-spill state will then be run according to the ecological events that occurred during and after the spill in an attempt to simulate the transition to the post-spill state. Furthermore, t The models tuned to the post-spill state will then be run according to proposed interventions in an attempt to simulate a transition to a new high-density state. We believe that the comparison of values for variable values for high and low density states, the results of a sensitivity analysis, and the findings obtained by force the model to a state transition in both directions will at a minimum allow us to successfully evaluate hypotheses and intervention schemes.

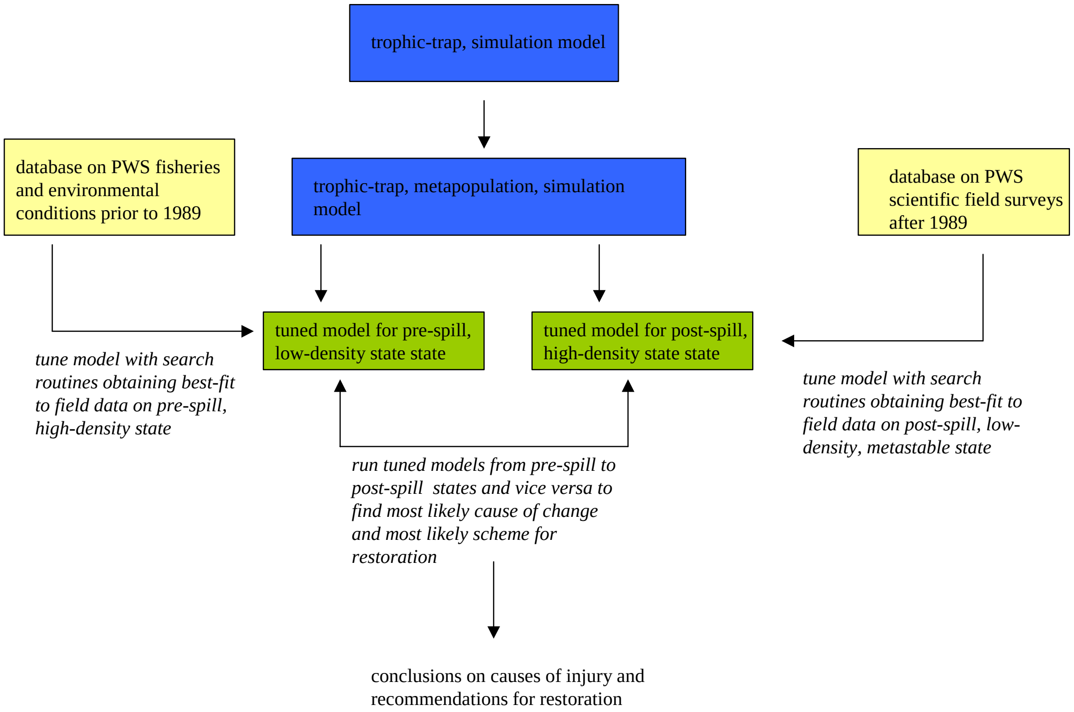


Figure 6. Steps in applying Herring Model analysis & GIS to analysis of injury and restoration schemes.

VI. Description of Study Area

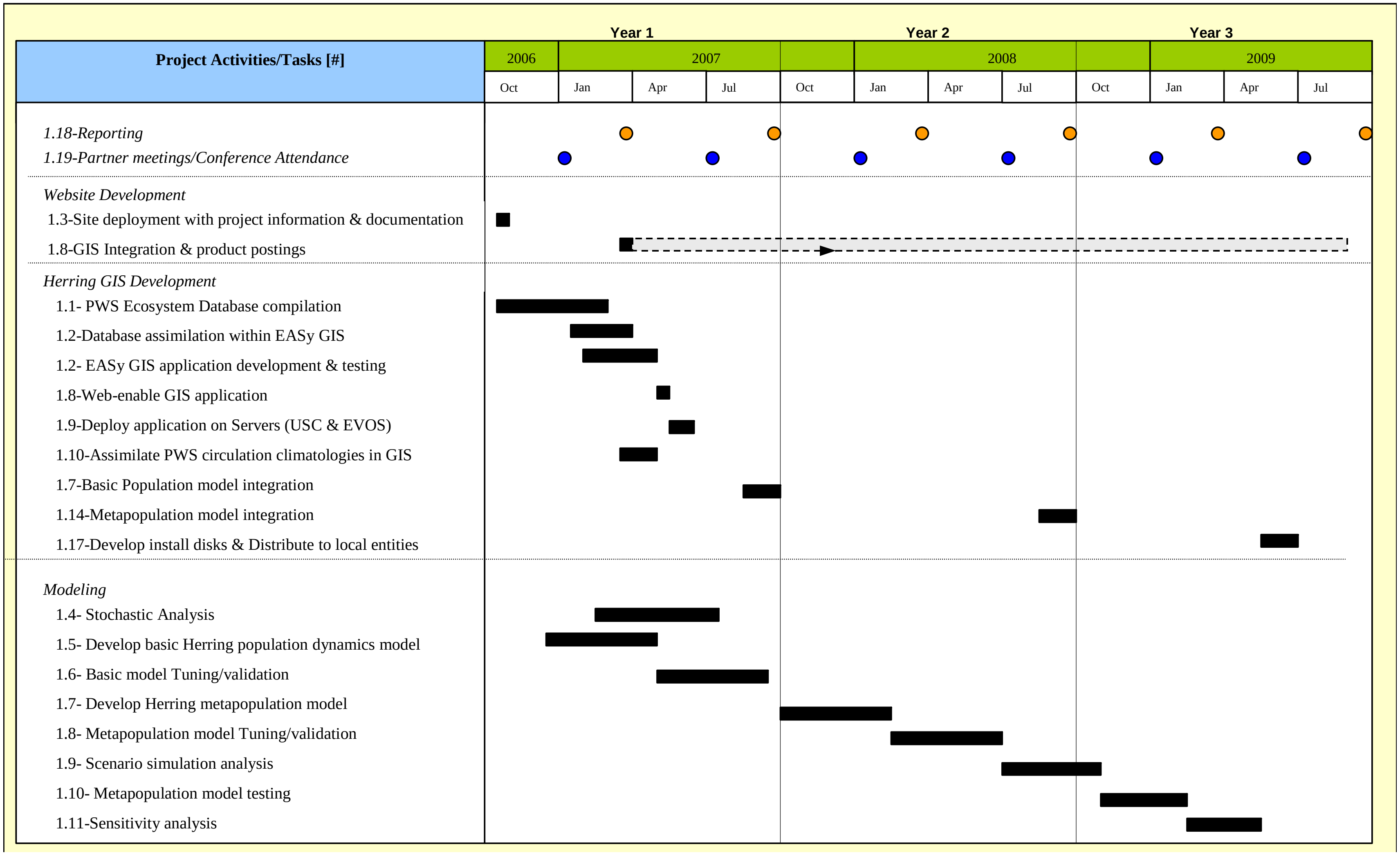
As described above and indicated by the listing of data in table 1, both the development of the EVOS GIS and the analysis/modeling of PWS herring stocks will focus on Prince William Sound. However, climate data, satellite imagery, and data on herring from Sitka Sound and more southerly coasts will be regional in scale- covering the Gulf of Alaska and beyond.

VII. Coordination with Other Efforts

Our team consists marine ecosystem modelers and GIS/database experts (Kiefer, Tsontos), a PWS herring expert and stochastic modeler (Brown), and a mathematician who formulated most of the models for the SEA program (Patrick). Our first outreach and coordination will be with the local group PWSFRAP which includes members from the Alaska Department of Fish and Game (Steve Moffit), the Prince William Sound Science Center (Richard Thorne and Shelton Gay) in addition to local experts and fishers. We need historic and current data from the group and we need to ensure that our product will be usable by the fishermen and other interested members of the public. We will confer with the larval drift group (Wang and Norcross proposers), the pathology group (Kocan and Hershberger proposers), and with Nate Bickford who is currently working with PWS herring otoliths. Dr. Bickford’s current and future results may help with adjustments to spatial stock structuring and in developing intervention evaluations. We will coordinate with groups funded to examine intervention and enhancement in order to simulate and evaluate their proposed actions within the model. We plan to participate in regularly scheduled herring research coordination or planning meetings, should they occur, and are looking forward to a team approach.

VIII. Schedule

The schedule for implementation of project tasks over its planned 3-year time horizon is summarized in the figure below. Discrete sets of activities and associated deliverables are foreseen for each year. Year 1 focuses on assembly of core project datasets, assimilation of these with the Herring GIS developed and integrated with the project Website, and the development of a basic Herring population dynamics model. Year 2 extends the prior modeling activity in developing and tuning a spatially explicit model for Herring, integrating this within EASy-GIS, and using the metapopulation model to conduct hypothesis testing of possible population regulation mechanism and stock management/rehabilitation scenario analysis. Year 3 foresees model testing and sensitivity analysis, and the delivery of the finalized Web-GIS to local entities.



IX. Expected Publications, Reporting & Outreach

The project Website will serve as a useful public outreach tool providing descriptive information on the project and access to resulting project tools and data products. In addition, we aim to publicize project findings at relevant conferences, including the EVOS annual science meeting, and publishing all key findings in peer-review science journals. It is our aim to produce scientific papers on the applications of our statistical and modeling analyses, and also one describing the Web-based information system. We will also arrange to give a seminar at the Alaska Department of Fish and Game in order to present the results of our analysis of PWS herring. We also commit to fulfilling all necessary project reporting requirements and a final report documenting the system and its evaluation.

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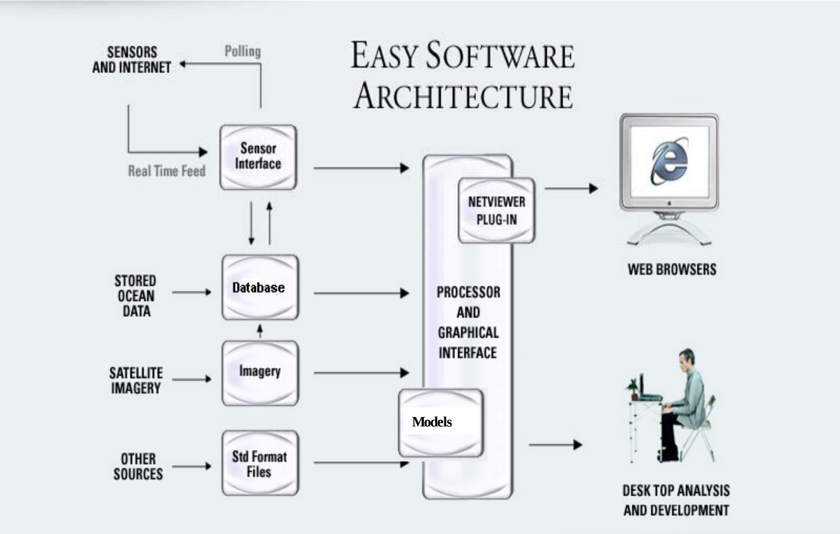
Appendix

EASy-GIS: Technical Features & Applications

Figure A. EASy software architecture and data integration



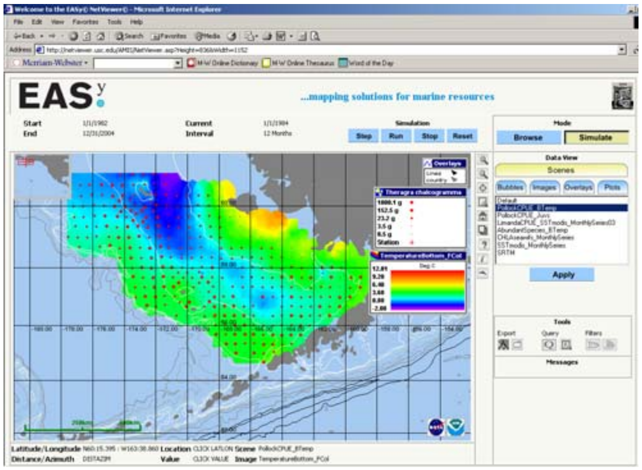
Environmental Analysis System (EASy), whose components are shown in Figure A, is an advanced, PC-based geographical information system designed for the storage, dissemination integration, analysis and dynamic display, of spatially referenced series of diverse oceanographic data. Developed by Systems Science Applications (http://www.runeasy.com/) has been used in a range of national and international oceanographic projects, including the storage and mapping of bio-optical parameters in the Atlantic Ocean and Mediterranean Sea, the OBIS-funded Gulf of Maine Biogeographic Information System (GMBIS) project and the NPRB-funded AMIS project (Alaskan Marine Information System). The software has been custom designed with the particularities of oceanographic applications, the needs of marine research and educational communities, and pathways for information exchange in mind. It facilitates interfacing of multivariate oceanographic data, including satellite imagery, with statistical algorithms and mechanistic models. The software's comprehensive COM-based Application Programming Interface (API) allows modular extension of EASy functionality and the incorporation of both dynamic process and statistical models into applications. The software graphically renders dynamically in time, within their proper geo-spatial context, both field and remotely sensed data and model outputs as diverse types of plots, including vector, contour, and false color image plots. Vertical structure of data, critical in oceanographic applications, is depicted as vertical contours for user-defined transects or depth profiles at selected point locations. Time series of measurements, and dependencies between data at individual stations can also be visualized interactively as XY-plots. The software also facilitates broad, platform independent access to data, integrated visualization products and analytical tools over the Internet via Netviewer, a client-server, plug-in for EASy.

Common requirements of information systems and EASy's capabilities are listed in the table below.

Requirement	**System's Capabilities**
Data handling and visualization	Dynamic (time-based), 3 dimensional home for data, visualization is 2 dimensional with interactive drilling and slicing of dynamic 3 dimensional fields; handles both real-time data streams as well as historical data
Database Access	Provides ODBC connectivity to relational databases and has "Database Wizard" for automated parsing of database fields into the GIS database. It also provides advanced interfaces to on-line data sources including DiGIR taxonomic queries utilized by the Ocean Biogeographic Information System (OBIS), NetCDF formats used by PMEL's Live Active Server, and NVODS, handles protocols recommended by the IOOS DMAC.
Multimedia	Provides home for information formatted as audio, video, photographs, and text, as well as hot links to websites.
Data Fusion	Has built-in contouring package for creation of contour plots and false color images; has applications programming interface for integration of customized of models and algorithms written in visual basic, FORTRAN, and C
Satellite Imagery	Advanced interface for automatic downloading satellite imagery into GIS, handles over 30 types of formats commonly used by the oceanographic community
Data storage & connectivity to traditional GIS data	Almost all data and imagery are stored in native and commonly used formats including shapefiles and other vector formats
Internet	GIS can be run in desktop mode on a PC and then easily deployed as a web mapping service by simple activation of Netviewer plug-in; all data and imagery in the system can be downloaded interactively to the client

An example of the type of value-added imagery products that can be generated within EASy/Netviewer for the proposed work is illustrated in Figure B below. Outputs are from two Web-based marine information system development projects focusing on Alaska that we have been involved in and have employed EASy/Netviewer. Panel 4A shows output from our AMIS (Alaskan Marine Information System) application, a collaboration with the NOAA Alaskan Fisheries Science Center (AFSC) and the North Pacific Research Board (NPRB). Details and access the Web-GIS application is available via http://netviewer.usc.edu/amis/amisintro.htm. Using the Internet as a medium, the AMIS project provides a framework and set of reusable tools for the integration, visualization, analysis and dissemination of diverse types of biogeographical and oceanographic information. Databases at the core of the information system include AFSC's Alaskan groundfish survey dataset and trophic interactions dataset, which are the product of multidisciplinary research efforts over the

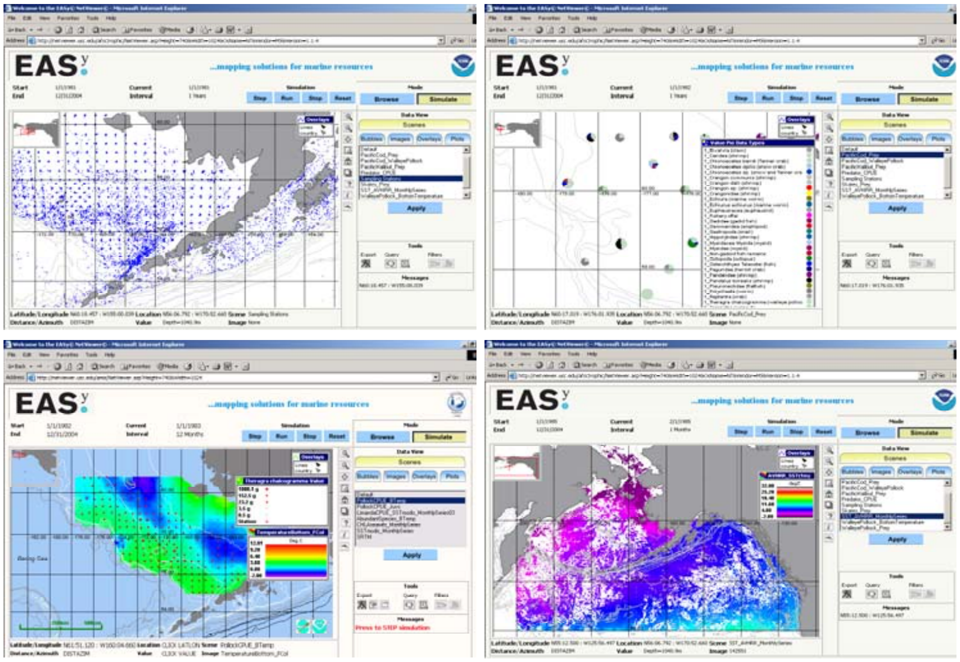
Figure B. Groundfish species abundance distributions in the Gulf of Alaska relative to environmental factors.



last couple decades. The figure shows relative abundance distribution patterns for pollock (bubble-plots) relative to bottom temperature observations (false color) and bathymetry (contours) in the Bering Sea at a given time when stepping dynamically through a 13 year series of available data.

Figure C shows a collage of outputs for a selected number of scenes from the AFSC GIS application that was developed for and is being hosted by EVOS. Detailed descriptions are provided in the figure caption, but essentially one sees the range of datasets encompassed, the various utilities available for viewing and overlaying the multivariate data, and Netviewer capabilities and tools for stepping through data temporally, filtering/subsetting datasets, undertaking spatial queries and exporting datasets as synthetic raster images or raw station data. The application may be accessed online directly from http://netviewer.usc.edu/afsctrophic/AFSCtrophicIntro.html.

Figure C. Netviewer GUI and tools showing outputs of selected scenes from the AFSC GIS application. Panels clockwise from left: 1) outputs from the "SamplingEffort" scene showing time integrated view of the distribution of sampling stations for the various AFSC GIS datasets. 2) bubble pie plot outputs showing the distrbution of Pacific cod top 30 prey items from the AFSC gut contents analysis/trophic database . 3) overlay of Pollock abundances and computed false



The GIS application development proposed here will build upon the technologies and approaches used in the aforementioned and more that 20 other marine information system application development projects we have been involved in over the past several years.

Table 1. Sources of data, status on location, and processing level to be incorporated or linked to the GIS database and synthesis.

Data Type	Period	Source	Location	Status/ Processing Level
Herring Data				
Annual PWS herring spawn (herring embryos) reported by regions (Northeast, Southeast, North Shore, Naked Island, and Montague Island) in miles of spawn per day	1973-2005	ADF&G	IMS Database / On Hand	Complete
Annual PWS herring spawn mapped in GIS Obtain for mapping	1973-1999 2000-2005	ADF&G	On Hand Can Obtain	Mapping complete; need to obtain latter years
Age-specific abundance and biomass of adult herring from aerial surveys allocated by region-specific age compositions; same regions as above	1973-2005	ADF&G	On hand	Complete
Sound Ecosystem Assessment (SEA) herring acoustic data spring, summer, fall and winter (includes early life history stages), age-weight-length composition, condition factor (lipid content), herring stomach contents, and associated marine species (caught in SEA sampling program at herring study sites)	1995-1997	UAF (EVOS funded studies)	On hand	Complete / Processed to species, abundance and biomass
Spring and summer distributions of juvenile herring schools from aerial surveys as part of the SEA and Alaska Predator Experiment (APEX) studies	1995-1999	UAF (EVOS funded studies)	On hand	Complete / Geo-coded database finished
Herring larval distribution, larval deformities by location, drift model output (one year 0 1989), egg-larval survival model, associated data from study sites on hatch success, egg mortality, and larval condition and length	1989-1991	UAF, Triton Environmental (EVOS funded)	On hand	Complete / database ready
Herring disease statistics and locations of sampling	1993-2005	ADF&G, UC Davis, Marty	On hand	Complete / ready to link within database
Other Co-occurring Species and Predators				
Distributions and abundance of sand lance, capelin, sea lions, whales, and sea birds associated with schools of herring and sand lance from aerial surveys (SEA and APEX studies)	1995-1999	UAF (EVOS funded)	On hand	Complete / database ready
Predator (includes pollock, halibut, sharks, other flatfish, and cod) abundance, length and stomach contents (SEA studies)	1995-1997	UAF (EVOS funded)	On hand	Complete / database ready
Competitor (sand lance, capelin, other fish species, jellyfish) abundance and length (SEA and APEX studies)	1995-1997	UAF (EVOS funded)	On hand	Complete / database ready
Distribution of pollock and other predatory fish from acoustics (SEA); mainly western PWS	1995-1997	UAF, PWSCC (EVOS funded)	On hand	Needs to be recalibrated, reprocessed and plotted
Migrational routes of radio-tagged seabirds foraging on small pelagic fishes (APEX), output of sea bird foraging models	1996-1999	UAF, OSU (EVOS	Can be obtained from	Data processing and database complete

		funded)	sources	(published data)
Oceanographic Data				
Hydrographic data (CTD casts) for PWS and adjacent shelf Offshore data (> 1 km from shore) (SEA and historic IMS cruises) Nearshore data (< 1 km from shore) (SEA data)	1973-2005 1995-1997	UAF IMS database	On hand	Ready to input to GIS
PWS circulation 3-D model output (SEA and SALMON projects); resolution at 500 m and 1 km horizontally and 1 m vertically to bottom	1995 on, Ongoing effort	UAF Super Computing Center, Kate Hedstrom	Available upon request	Output GIS ready
Annual zooplankton settled volumes from PWS hatchery sites More recent sampling	1980-1999 2000-2005	PWS Aquaculture Corp	On hand Can be obtained	Complete / GIS ready Unsure of data status
Offshore (> 1km) zooplankton abundance, biomass and species composition from vertical tows (SEA study sampling	1995-1997	IMS database (EVOS funded)	On hand	Complete / GIS ready
Nearshore (< 1km) zooplankton abundance, biomass and species composition from vertical tows (SEA and APEX studies)	1995-1997	IMS database (EVOS funded)	On hand	Needs compilation for GIS database
Zooplankton biomass and distribution from high frequency acoustics (SEA study)	1995-1997	IMS database (EVOS funded)	On hand	Unsure of processing level, need for calibration collections; locations available for GIS plotting
Larval fish abundance, distribution and species composition, nearshore and offshore from horizontal tows with Mocness or Tucker Trawl (EVOS damage assessment and SEA studies)	1995-1997 1989 only	IMS database (EVOS funded)	On hand	Raw data available; needs to be input to GIS database
Climate Data				
Seasonal Pacific Decadal Oscillation (PDO) More recent data	1900-1999 2000-2005	Mantua et al. 1997	On hand Available on request	Easily downloaded data representing large region
Seasonal El Niño-Southern Oscillation (ENSO) More recent data	1870-1998 1999-2005	Enfield and Mestas-Nuñez, 1999	On hand Available on request	Easily downloaded data representing large region
Seasonal Pacific Inter- and Multi-Decadal Oscillation (PIDO & PMDO) More recent data	1956-1998 1999-2005	Enfield and Mestas-Nuñez, 1999	On hand Available on request	Easily downloaded data representing large region
Annual Aleutian Low Pressure Index (ALPI) More recent data	1901-1998 1999-2005	Beamish and Bouillon, 1993	On hand Available on	Easily downloaded data representing large region

			request	
Annual Atmospheric Forcing Index (AFI)	1900-1999 2000-2005	MacFarlane et al. 2000	On hand Available on request	Easily downloaded data representing large region
Monthly Fresh Water Discharge (FWD), modeled	1931-2005	Royer, 1982, IMS Database	On hand	Represents large region
Monthly Bakun Unwelling Index for Hinchinbrook Entrance to PWS	1946-1999 2000-2005	Bakun 1973, 1975	On hand Available on request	Easily downloaded data representing large region
Daily, weekly, and monthly data for Middleton Island near Hinchinbrook Entrance to PWS Other sites within PWS more patchy and recent	1972-1999 2000-2005 1980s-2005	National Climate Data Center, North Carolina	On hand Available on request for fee	Easily downloaded data representing large region
Daily, weekly, and monthly precipitation and air temperature data for misc. sites in PWS More recent data	1972-1999 2000-2005	National Climate Data Center, North Carolina	On hand Available on request for fee	Easily downloaded data representing large region
TEK				
Geo-referenced information on forage fish distribution by life stage (including herring) as obtained from local experts and Native Americans	1800s to 21st century	Brown et al. 2002	On hand	Already in GIS database
Remote Sensing				
SeaWiFS (ocean color) and AVHRR imagery for GEM regions	1982 to present	IMS database, SALMON & GLOBEC projects	On hand; archived IMS and GINA,Geophysical Institute (UAF)	May have to convert formats to import but metadata and imagery well documented
MODIS imagery	1991-present	Same as above	Same as above	Same as above
Data from airborne surveys including LIDAR (biological structure in upper 40 m), MicroSAS (ocean color), RGB imagery (fronts, sea birds, marine mammals), and IR imagery (thermal structure, night-time distribution of predators)	2000-2002	IMS archive (EVOS, NPRB and NOAA funded projects)	On hand	All metadata ready to import; may want to rescale and reprocess some data

Management, Roles & Personnel

Dr. Dale Kiefer, the Principal Investigator and Chief Scientist of System Science Applications, will be responsible for management and coordination of the project and will lead both the development of both the ecosystem dynamics model and the associated GIS. He is well qualified for both tasks (See C.V.); he is one of the developers of the EASy GIS and he has developed numerous models the dynamics of marine populations- from plankton dynamics to a spatial model of the growth and distribution of small pelagic species.

Dr. Vardis Tsontos, (PhD in population ecology from Renewable Resources Assessment Group, Imperial College, London) will support Dr. Kiefer in all tasks. In particular he will be in charge of assembling and testing the PWS Herring GIS. He will also enter code for the PWS herring model into for the GIS, using its Visual Basic applications programming interface.

Frank O'Brien, who is the Software Engineer of EASy (SSA), will address all software needs that develop; these include incorporating new spatial analysis tools into the GIS, improving the easy of using our non-linear search routines to obtain optimal values for coefficient for the equations of population dynamics addressing problems associated with moving materials into computational regions of differing sizes and shapes.

Dr. Evelyn Brown, who wrote her doctorate on ecology of population dynamics of herring in PWS, will guide the conceptual development of the model, help gather environmental, fisheries, and herring ecology that will be entered into the GIS and used to tune the model, and she will update her statistical analyses of herring dynamics in PWS with more recent information.

Dr. Vince Patrick, a mathematician from the PWSFRAP and a key developer of the PWS Juvenile Pink Salmon Model, will provide the simulation modeling and mathematical programming expertise and insure that our herring model includes as much as possible those concepts and mathematical formulations that have emerged from the SEA project. He will also be responsible for applying the model to the testing of intervention and restoration activities within PWS.

Resumes

Dale A. Kiefer, Ph.D

Professional Preparation

Yale University	Biology	B.Sc.	1966
University of Oregon	Marine Biology	M.S.	1967
UC San Diego (Scripps)	Biological Oceanography	Ph.D.	1973

Appointments

Professor, Department of Biological Sciences, University of Southern California, 1990-
SeaWiFS Science Team, NASA, 1993-
Visiting Scientist, Food and Agricultural Organization, United Nations, Rome, Italy 1994-98
Visiting Scientist, Laboratoire de Pierre et Marie Curie, University of Paris, France, 1987
Associate Professor, Department of Biological Sciences, University of Southern California, 1981-90
Assistant Professor, Department of Biological Sciences, University of Southern California, 1976-81
Assistant Research Biologist, U.C. San Diego Visibility Laboratory, 1975-76

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Selected Publications

C.A. Atkinson, Kiefer, D.A. and J.S. Reitzel. 1979. Ocean Thermal Energy Conversion (OTEC), Preoperational Ocean Test Platform, Draft Environmental Impact Assessment. Volume 1, Chapter 3.6 and Chapter 4.5. Prepared for U.S. Department of Energy.

Kiefer, D.A. and C.A. Atkinson. 1987. The calculated effect of pulpmill effluent upon the growth and distribution of phytoplankton in the coastal waters of Eureka, California. Submitted to Beveridge and Diamond.

Kiefer, D.A. and C.A. Atkinson. 1989. The calculated response of phytoplankton in south Puget Sound to nutrient loading by Swecker Farm. A report prepared for Swecker Farms, Inc., Tumwater, Washington.

Kiefer, D.A. and J. Berwald. 1992. A Random Encounter Model for the Microbial Planktonic Community. Limnol. Oceanogr. 37: 457-467.

Ondercin, D., Atkinson, C. A., & Kiefer, D. A. 1995. The Distribution of Bioluminescence and Chlorophyll During the Late Summer in the North Atlantic: Maps and a Predictive Model. Jour. Geophys. Res., 100, 6575-6590.

D.A. Kiefer and DoChi (editors) (1996) Workshop on the Coastal Pelagic Resources of the Upwelling Ecosystem of Northwest Africa: Research and Predictions, Technical Cooperation Programme Report, FAO, Rome, Italy Field Document 1, FI:TCP/MOR/4556(A), pp. 80 pp.

Kiefer, D. A. 1996. An Environmental Model for Small Pelagics. In DoChi &. Kiefer (Ed.), Workshop on the Coastal Pelagic Resources of the Upwelling Ecosystem of Northwest Africa: Research and Predictions, (pages 37). Casablanca, Morocco: FAO.

S.E. Lluch-Cota, D. Kiefer, A. Parés-Sierra, D.B. Lluch-Cota, J. Berwald, and D. Lluch-Belda. Toward an Environmental Analysis System for the Gulf of California sardine fishery. 2002. Spatial Processes and Management of Marine Populations. University of Alaska Sea Grant, AK-SG-01-02, Fairbanks. 120-135.

V.M. Tsontos and D.A. Kiefer. 2002. Development of a Dynamic Biogeographic information system for the Gulf of Maine. Oceanography, 13(3) 25-30.

Tsontos, V.M. & D.A. Kiefer. 2003. The Gulf of Maine Biogeographical Information System Project: Developing a Spatial Data Management Framework in Support of OBIS. Oceanologica Acta. 25, 199-206.

Michael L Domeier, Dale Kiefer, Nicole Nasby-Lucas, Adam Wagschal and Frank O'Brien. 2005 Tracking of Pacific bluefin tuna (Thunnus thynnus orientalis) in the northeastern Pacific using an automated algorithm to match sea surface temperature from satellites and tags. Fisheries Bulletin, 103(2). 292-306.

Rensel, J.E., D.A. Kiefer, J.R.M. Forster, D.L. Woodruff and N.R. Evans. 2006**.** In Press. *Offshore finfish mariculture in the Strait of Juan de Fuca***.** U.S.-Japan Cooperative Program in Natural Resources, 33rd Annual Proceedings. Nagasaki Japan 2004. See http://www.wfga.net/sjdf/reports/publication.pdf

Evelyn D. Brown, Ph.D

Flying Fish, Ltd.
1341 Overhill Dr., Fairbanks AK 99709
tel: 907-590-2462 email: ebrown@ims.uaf.edu

Education:
B.S. Zoology and Chemistry, University of Utah, Salt Lake City, 1977
M.S. Fisheries Biology & Aquacultural Engineering, Oregon State University, Corvallis, OR, 1980
PhD in Fisheries at University of Alaska, Fairbanks, 2003

Recent Experience:
Research Associate, University of Alaska, Fairbanks, 1995 to the present;
Herring Research Biologist, Alaska Department of Fish and Game, Cordova, Alaska (1988-1995)
Principal Investigator, Injury to PWS Herring from *Exxon Valdez* Oil Spill, NRDA FS 11(1989-92)

Expertise: Fisheries, Fisheries Oceanography, Marine Ecology, Aerial Survey/Remote Sensing, & Statistical Modeling

Current Research Projects:
Development of new methods for detecting and assessing pelagic fishes (sardines and albacore; Office of Naval Research, NOPP program)

Relevant Publications

Brown, E.D. 2002. Life history, distribution and size structure of Pacific capelin in Prince William Sound and the Northern Gulf of Alaska. ICES Journal of Marine Science, 59:983-996.

Brown, E.D., Seitz, J., B. L. Norcross, and H. P. Huntington. 2002. Ecology of Herring and Other Forage Fish as Recorded by Resource Users of Prince William Sound and the Outer Kenai, Alaska. Alaska Fishery Research Bulletin 9(2): 75-101.

Brown, E.D. and B.L. Norcross. 2001. Effect of herring egg distribution and ecology on year-class strength and adult distribution: preliminary results. Herring 2000, Alaska Sea Grant College Program, AK-SG-01-04: 335-345.

Ford, R.G., D.G. Ainley, E.D. Brown, R.M. Suryan, and D.B. Irons. In Press. The foraging of black-legged kittiwakes in Prince William Sound, Alaska: a model optimizing success as a function of colony size and location. Ecological Monographs.

Suryan, R.M., D.B. Irons, M. Kaufman, J. Benson, P.G.R. Jodice, D.D. Roby, and E.D. Brown. 2002. Short-term fluctuations in forage fish availability and the effect on prey selection and brood-rearing in the black-legged kittiwake *(Rissa tridactyla*). Mar. Ecol. Progr. Ser. 236: 273-287.

Purcell, J.E., E.D. Brown, K.D.E. Stokesbury, L.H. Haldorson, and T.C. Shirley. 2000. Aggregations of the jellyfish *Aurelia labiata*: abundance, distribution, association with age-0 walleye Pollock, and behaviors promoting aggregation in Prince William Sound, Alaska, USA. Mar. Ecol. Prog. Ser. 195: 145-158.

Research and Publication Collaborations

Rick Broduer, NMFS, NW Science Center
James Churnside, NOAA Environmental Technology Laboratory
Robert Foy, UAF SFOS FITC
Martín Montes Hugo, UAF SFOS IMS
Jennifer Purcell, University of Maryland
Robert Suryan, Oregon State University
Mark Benfield, LSU, Baton Rouge
John Horne, University of Washington, School of Fisheries
David Irons, USFWS, Migratory Bird Unit
Brenda Norcross, UAF SFOS IMS
Mike Sigler, NMFS Auke Bay Lab
Chris Wilson, NOAA NMFS Alaska Fisheries Science Center, Seattle

E. Vincent Patrick, Ph.D.

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University of Maryland
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EDUCATION

1967 B.A. Physics Thiel College, Greenville, Pennsylvania
1982 M.A. Mathematics University of Maryland, College Park
1987 Ph.D. Mathematics University of Maryland, College Park

EXPERIENCE

1993 - present Research Associate, Institute for Systems Research, University of Maryland
2000 Research Associate, Advanced Visualization Lab, University of Maryland
1992 - 1993 Asst. Research Scientist, Chesapeake Biological Laboratory, Univ. of Maryland
1991 - 1992 Research Associate, Advanced Visualization Lab, University of Maryland
1991 Asst. Research Scientist, Chesapeake Biological Laboratory, Univ. of Maryland
1988 - 1990 Research Associate, Chesapeake Biological Laboratory, Univ. of Maryland
1994 - 1999 Principal Investigator, Information Systems and Model Development,
Prince William Sound Science Center, Cordova Alaska
1993 - 1994 A_liate Scientist, Prince William Sound Science Center, Cordova, Alaska

SELECTED PUBLICATIONS

K. D. E. Stokesbury, J. Kirsch, E. V. Patrick and B. L. Norcross. 2002. Natural mortality estimates of juvenile Paci_c herring (Clupea pallasi) in Prince William Sound, Alaska. Can J. Fish. Aquat. Sci. 59:416-423.
T. M. Willette, R. T. Cooney, V. Patrick, G. L. Thomas, and D. Scheel. 2001. Ecological Processes influencing mortality of juvenile pink salmon (Oncorhynchus gorbuscha) in PrinceWilliam Sound, Alaska. Fisheries Oceanography 10(Suppl. 1).
J. Wang, M. Jin, E. V. Patrick, J. R. Allen, D. L. Eslinger, C. N. K. Mooers and R. T. Cooney. 2001. Numerical simulations of the seasonal circulation patterns and thermohaline structures of Prince William Sound, Alaska. Fisheries Oceanography 10(Suppl. 1):132-148.
B. L. Norcross, E. D. Brown, R. J. Foy, M. Frandsen, S. Gay, T. Kline, D. M. Mason, E. V. Patrick, A. J. Paul and K. D. E. Stokesbury. 2001. A synthesis of the life history and ecology of juvenile Pacific herring in Prince William Sound, Alaska. Fisheries Oceanography 10(Suppl. 1):42-57.
J. Wang, V. Patrick, J. Allen, S. Vaughan and C. N. K. Mooers. 1999. Modeling seasonal ocean circulation of Prince William Sound, Alaska. model for Prince William Sound, Alaska using freshwater of a line source. In: Coastal Engineering and Marina Developments, eds. C. A. Brebbia and P. Anagnostopoulos. WIT Press, Southampton, pp 57-66.
PWSFERPG. 1993. Sound Ecosystem Assessment: Initial Science Plan and Monitoring Program. Report No. 1, Prince William Sound Fisheries Ecosystem Research Planning Group, Cordova, AK, November 24, 1993.
D. M. Mason and E. V. Patrick. 1993. A model for the space-time dependence of feeding for pelagic fish populations. Trans. Am. Fisheries Soc. 122(5):884-901.
S. B. Brandt, D. M. Mason and E. V. Patrick. 1992. Spatially explicit models of fish growth rate. Fisheries 17(2):23-35.

Vardis Maximilian TSONTOS, PhD

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Los Angeles, CA 90089-0371

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APPOINTMENTS & EDUCATION

1998-2006	Research Associate (Biology Department, Univ. Southern California) & Consultant, System Science Applications (SSA)
2003-2004	Lead informatics consultant to FAO/UN Integrated Coastal Analysis & Monitoring System (ICAMS) Nile Delta (Egypt) project.
1998-99	Visiting Scholar to UN Food & Agricultural Organisation (FAO, Rome) – Academic Partnership Program Research Associate (Biology Department, University of Southern California)
1997-98	MAFF/CEFAS (Lowestoft Fisheries Laboratory - Fisheries Science & Management Group)
1991-97	IMPERIAL COLLEGE (Centre for Environmental Technology - Renewable Resources Assessment Group) PhD: Fisheries / Population Ecology (Conferred, May 1997)
1989-91	UNIVERSITY COLLEGE OF NORTH WALES, BANGOR (School of Animal Biology) MSc: Fisheries Biology and Management
1986-89	UNIVERSITY OF SOUTHAMPTON (Department of Oceanography) BSc (Honours): Oceanography with Biology

SELECTED PUBLICATIONS

"The Gulf of Maine Biogeographical Information System Project: Developing a Spatial Data Management Framework
in Support of OBIS". Oceanologica Acta., 25, 199-206.

"GMBIS: Developing an information system for the Gulf of Maine in support of OBIS".
Proceedings Colour of Ocean Data Conference, Brussels Belgium, 25-27 November, 2002.

"EASy: A GIS tool for the integration and analysis of multivariate fisheries oceanography data". Informes y estudios
Copemed, 8, 70-72. Proceedings FAO workshop on Environmental variability and small pelagics fisheries in the Mediterranean Sea, Palma, Mallorca, Spain, 26-29 June, 2001.

" Development of a Dynamic Biogeographic Information System for the Gulf of Maine"
Oceanography 13(3): 25-30. 2000 (special issue on the OBIS and the Census of Marine Life)

" Spatial Abundance Distribution Patterns and Scaling Properties within an Exploited Bivalve Population "
ICES CM 1998/J:15 (Proceedings ICES Annual Science Meeting, Cascais, Portugal, 16-19 September, 1998).

Frank O'Brien

System Science Application
3 Trovita, Irvine, CA92620
fjobrien@cox.net

Professional Preparation

University of Vermont, Burlington, VT	Mathematics	B.A.	1965
University of Vermont, Burlington, VT	Mathematics	M.A.	1967
Cal State University, Fullerton, CA		MBA (33 credits towards)	

Advanced Technical Training in DCOM, MTS, MSMQ, OLEDB, C#, and DotNet

Appointments

Director of Software Engineering, System Science Applications, CA. 2001-2006
Systems Engineering Lead, Logicon, Inc., San Pedro, CA. 1988-2001
Division Manager, Comarco Inc., Anaheim CA. 1981-1988
Program Development Manager, , Logicon, Inc., San Pedro, CA. 1972-1980
Programmer, North American Rockwell, Anaheim, CA. 1969-1972.

Computer Experience

Machines:	PC (26 years), Sun (years1), DEC (2years), IBM mainframes (15 years)
Operating Systems:	Windows XP, 2000, NT, 98, 95, 3.1 (11 years), UNIX (1 year), DOS (22 years)
Languages:	VC++ (14 yrs), VB (9 yrs), Java (7 yrs), Assembler (22 yrs), Fortran (30 yrs)
Technologies:	COM (8 years); ODBC, DAO (8 years); MTS, MSMQ, ADO, OLE-DB (7 years)

Extensive experience in every phase of software development including management and business development, requirements analysis, algorithm development, and prototyping.

Synergistic Activities

1. Architect and lead developer of EASy GIS software, a dynamic 3D oceanographic GIS system, and its NetViewer GIS web-server component.
2. Programming support for the development of a series of information systems in support of mariculture environmental analysis, fisheries management, fish tracking, marine biogeographical, hydro-optical water analysis, water quality studies, and coastal area management projects including the Gulf of Maine Biogeographic Information System (Sloan/NOPP), NOAA-NESDIS Sea Nettles, Santa Monica Bay Virtual Ocean (SMBRP).

List of Collaborators last 48 Months

J. Rensel, Rensel Associates
R. Branton, Bedford Institute of Oceanography
M. Yamaguchi, Santa Monica Bay Restoration Project
J. Latham, SDRN, FAO-United Nations
P. Cornillon, University of Rhode Island
M. Domeier, PIER Institute
B. White, LA Department of Water & Power
C. Brown, NOAA/NESDIS
D. Foley, NOAA/NMFS NWFSC
L. Ford, University of Southern California

Letter of Support/Participation

Dr. E. Vincent Patrick
PWS Fisheries Research Applications and Planning
Union Hall
509 First St.
PO Box 1848
Cordova, Alaska 99574

August 3, 2006

Dr. Dale Kiefer
System Science Applications
PO Box 1589
Pacific Palisades CA 90272

Dear Dr. Kiefer:

During the past several months, things have been changing at a phenomenal rate. What is even more remarkable is the fact that the changes have been for the good.

I first learned of your work early this spring. PWSFRAP was formed to improve the way the spill-impacted region was using the investments in marine research by the EVOS Restoration Program. A basic but often very effective strategy is keeping alive the network of expertise regarding Prince William Sound that is a very real legacy of restoration efforts. During the process of connecting with herring investigators, we learned that Dr. Evelyn Brown would soon be leaving Alaska. But we also learned that she would be working with you and continuing at least in part her work on forage fish in this region.

Since then I have learned more about your work. Not everyone creates a new, ground up GIS because the existing ones do not handle marine systems well. To have the new package not just work as intended but to then also get adopted by others is a proper outcome.

Your interests in moving from the data level to the model and theory level is timely. I was part of the group that this community assembled to produce and conduct the SEA Program. I was the co-developer of the SEA nekton models and the project manager for the development of the PWS circulation model. In those early days, we frequently thought about the question of a "best" solution to the problem of representing what these models were to produce. We were then at the beginning of some rather long roads, and the question could be put on hold. However, today, with this revival of efforts with herring, the pace is much, much faster because we are using large chunks of knowledge acquired from SEA and other places rather than having to build those chunks first. For example, as the relevance of the pink salmon fry model to an understanding of Pacific herring today came into focus, instantly there was that whole body of knowledge that took a decade to produce swinging into place and starting to answer heretofore impossible questions.

In this environment, we need software solutions that can move into the arena and be useful. I see your development of a custom GIS for marine systems as precisely the sort of up and running partner in the herring arena. And your interest in having the community be an active part in the process is the type of understanding that is needed.

The exchanges with you have already been very productive for me. I look forward to the opportunity to continue with you and Dr. Brown and your group. I will be happy to work with you as a consultant on the project you are submitting to the Trustee Council. I will be including these comments, possibly condenced as part of our submissions.

Best regards,

Vince Patrick

Data Management & QA/QC Statement

The proposed synthesis activity is essentially comprised of two main work components and products: 1) the development of a Web-based GIS for PWS Herring used for project geospatial analyses, data product access, and outreach. 2) hierarchical development of a probabilistic, stage-structured metapopulation model of PWS Herring dynamics that will be used to test hypotheses of population regulation and support analyses aimed at identifying viable management and remediation strategies. All of these activities will be based on existing and available data that have been described in the project plan, and outputs resulting from this project will largely take the form of synthetic, value added data products accessible via the GIS and as model calculation results. Every effort will be made to document, according to approved standards (FGDC) using Metalite, and fully ensure the integrity of both the core data and model data results.

The Data Management QA/QC guidelines in the FY07 RFP lists seven specific areas of compliance. Most of these assume some form of sample/data collection activity, which does not apply in the case of this synthesis project. Information pertaining to relevant areas is however discussed below:

1. Describe the study/sampling design: The proposed study is exclusively a data analysis and modeling exercise, based on existing data. As such, no field-sampling program will be implemented.

2. Discuss data quality criteria: Existing ecosystem datasets relevant to an understanding of Herring dynamics in PWS have been described previously (Table 1). Specific subsets of data will be selected to meet the needs of particular planned analyses given accompanying metadata and via discussion/arrangement with the data source/manager who will be able to provide most efficient access to data and highlight potential issues of quality.

3. Data characteristics that your project will produce: The project will produce a relational database that will be used to manage all datasets serving as inputs to the project synthesis activities, and analogous archives for satellite imagery and related data. This database and archive will serve as the central data repository and management system onto which both the project GIS will be coupled and the analysis/modeling exercises will tap. Available metadata associated with all data inputs will be managed as well and rendered accessible, and all synthetic datasets/data products yielded by the GIS and models will be documented with metadata according to FGDC standards via the Metalite system. Quantitative datasets resulting from the work will include estimates of both physical parameters, and population census data and model parameter estimates from simulation model runs and fitting. Outputs will include both tabular numeric formats and take the form of synoptic maps. The modeling assumptions or scenarios used to generate particular sets of output will be documented as metadata.

4. Algorithms for converting signals from sensors to observations: Not applicable.

5. Handling of Samples: Not applicable here.

6. Instrumentation Calibrate and Associated Analysis Methods: Not applicable as no field or laboratory observations are going to be made.

7. Data Reduction/Reporting (statistical methods, software, models & validation):
A detailed account of planned geospatial data analyses, population dynamics modeling, hypothesis testing and scenario analysis is described in Section IV (Procedural & Statistical Methods) of the project plan and will not be repeated here. Suffice it to say that an appropriate set of quantitative data modeling procedures will be adopted to match specific analysis needs. So too for software tools used in analyses: EASy/Netviewer for GIS analysis and data integration activities, S-Plus for statistical data analysis (with spatial stats and wavelet module), MATLAB and the Visual Studio programming environments for process model implementation and analysis. Robust model tuning procedures and numerical optimization routines will be employed (eg. Maximum Likelihood estimators, Levenberg-Marquardt), and a formal assessment of model fit and predictive capacity will be made (eg. compare model predictions from a partial data series to actual full data series). All model code developed as part of this project will be properly documented and made available on request for review. The robustness of estimated population trajectories to specific model parameter selections under varying scenarios will be examined via a sensitivity analysis activity.

Budget Justification
Total Request for FY 2007 – FY 2009 = $752.4

The proposed 3-year project represents a comprehensive modeling and synthesis activity for PWS Herring aimed at providing practical tools for management and ecosystem restoration in accordance to EVOSTC priorities. Naturally, it is understood that EVOS supports projects on an annual basis, and that proposed multi-year projects, such as this one, will be funded one year at a time contingent on performance and fund availability. The proposed work is structured in a way that discrete sets of deliverables will be produced each year to accommodate this award structure.

A completed EVOS budget form for is provided below, and the total amount requested for FY07 is $250.8K. Funding support requested for the 2 subsequent years are also at the same levels, such that the core project cost over the planned 3 years is $752.4K. For each of the 3 years, the allocations by budget subcategories are identical and described below.

System Science Applications Inc., under the lead of the project PI, Dr. Kiefer, will administer the award. SSA personnel (Drs. Kiefer, Tsontos, & O’Brien) costs for this project total $94.9K per year. Their roles in the project are described in the Personnel section above, and their effort allocation to project work per year is 1, 6.3, and 2 months respectively. There is a modest allocation for SSA personnel to travel to Alaska to attend project meetings/conferences (2 trips annually for a total of $3K/yr).

The budget also includes 2 subcontracts for consultancies totaling $76.4K. Consultants to the project are responsible for specific tasks (see Management, Roles & Personnel section above): Dr Brown of Flying Fish Ltd. and Dr. Patrick. The budget for the former is $56,441 for 4 months of effort (includes travel). Dr. Patrick will assist modeling efforts for 2 months annually for a total $20,000/year. Both consultants will participate in the project at comparable levels of effort and rate for the planned 3 years.

No allocations have been made for the purchase of new equipment or commodities.

The budget subcategory total is $174.3K annually. The proposed company indirect rate of 32% includes General and Administrative expenses of 20% and a fee of 10%. Fringe benefits and other direct labor expenses are included in the Personnel labor costs. These rates are based on accounting practices that have been previously audited and approved by DCAA. In our indirect cost calculation, the 32% rate is applied to personnel, travel and contractual budget subcategory values. Annual indirect costs are $55.8, making the project cost per year (including G&A and fee) $230.1K/yr; with TC Agency G&A of $20.7K a total of $250.8K. Over the 3 year period of performance the project grand total is $752.4K.

In kind contributions to the project include 7 copies of the EASy-GIS/Netviewer software package provided by SSA totaling $70K in value ($10K per copy). Five copies will be made available to project collaborators, and 2 copies (with the finalized information system developed as part of the work proposed here) will be delivered to stakeholder agencies (EVOS & Prince William Sound Science Center).

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

Budget Category:	Authorized FY 2006	Proposed FY 2007	Proposed FY 2008	Proposed FY 2009	Total Proposed
Personnel		$94.9	$94.9	$94.9	$284.7
Travel		$3.0	$3.0	$3.0	$9.0
Contractual		$76.4	$76.4	$76.4	$229.2
Commodities		$0.0	$0.0	$0.0	$0.0
Equipment		$0.0	$0.0	$0.0	$0.0
Subtotal	$0.0	$174.3	$174.3	$174.3	$522.9
Indirect		$55.8	$55.8	$55.8	$167.4
Project Total w/o G&A	$0.0	$230.1	$230.1	$230.1	$690.3
G&A - (9%)		$20.7	$20.7	$20.7	$62.1
Project Total w/G&A		$250.8	$250.8	$250.8	$752.4
Full-time Equivalents (FTE)		0.8	0.8	0.8	

Dollar amounts are shown in thousands of dollars.

Comments:
It is understood that projects are funded on an annual basis, and that proposed multi-year projects such as this one will be funded one year at a time contingent on performance and fund availability. We are proposing a 3 year project that will be a comprehensive modelling and synthesis activity for PWS Herring aimed at providing practical tools for management and ecosystem restoration in accordance to EVOSTC priorities. However, discrete sets of deliverables will be produced each year to accommodate both current priorities and potential future funding constaints.
A detailed description of budget items is provided in the Budget Justification section of the proposal document. In terms of SSA's cost, which will lead the project management, all costs relate to personnel for work done on the project and travel to attend project meetings.conferences (2 per year). The budget also includes to subcontracts to consultants to the project Dr. E. Brown and Dr. V. Patrick for supporting specific project work components.

Proposed company indirect rate of 32% (ref. E10, F10 and G10 above) includes General and Administrative expenses of 20% and a fee of 10%. Fringe benefits and other direct labor expenses are included in the Personnel labor costs. These rates are based on accounting practices that have been previously audited and approved by DCAA.

FY07 - FY 09

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

Prepared:

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET

October 1, 2000 - September 30, 2001

Personnel Costs:			Months	Monthly		Proposed
Name	Position Description		Budgeted	Costs	Overtime	FY 2007
Dale A. Kiefer	PI: Modeling		1.00	14.1		14.1
Vardis M. Tsontos	Co-PI: GIS & Modeling		6.30	7.9		49.8
Frank J. O'Brien	Software Engineer and Modeler		2.00	15.5		31.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
	Subtotal		9.3	37.5	0.0	
					Personnel Total	$94.9

Travel Costs:	Ticket	Round	Total	Daily	Proposed
Description	Price	Trips	Days	Per Diem	FY 2007
Alaska Marine Symposium FY 2007	0.6	1	4	0.2	1.4
Meeting with Consultant and EVOS technicians FY 2007	0.6	1	5	0.2	1.6
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
				Travel Total	$3.0

FY07

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

Contractual Costs:	Proposed
Description	FY 2007
Dr. Evelyn Brown, Consultant and Co-PI : salary & travel in support of Herring model/Model project (Effort: 4 months/yr)	56.4
Dr Vince Patrick, Consultant: salary & travel to support Modeling work component (Effort: 2 months/yr)	20.0
Contractual Total	$76.4

Commodities Costs:	Proposed
Description	FY 2007
Commodities Total	$0.0

FY07

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

New Equipment Purchases: Description	Number of Units	Unit Price	Proposed FY 2007
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
Those purchases associated with replacement equipment should be indicated by placement of an R.			0.0
		New Equipment Total	$0.0

Existing Equipment Usage: Description	Number of Units	

FY07

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET

October 1, 2000 - September 30, 2001

Personnel Costs:			Months Budgeted	Monthly Costs	Overtime	Proposed FY 2008
Name	Position Description					
Dale A. Kiefer	PI: Modeling		1.00	14.1		14.1
Vardis M. Tsontos	Co-PI: GIS & Modeling		6.30	7.9		49.8
Frank J. O'Brien	Software Engineer and Modeler		2.00	15.5		31.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
	Subtotal		9.3	37.5	0.0	
					Personnel Total	$94.9

Travel Costs:	Ticket Price	Round Trips	Total Days	Daily Per Diem	Proposed FY 2008
Description					
Alaska Marine Symposium FY 2008	0.6	1	4	0.2	1.4
Meeting with Consultant and EVOS technicians FY 2008	0.6	1	5	0.2	1.6
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
				Travel Total	$3.0

FY08

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

Contractual Costs:	Proposed
Description	FY 2008
Dr. Evelyn Brown, Consultant and Co-PI : salary & travel in support of Herring model/Model project (Effort: 4 months/yr)	56.4
Dr Vince Patrick, Consultant: salary & travel to support Modeling work component (Effort: 2 months/yr)	20.0
Contractual Total	$76.4

Commodities Costs:	Proposed
Description	FY 2008
Commodities Total	$0.0

FY08

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

New Equipment Purchases: Description	Number of Units	Unit Price	Proposed FY 2008
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
Those purchases associated with replacement equipment should be indicated by placement of an R.			0.0
		New Equipment Total	$0.0

Existing Equipment Usage: Description	Number of Units	

FY08

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

Personnel Costs:			Months Budgeted	Monthly Costs	Overtime	Proposed FY 2009
Name	Position Description					
Dale A. Kiefer	PI: Modeling		1.00	14.1		14.1
Vardis M. Tsontos	Co-PI: GIS & Modeling		6.30	7.9		49.8
Frank J. O'Brien	Software Engineer and Modeler		2.00	15.5		31.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
	Subtotal		9.3	37.5	0.0	
					Personnel Total	$94.9

Travel Costs:	Ticket Price	Round Trips	Total Days	Daily Per Diem	Proposed FY 2009
Description					
Alaska Marine Symposium FY 2007	0.6	1	4	0.2	1.4
Meeting with Consultant and EVOS technicians FY 2007	0.6	1	5	0.2	1.6
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
				Travel Total	$3.0

FY09

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

Contractual Costs: Description	Proposed FY 2009
Dr. Evelyn Brown, Consultant and Co-PI : salary & travel in support of Herring model/Model project (Effort: 4 months/yr)	56.4
Dr Vince Patrick, Consultant: salary & travel to support Modeling work component (Effort: 2 months/yr)	20.0
Contractual Total	$76.4

Commodities Costs: Description	Proposed FY 2009
Commodities Total	$0.0

FY09

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,

2001 EXXON VALDEZ TRUSTEE COUNCIL PROJECT BUDGET
October 1, 2000 - September 30, 2001

New Equipment Purchases: Description	Number of Units	Unit Price	Proposed FY 2009
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
Those purchases associated with replacement equipment should be indicated by placement of an R.			0.0
		New Equipment Total	$0.0

Existing Equipment Usage: Description	Number of Units	

FY09

Prepared:

Project Number: 070810
Project Title: An Ecosystem Model of PWS Herring: A Management & Restoration Tool
Name: Dale Kiefer - Systems Science Applications, Inc.,