THE GULF OF ALASKA
BIOLOGY AND OCEANOGRAPHY

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Modeling
Gretchen Oosterhout

Modeling, as well as observing systems designed to support modeling efforts, have been established in the Gulf of Alaska (GOA) and North Pacific. Regional monitoring and research programs should build on the strengths of past and existing programs. In this chapter, modeling strategies of established programs are reviewed, followed by discussion of the purposes of modeling, a hierarchical framework for organizing different types of models, options available in modeling strategies and methods, and the means of evaluating modeling proposals.

The chapter concludes with a section on North Pacific models.

11.1 SURVEY OF MODELING

11.1.1 Modeling Strategies of Established Programs

This subsection provides statements summarizing modeling strategies.

GOOS (Global Ocean Observing System)

Linking user needs to measurements requires a managed, interactive flow of data and information among three essential subsystems of the IOOS (Integrated Ocean Observing System): (1) the observing subsystem (measurement of core variables and the transmission of data), (2) the communications network and data management subsystem (organizing, cataloging, and disseminating data), and (3) the modeling and applications subsystem (translating data into products in response to user needs). Thus, the observing system consists of the infrastructure and expertise required for each of these subsystems as well as that needed to insure the continued and routine flow of data and information among them. (U.S. GOOS 2000)

PIECES (North Pacific Marine Science Organization)/NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography)

Models serve to extrapolate retrospective and new observations through space and time, assist with the design of observational programs, and test our understanding of the integration and functioning of ecosystem components. Clear differences were identified in the level of advancement of the various disciplinary models. Atmosphere-ocean and physical circulation models are the most advanced, to the extent that existing models are generally useful now for CCC (climate change and carrying capacity) objectives, at least on the basin scale. Circulation models in territorial and regional seas are presently more varied in their level of development, and may need some coordination from PICES. Lower trophic level models are advancing, and examples of their application coupled with large-scale circulation models are beginning to appear. There is a need for comparisons of specific physiological models, and for grafting of detailed mixed layer models into the general circulation models. With upper trophic level models, there are several well-developed models for specific applications, but workshop participants felt there were as yet no leading models available for general use within the CCC program. This is an area that needs particular attention and encouragement from PICES. (Perry et al. 1997)

GLOBEC (Global Ocean Ecosystems Dynamics)

The physical models . . . can be coupled with a suite of biological, biophysical and ecosystems models. Development of biological models should occur concurrently with development of the physical model. Four types of biological or biophysical models are recommended . . . Linking outputs from each of these models will allow the examination of ecosystem level questions regarding top down or bottom up controls in determining pelagic production in the Bering Sea. (U.S. GLOBEC, No date)

11.1.2 Core Variables for Modeling

Table 11.1 shows spatial domains, currencies, inputs, and outputs for several of the most relevant North Pacific models.

11.2 PURPOSES OF MODELING

The ultimate goal of both gathering data and developing models is to increase understanding. Pickett et al. (1994, cited in Pace 2001, p. 69) define this goal, in the realm of science, as "an objectively determined, empirical match between some set of confirmable, observable phenomena in the natural world and a conceptual construct."
<table>
<thead>
<tr>
<th>Model name/Model region</th>
<th>Model spatial domain</th>
<th>Inputs</th>
<th>Outputs/currency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-species stock assessment models that include predation</td>
<td>Across EBS and GOA pollock distributions</td>
<td>Fisheries data and predator biomass</td>
<td>Pollock population and mortality trends—number at age (and biomass at age)</td>
</tr>
<tr>
<td>Bering Sea MSVPA</td>
<td>The modeled region is the EBS shelf and slope north to about 61°N</td>
<td>Fisheries, predator biomass, and food habits data. This model requires estimates of other food abundance supplied by species outside the model.</td>
<td>Age-structured population dynamics for key species—numbers at age</td>
</tr>
<tr>
<td>BORMICON for the Eastern Bering Sea</td>
<td>The model is spatially explicit with 7 defined geographic regions that have pollock abundance and size distribution information.</td>
<td>Temperature is included and influences growth and consumption.</td>
<td>Spatial size distribution of pollock</td>
</tr>
<tr>
<td>Evaluating alternative fishing strategies</td>
<td>U.S. Exclusive Economic Zone</td>
<td>Gear-specific fishing effort, including bycatch</td>
<td>Biomass of managed fish species</td>
</tr>
<tr>
<td>Advection on larval pollock recruitment</td>
<td>Southeastern Bering Sea shelf</td>
<td>OSCURS surface currents (wind-driven)</td>
<td>Index of pollock recruitment</td>
</tr>
<tr>
<td>Shelikof Pollock IBM</td>
<td>Western GOA from just southwest of Kodiak Island to the Shumagin Islands shelf, water column to 100 m</td>
<td>From physical model: Water velocities, wind field, mixed-layer depth, water temperature, and salinity; <em>Pseudocalanus</em> field (from NPZ model)</td>
<td>Individual larval characteristics such as age, size, weight, location, life stage, hatch date, consumption, respiration</td>
</tr>
<tr>
<td>GLOBEC NPZ 1-D and 3-D Models</td>
<td>Water column (0-100 m), coastal GOA from Dixon Entrance to Unimak Pass, 100 m of water column over depths &lt;2,000 m, 5 m depth bins x 20 km horizontal grid</td>
<td>Irradiance, MLD</td>
<td>Diffusivity, ammonium, nitrate, detritus, small and large phytoplankton, dinoflagellates, tintinnids, small coastal copepods, <em>Neocalanus</em>, and euphausiids</td>
</tr>
<tr>
<td>Steller Sea Lion IBM</td>
<td>Should be applicable to a specific sea lion rookery or any domain surrounding haul-out in the Bering Sea, Aleutian Islands, or GOA</td>
<td>The main input will be a 3-D field of prey (fish) distribution, derived either from hypothetical scenarios or (later) modeled based on acoustic data.</td>
<td>Individual sea lion characteristics such as age, location, life stage, and birth date are recorded. Caloric balance is the main variable followed for each individual.</td>
</tr>
<tr>
<td>Shelikof NPZ Model, 1-D and 3-D Versions</td>
<td>Water column (0-100 m), GOA from southwest of Kodiak Island to Shumagin Islands. 1 m depth bins for 1-D version; 1 m depth x 20 km for 3-D version</td>
<td>Irradiance, MLD, temperature, bottom depths, water velocities (u, v, w)</td>
<td>Nitrogen, phytoplankton, <em>Neocalanus</em> densities, <em>Pseudocalanus</em> numbers m⁻³ for each of the 13 stages (egg, 6 naupliar, 6 copepodite)</td>
</tr>
<tr>
<td>Model name/Model region</td>
<td>Model spatial domain</td>
<td>Inputs</td>
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<tr>
<td>GOA Pollock Stochastic Switch Model</td>
<td>Shelikof Strait, Gulf of Alaska</td>
<td>Number of eggs to seed the model. Base mortality, additive and multiplicative mortality. Adjustment parameters for each mortality factor.</td>
<td>Number of 90-day-old pollock larvae through time</td>
</tr>
<tr>
<td>NEMURO</td>
<td>Ocean Station P (50°N 145°W), Bering Sea (57.5°N 175°W), and Station A7 off the east of Hokkaido Island, Japan (41.3°N 145.3°W)</td>
<td>15 state variables and parameters, including 2 phytoplankton, 3 zooplankton, and multiple nutrient groups</td>
<td>Ecosystem fluxes are tracked in units of nitrogen and silicon.</td>
</tr>
<tr>
<td>Eastern Bering Sea Shelf Model 1 Ecopath</td>
<td>500,000 km² in EBS south of 61°N</td>
<td>Biomass, production, consumption, and diet composition for all major species in each ecosystem</td>
<td>Balance between produced and consumed per area biomass (t km⁻²). Future work will explore energy (kcal km⁻²) and nutrient dynamics.</td>
</tr>
<tr>
<td>Eastern Bering Sea Shelf Model 2</td>
<td>500,000 km² in eastern Bering Sea south of 61°N</td>
<td></td>
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</tr>
<tr>
<td>Western Bering Sea Shelf Ecopath</td>
<td>300,000 km² on western Bering Sea shelf</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gulf of Alaska Shelf Ecopath</td>
<td>NPFMC management areas 610, 620, 630, and part of 640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aleutian Islands, Pribilof Islands Ecopath</td>
<td>Not determined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prince William Sound Ecopath</td>
<td>Whole Prince William Sound</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Kerim Aydin, NMFS, Seattle, WA.
BORMICON = Boreal Migration and Consumption Model
EBS = Eastern Bering Sea
GLOBEC = Global Ocean Ecosystem Dynamics
GOA = Gulf of Alaska
km = kilometer
kcal = kilocalorie
m = meter
MLD = mixed layer depth
mmol = millimolar
MSVPA = Multispecies Virtual Population Analysis
NEMURO = North Pacific Ecosystem Model for Understanding Regional Oceanography
NPFMC = North Pacific Fishery Management Council
NPE = nutrient-phytoplankton-zooplankton
OSCURS = Ocean Surface Current Simulations
t = metric ton
YD = days of year
A model—Pickett’s “conceptual construct”—is useful if it helps people represent, examine, and use hypothetical relationships. Data—Pickett’s “confirmable, observable phenomena in the natural world”—can be analyzed with statistical tools such as the following:

- Analyses of the variance, regressions, and classification and regression trees (CARTs);
- Mathematical tools such as Fourier transforms or differential equations; and
- Qualitative models such as engineering “free body” diagrams, network diagrams, or loop models.

Fundamental goals of statistical or mathematical analyses are to develop correlative, and perhaps even causal, relationships and an understanding of patterns and trends. In particular, there is a need to distinguish between random variability, noise, and patterns or trends that can be used to explain and predict.

In other words, the goal of gathering and analyzing data is to improve our conceptual and analytical models of the world, and the goal of developing models is to represent and examine hypothetical relationships that can be tested with data.

One of the most useful applications of even relatively simple statistical and conceptual models is in experimental design that permits investigating the possible roles of various parameters and their interactions, ranking the relative importance of uncertainties that may need to be resolved (Fahrig 1991, Oosterhout 1998), and estimating impacts of sample size and observational error (Carpenter et al. 1994, Ludwig 1999, Botkin et al. 2000, Meir and Fagan 2000). Statistical models assess how the variability in one or more kinds of data relates to variability of others. To answer the “why” and “how” questions, however, mechanistic models can be used to develop and test hypotheses about causes and effects (Gargett et al. 2001). (Mechanistic in this use is intended to describe the philosophy of mechanism, especially explaining phenomena through reference to physical or biological causes.) For monitoring and modeling to be useful for solving problems, they must contribute to improving decision-making (Holling and Clark 1975, Holling 1978, Hilborn 1997, Botkin et al. 2000, Ralls and Taylor 2000).

Toward this end, one goal of GOA research programs is to use models predictively to assist managers in solving problems. It is important that expectations be realistic, however. The mechanisms that drive ecological systems, particularly those related to climatic and human activities, are not currently well understood for predictions about natural systems to be reliably successful. It is not unreasonable to expect that predictive models that managers will be able to use to produce at least short-term reliable forecasts will eventually be developed, but advances in decision-support models will require a long-term commitment to advancing understanding on which those decision-support models will ultimately have to be based.

Prediction is, however, an important goal of a modeling program even in the short run, because science advances with the development and testing of predictive hypotheses. Mechanistic studies are essential to advancing understanding, but carrying out these studies requires defining cause-effect or predictive hypotheses, and then testing those predictions against subsequent data or events with analytical models.

The fundamental goal of GOA research programs is to identify and better understand the natural and human forces that cause changes in GOA ecosystems. This research goal has a pragmatic purpose that can only be served, in the end, by linking correlative and mechanistic studies with the predictive needs of decision makers. Decision-making, prediction, and understanding are inevitably linked, and maintaining that link can help keep a research program focused on its ultimate objectives, and help it to avoid narrow inquiry and the distractions of small temporary problems (Pace 2001).

An often-overlooked benefit provided by the process of developing a model is that it can, and probably should, facilitate communication among researchers, managers, and the public.

To summarize, in GOA research programs, the specific purposes of modeling are to

- Inform, communicate, and provide common problem definition;
- Identify key variables and relationships;
- Set priorities;
- Improve and develop experimental designs to attain monitoring objectives; and
- Improve decision-making and risk assessment.

11.3 Hierarchical Framework

It is critical that GOA research programs develop a hierarchical modeling strategy to ensure that short-
term, smaller-scale decisions about monitoring and modeling studies will be consistent with the conceptual foundation. Smaller-scale research studies to test particular hypotheses and develop correlative relationships must fit within a larger synthesis framework connecting the more narrowly focused research disciplines. Deductive studies to relate empirical data to synthetic constructs are just as important as inductive studies to elucidate general principles, and it is important that researchers keep straight whether they are investigating the meaning of the data, given the theory, or the validity of the theory, given the data. Neither can be done unless modeling, monitoring, and data management strategies are developed together.

Models may be verbal, visual, statistical, or numerical. Statistical models are also known as “correlative” and “stochastic,” and numerical models are also known as “deterministic” and “mechanistic.” Note that “prediction,” “analysis,” and “simulation” are terms that describe the use of models, and not necessarily their type. The modeling hierarchy provides links between observations and explanations, development of theory and design of experiments, and advancement of science and the practice of management. The “top” of this hierarchy, the conceptual foundation, is the source of questions and hypotheses to be explored. Statistical, analytical, and simulation models will be developed explicitly to link the “confirmable, observable phenomena in the natural world” to the “conceptual construct,” as Pickett et al. put it (1994, cited in Pace 2001, p. 69).

For example, a visual model of the conceptual foundation is shown in an influence diagram in Figure 11.1, which shows the forces of change on the left and the objects of ultimate interest that are subject to change on the right. In between the two are the intervening elements and relationships on which the human and natural forces act. It is the nature of the connections among these physical and ecological elements that is hypothesized to bring about the changes that GOA research programs seek to understand. Therefore, these connections should provide the overall modeling structure.

This conceptual model is linked to the monitoring plan through the variables defined as “essential to monitor” in the conceptual foundation, illustrated in a network diagram in Figure 1.3 (Chapter 1). The analytical relationships between the monitored variables of Figure 1.3 and the conceptual foundation represented by Figure 1.4 (Chapter 1), are developed and investigated with statistical and analytical tools, called models.

The ultimate goal of GLOBEC’s Northeast Pacific modeling appears to be a suite of computer models that represents an entire conceptual foundation. The way this is framed in programs like GLOBEC, the North Pacific Marine Science Organization (called PICES), and Global Ocean Observing System (GOOS) (see section 11.2 of this chapter) is as linked physical and biological models representing the physical and biological worlds over time and space (marine as well as terrestrial).

The National Research Council describes this idealized goal as follows (NRC 2000, p. 16): develop a whole-ecosystem fishery model as a guide to think about what needs to be monitored. Such a model would use current and historical data to relate yields to climate data and contaminant levels and might stress biological and physical endpoints (zooplankton/phytoplankton blooms, macrofauna populations) and climate and physical oceanography endpoints, in conjunction with modeling.

Such a conceptual framework can stimulate heated arguments, creative debate, and perhaps synthesis among researchers who have tended to work in somewhat independent fields with different theoretical foundations and languages (Zacharias and Roff 2000). On a pragmatic level, however, it is too general to help decision makers choose to fund one proposal over another.

A feasible way to proceed from what can be done now is through an iterative process framed by the conceptual foundation (Figure 11.1). The conceptual foundation should be the explicit source of hypothetical correlative and cause-and-effect relationships. Those relationships should be stated as hypotheses, and should be used to determine what needs to be measured and when, where, and how. If the monitoring and modeling plans are developed within this framework, the measurements can be compared to model predictions, the results can be used to update the scientific background and the monitoring plan, and the iteration can continue.

11.4 Defining and Evaluating Modeling Strategies

Modeling efforts for the short term should be developed as part of a long-term strategy defined by goals of research programs. The modeling strategy must be consistent with research implementation tools and strategies and mission goals. Research modeling should accomplish the following:
11.5 Modeling Methods

The modeling "niche" of GOA research will be defined in part by a gap analysis, particularly focused on where it fits with established major regional programs, especially those of GLOBEC, GOOS, and PICES.

The relationship between monitoring, modeling, and decision-making described here is consistent with the relationships of these programs. A useful context is provided by a table compiled for GLOBEC by K. Aydin of the National Oceanic and Atmospheric Administration (Seattle), which summarizes North Pacific models of the Alaska Fisheries Science Center and others (Table 11.2). Correctly defining the GOA research niche is important to avoid duplication of effort and to make best use of work already being done by others.

Developing a model should be perfectly analogous to designing a controlled experiment. A useful model structure will be driven by the questions it needs to help people answer, not by the computer technology and programming expertise of model developers (although technology and expertise may impose constraints). As a general rule, useful models do not tend to be complex, in part because they must be comprehensible to be believed and used by decision makers. That said, models based on laws of physics, which can be validated against those laws and either data or scale physical models, have advanced further than ecological models in their ability to provide useful output from highly complex models.

11.5.1 Links among Models and among Modelers

One of the most important challenges confronting modelers will be to develop common languages and modeling frameworks that will allow them to resolve the temporal, mathematical, ecological, physical, and spatial sources of disconnects among the various academic paradigms. This challenge will require significant commitment to improving communication skills, developing qualitative verbal or visual models, and using intuitive problem-structuring tools that combine different modeling techniques, such as network, systems, or loop models. An additional benefit of this kind of approach is that these types of visual, qualitative models should be comprehensible to researchers from any scientific discipline, managers, and the public. The attribute of being widely comprehensible will help facilitate the support of stakeholders.
The feasibility of managing research programs depends in large part on the communication skills of experts in the components and linkages that make up the conceptual foundation. Establishing effective communication among experts from different organizations is a widespread problem facing systems modelers (Caddy 1995). Experts in these fields should bring substantial background capabilities to their work from their common language of mathematics and science learned in graduate school. The modelers also should be required to demonstrate the ability to work with counterparts to develop a shared systems view and conceptual models.

11.5.2 Deterministic Versus Stochastic Models

Detecting and understanding change requires that uncertainty and variability play a central role in the analyses (Ralls and Taylor 2000). Two key questions that must be addressed by anyone trying to detect and understand change are the problems of Type I and Type II error. Type I error is “seeing” something that is not really there; and Type II error is concluding something is not there, when it really is. Dealing with these types of error in decision-making requires weighing the evidence that suspected change is caused by a (theoretically) definable pattern or trend or is “normal” process error, observation error, or some combination. Equally important, and often overlooked, is how real indicators of change may be hidden by process or observation error or by incorrect assumptions about how things work.

Dealing with uncertainty and variability in models requires at a minimum carrying out sensitivity analysis on simple deterministic models, with particular emphasis on model structure (Hilborn and Mangel 1997). But it is often more efficient and more useful to incorporate stochasticity into simple models. Stochastic models need not necessarily be more data intensive than deterministic models. Overlooking the assumptions required in choosing a mean (or median) or geometric mean, as a representative value for a deterministic parameter is one of the most widespread, but overlooked, sources of modeling error (Vose 2000). At least stochastic modeling requires that probability distributions be explicitly defined.

Simplistic deterministic models can be every bit as misleading and improper as stochastic models (Schnute and Richards 2001), but because they are more familiar, and their single-number inputs and outputs are easier to think about than uncertainties and ranges, they may lead to false confidence on the part of decision makers. Risk assessment in most fields requires analyzing probability distributions and uncertainties, not mean trajectories (Glickman and Gough 1990, Burgman et al. 1993, Vose 2000).

One fundamental issue of interest to decision makers is often how best to prioritize research efforts. A key part of such an issue is ranking the relative impacts of uncertainties on a decision. In this case, it is possible that thoughtful sensitivity analysis carried out on a simple, deterministic model (or multiple models) may be adequate for the job, particularly as a first step in “weeding out” variables that are likely to be extraneous. But developing a stochastic version of relatively simple models may be more efficient (Vose 2000). If care is taken to distinguish between environmental or process variation and observational or functional uncertainty, then statistical tools such as analysis of variance or regression can be used to investigate the relative impacts of uncertainties (Meyer et al. 1986, Mode and Jacobson 1987a,b, Fahrig 1991, Law and Kelton 1991, Oosterhout 1996, Ruckelshaus et al. 1997, Oosterhout 1998, Vose 2000). This approach can be very helpful in developing analytical structures as well as modeling plans. It also lends itself well to decision analysis and risk assessment because it is similar to the “value of imperfect information” analyses widely used in risk assessment and decision analysis (von Winterfeldt
Table 11.2. Potential Objectives and Attributes for Use in Evaluation of Modeling Strategies.

<table>
<thead>
<tr>
<th>Objective or Attribute</th>
<th>Supported by models that help . . .</th>
</tr>
</thead>
</table>
| Relevance to research  | Identify variables and relationships.  
                        | Characterize uncertainty and noise, impacts of process and observation error.  
                        | Elucidate general principles rather than narrow, unique focus driven by short-term perceived crisis. |
| Contribution to future | Inform, communicate, develop common problem definitions.  
                        | Set priorities, clarify relative impacts of variables and relationships.  
                        | Improve and develop experimental (monitoring) designs.  
                        | Prioritize and elucidate impacts of uncertainties in data and in model structure and assumptions.  
                        | Increase utility of using simpler models to identify key variables and relationships to use in future models. |
| Efficiency of approach  | Synthesize, exploit, and integrate existing data and existing programs whenever possible; for example, from oceanographic programs such as NOAA, OCSEAP, GLOBEC, and GOOS.  
                        | Elucidate links between things that are easy to measure and key indicators of change, whatever they might be.  
                        | Elucidate links between correlations (which are usually easier to develop) and explanatory mechanisms (which are usually more difficult). |
| Maintenance and development | Accessibility of models to end users, other modelers.  
                        | Contribution to data management, data assimilation effort.  
                        | Contribution to solving problems for resource managers and regulators. |


11.5.3 Correlative Versus Mechanistic Models

The use of statistics-based tools such as regressions to make deterministic or probabilistic predictions will generally be easier than developing deterministic or stochastic biological models, because of a dearth of predictive “laws” of biology, let alone ecology. Because statistics-based models are correlative, cause-and-effect explanations will eventually be needed if change is to be understood and predicted reliably. Because some things are easier and more reliable to measure than others, simple models that can help develop correlative relationships between hard-to-measure parameters and easy-to-measure parameters may be of particular interest.

11.5.4 Modeling and Monitoring Interaction

Models should be developed to use and synthesize readily available data whenever possible. This approach will also help identify data needs. Similarly, whenever possible, monitoring plans should be developed to fit the models that will be used to analyze and interpret them. Data management, assimilation, and synthesis should be key considerations for both monitoring and modeling.

One useful way to incorporate data into improving an existing statistical or simulation model is with the Bayesian revision methods (Marmorek et al. 1996, Punt and Hilborn 1997, Hilborn 1997). Bayesian methods might be useful to consider with respect to the question about how much emphasis should be put on annual forecasts, because Bayesian methods lend themselves well to incorporating incoming data
into previous forecasts. This entire approach also lends itself well to decision-analysis techniques.

Models are tools for assimilating data and optimizing data collection as expressed for the GOOS program (IOC 2000, p. 36):

A validated assimilation model can be most useful in optimizing the design of the observing subsystem upon which it depends. This underscores the mutual dependence of observing and modeling the ocean, i.e., observations should not be conducted independently of modeling and vice versa. For example the so-called "adjoint method" of assimilation can be used to gauge the sensitivity of model controls (e.g., open boundary and initial conditions, mixing parameters) to the addition or deletion of observations at arbitrary locations within the model domain. In this regard, "observation system simulation experiments" are becoming increasingly popular in oceanography as a way of assessing various sampling strategies. The model is first run with realistic forcing and model parameters. The output is then subsampled at times and locations at which the observations were sampled. These simulated observations are then assimilated into the model and the inferred field compared against the original field from which the "observations" were taken. This allows the efficacy of the assimilation scheme and sampling strategy to be evaluated (at least to the extent that the model is believed to be a reasonable representation of reality).

11.6 Evaluating Model Proposals

The following guidelines were proposed for evaluating research model proposals for the GOA. They are presented here for their utility in the GOA as well as other locations.

Model proposals should be evaluated within a decision-structured framework such as that outlined above and detailed in Table 11.2. As a starting point, successful model proposals can provide the following:

- Define who will use the model and for what. If the proposal is to continue or expand an existing model, it should describe who is currently using it and for what. If relevant, the proposal should also identify who could be using it, for what, and why they are not able to use it now.
- Define the questions the model is supposed to answer, and directly link those questions to the key questions and hypotheses for research.
- Argue convincingly that the model structure is adequate for the purpose, and that no better (cheaper, faster, more comprehensible, more direct) way exists to answer these questions.
- Show a schematic (flowchart) that is clear, complete, and concise.
- Explain how uncertainty and variability will be represented and analyzed.
- Describe the system characteristics that will be left out or simplified and how the analysis will evaluate the impacts.
- Define data needs and show how the modeling effort will be coordinated with data assimilation and data management efforts.
- Define validation approach.
- Define how the modeling efforts will be communicated to other scientists, managers, and the public; and how input from model stakeholders will be incorporated into the effort, if appropriate.

11.7 Summary

Feasibility and pragmatism in research programs dictate that walking will have to come before running and that focused, simpler models will have to come before large-scale, multidisciplinary models. Walking first means developing verbal and statistical models where numerical models cannot be developed because of a lack of data and understanding. Learning to run requires developing coupled numerical biophysical models that accurately portray the ecosystem. Running means using the biophysical models in a predictive sense. The models must adapt to changes in the conceptual foundation, because the conceptual foundation is designed to change as new information is incorporated. Nonetheless, no matter how many improvements are made, it is probably not reasonable to expect consensus on how that conceptual foundation should be used to develop a strategic modeling policy.

In a constrained world, "consensus" in practice usually means accepting a strategy that enough decision makers find no more offensive than they can accept; optimization, on the other hand, means figuring out the tradeoffs necessary to achieve as many objectives as reasonably possible. Adopting a decision-structured approach for the modeling strategy will help ensure that it is driven by the fundamental objectives of research programs, that the modeling questions are defined by the conceptual foundation, and the tradeoffs can be defined, weighed, and justified.
11.8 NORTH PACIFIC MODELS

The following summary of physical and biological modeling in the North Pacific was prepared by K. Aydin, National Marine Fisheries Service (NMFS), Seattle (Kerim.Aydin@noaa.gov). Descriptions of the hypotheses embodied by each model are followed by details of model features and development in tables for ease of reference and comparison of models. Geographic areas, time periods addressed, status of development, and person to contact for more information is included in Table 11.3.

11.8.1 Predation

The NMFS Alaska Fisheries Science Center has developed two single-species stock assessment models that include predation: one for Eastern Bering Sea pollock (Livingston and Methot 1998) and one for Gulf of Alaska pollock (Hollowed et al. 2000). One for Aleutian Islands Atka mackerel may be developed in the future. The purpose of these models is to better understand the sources and time trends of natural mortality for pollock by explicitly incorporating predation mortality induced by their major predators into an age-structured fish stock assessment model. We have learned that not only is natural mortality for younger fish much higher than that for adults, but also that it varies across time, depending on time trends in predator stocks. This finding about mortality has given us better ideas of what influences predation has on fish recruitment through time and helps us to separate predation and climate-related effects on recruitment. We can better show the demands of other predators such as marine mammals for a commercially fished stock and how it might influence the dynamics of that stock (although we still need to make progress in understanding the effects on the marine mammals).

11.8.2 Bering Sea MSVPA

We now have a multispecies virtual population analysis (MSVPA) model for the Bering Sea (Livingston and Jurado-Molina 2000). This model includes predation interactions among several commercially important groundfish stocks and also predation by arrowtooth flounder and northern fur seal on these stocks. This model can give us a better idea of the predation interactions among several stocks. We can use outputs from this type of model to help us understand what the possible multispecies implications are of our single-species-oriented fishing strategies. Results from these forecasting exercises show that a particular fishing strategy may have the opposite of the intended effect if multispecies interactions are taken into consideration. We have also done multispecies forecasting with this model by using different hypotheses about regime shifts and associated fish recruitment patterns.

11.8.3 Eastern Bering Sea BORMICON

We have an initial version of a spatially explicit model of pollock movement and cannibalism in the Eastern Bering Sea. We hope to better understand the differences in spatial overlap of predators and prey and how that affects the population dynamics of each. The model we have modified for the Bering Sea, BORMICON (boreal migration and consumption model), is being used in other boreal ecosystems. Migrations are prescribed currently, with the hope that we can prescribe movement based on physical factors in the future. The influence of spatial overlap of cannibalistic adult pollock with juveniles on the population dynamics of pollock is being investigated. Hypotheses about larval drift positions and the resulting overlap and cannibalism are also being explored. This model could be linked in the future to an individual-based larval pollock model and to a nutrient-phytoplankton-zooplankton model that could prescribe zooplankton abundance by area as alternate food for adults and as the primary food for juveniles.

11.8.4 Multiple Gear Types

Analytical approaches to evaluating alternative fishing strategies with multiple gear types have been employed. The analytical approach for simulating current groundfish management in the North Pacific U.S. Exclusive Economic Zone involves considering interactions among a large number of species (including target, nontarget, and prohibited) areas and gear types. To evaluate the consequences of alternative management regimes, modeling was used to predict the likely outcome of management decisions by using statistics on historical catch of different species by gear types and areas. Management of the Alaska groundfish fisheries is complex, given the large numbers of species, areas, and gear types. The managers schedule fisheries openings and closures to maximize catch subject to catch limits and other constraints. These management actions are based on expectations about the array of species likely to be captured by different gear types and the cumulative effect that each fishery has on the allowable catch of each individual target species and other species groups. Management decisions were simulated by an in-season management model that predicts capture
<table>
<thead>
<tr>
<th>Model name/Model region</th>
<th>Time period</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-species stock assessment</td>
<td>EBS: 1964-95</td>
<td>Patricia Livingston¹</td>
</tr>
<tr>
<td>models that include predation</td>
<td>GOA: 1964-97 (Annual)</td>
<td></td>
</tr>
<tr>
<td>Bering Sea MSVPA</td>
<td>1979-98 3 months (Quarterly)</td>
<td>Patricia Livingston</td>
</tr>
<tr>
<td></td>
<td>1 month</td>
<td>Jesus Jurado-Molina¹</td>
</tr>
<tr>
<td>BORMICON for the Eastern Bering Sea</td>
<td>1979-97</td>
<td>Patricia Livingston</td>
</tr>
<tr>
<td>Evaluating Alternative Fishing Strategies</td>
<td>Current</td>
<td>Jim Ianelli¹</td>
</tr>
<tr>
<td>Advection on Larval Pollock Recruitment</td>
<td>90 days of larval drift</td>
<td>Jim Ianelli</td>
</tr>
<tr>
<td></td>
<td>1970s-present</td>
<td></td>
</tr>
<tr>
<td>Shelikof Pollock IBM</td>
<td>YD 60-270 (Daily)</td>
<td>Sarah Hinckley¹</td>
</tr>
<tr>
<td>GLOBEC NPZ 1-D and 3-D Models</td>
<td>YD 60-270 (eventually</td>
<td>Sarah Hinckley</td>
</tr>
<tr>
<td></td>
<td>year-round) (Daily)</td>
<td></td>
</tr>
<tr>
<td>Steller Sea Lion IBM</td>
<td>Summer or winter,</td>
<td>Sarah Hinckley</td>
</tr>
<tr>
<td></td>
<td>minutes to days</td>
<td></td>
</tr>
<tr>
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<td>YD 60-270 (eventually</td>
<td>Sarah Hinckley</td>
</tr>
<tr>
<td></td>
<td>year-round) (Daily)</td>
<td></td>
</tr>
<tr>
<td>GOA Pollock Stochastic Switch Model</td>
<td>32 years (replicates) (Daily)</td>
<td>Bern Magrey¹</td>
</tr>
<tr>
<td>NEMURO</td>
<td>1 full year, (Daily)</td>
<td>Bern Magrey</td>
</tr>
<tr>
<td>Eastern Bering Sea Shelf Model 1 Ecopath</td>
<td>1950s and early 1980s (Annual)</td>
<td>Patricia Livingston</td>
</tr>
<tr>
<td>Eastern Bering Sea Shelf Model 2 Ecopath</td>
<td>1979-1998 (Annual)</td>
<td>Kerim Aydin¹</td>
</tr>
<tr>
<td>Western Bering Sea Shelf Ecopath</td>
<td>Early 1980s (Annual)</td>
<td>Kerim Aydin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Victor Lapko²</td>
</tr>
<tr>
<td>Gulf of Alaska Shelf Ecopath</td>
<td>1990-99 (Annual)</td>
<td>Sarah Gaiches¹</td>
</tr>
<tr>
<td>Aleutian Islands, Pribilof Islands Ecopath</td>
<td>1990s-2000s (Annual)</td>
<td>Patricia Livingston</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lorenzo Giannelli¹</td>
</tr>
<tr>
<td>Prince William Sound Ecopath</td>
<td>Pre- and post 1989</td>
<td>Tom Okey³</td>
</tr>
<tr>
<td></td>
<td>oil spill (Annual)</td>
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</tbody>
</table>

¹NMFS, Seattle, WA.
²INRO-Centre.
³University of British Columbia, Vancouver.
BORMICON = Boreal Migration and Consumption Model
EBS = Eastern Bering Sea
GLOBEC = Global Ocean Ecosystem Dynamics
GOA = Gulf of Alaska
MSVPA = Multiplespecies Virtual Population Analysis
NEMURO = North Pacific Ecosystem Model for Understanding Regional Oceanography
NPZ = nutrient-phytoplankton-zooplankton
YD = days of the year
of target and nontarget species by different fisheries based on historical catch data by area and gear type. The groundfish population abundance for each alternative regime was forecast for a 5-year period beginning from the present. This approach provides a reasonable representation of the current fisheries management practice for dealing with the multispecies nature of catch in target fisheries.

In addition to the model and its projected results, agency analysts also used the scientific literature, ongoing research, and professional opinion of fishery experts in their respective fields to perform qualitative assessments.

11.8.5 Larval Pollock Recruitment

A model involving the influence of advection on larval pollock recruitment investigates the environmental relationship between surface advection during the post-spawning period (pollock egg and larval stages) and pollock survival. Wespestad et al. (1997) found that during years when the surface currents tended north-northwestward along the shelf, class strength was improved compared to years when currents were more easterly. They used the ocean surface current simulations (OSCURS) surface advection model to simulate drift. Subsequently (Lanelli et al. 1998), their analysis was extended to apply within a stock assessment model. The model uses surface advection during a 90-day period to determine the “goodness” of the advective field for juvenile pollock.

11.8.6 Shelikof Pollock IBM

A pollock individual-based model (IBM) was designed to run in conjunction with the 3-D physical model (SPEM) and the Shelikof nutrient-phytoplankton-zooplankton model. Its purpose is to examine, at a mechanistic level, hypotheses about recruitment of pollock in Shelikof Strait, especially as they refer to transport, growth, and (somewhat) mortality of pollock from spawning through the fall of the 0-age year.

11.8.7 GLOBEC and NPZ

A Global Ocean Ecosystem Dynamics (GLOBEC) nutrient-phytoplankton-zooplankton (NPZ) 1-D and 3-D modeling effort (the 3-D NPZ model coupled with a physical model of the circulation of the region) is designed to test hypotheses about the effect of climate change/regime shifts on production in the coastal region of the GOA, including effects on cross-shelf transport, upstream effects, local production, and suitability of the region as habitat for juvenile salmon.

11.8.8 Steller Sea Lion IBM

This sea lion individual-based model (IBM) will be designed to examine how sea lion energy reserves change, through foraging and bioenergetics, depending on the distribution, density, patchiness, and species composition of a dynamic prey field (as influenced by factors such as potential local depletion by fishing). It should be applicable to any domain surrounding a specific sea lion rookery or haul-out in the Bering Sea, Aleutian Islands, or Gulf of Alaska. Sea lion characteristics such as age, location, life stage, and birth date are recorded. Caloric balance is the main variable followed for each individual.

11.8.9 Shelikof NPZ

Shelikof nutrient-phytoplankton-zooplankton models, 1-D and 3-D versions, were designed to produce a temporally and spatially explicit food source (Pseudocalanus stages) for larval pollock, as input to the pollock IBM model. This set of coupled (biological and physical) models was designed to be used to examine hypotheses about pollock recruitment in the Shelikof Strait region.

11.8.10 GOA Pollock Stochastic Switch

A GOA walleye pollock stochastic switch model was designed as a mathematical representation of a conceptual model, presented in Megrey et al. 1996. It is a numerical simulation model of the recruitment process. A generalized description of stochastic mortality is formulated as a function of three specific mortality components considered important in controlling survival (random, caused by wind mixing events, and caused by prevalence of oceanic eddies). The sum total of these components, under some conditional dependencies, determines the overall survival experienced by the recruits.

11.8.11 NEMURO

A North Pacific ecosystem model for understanding regional oceanography (NEMURO) represents the minimum state variables needed to represent a generic nutrient-phytoplankton-zooplankton (NPZ) marine ecosystem model for the North Pacific. Ecosystem fluxes are tracked in both units of nitrogen and silicon. Carbon flux process equations recently have been added. The purpose of the model is to examine
the effects of climate variability on the marine ecosystem through regional comparisons using the same ecosystem model structure and process equations.

11.8.12 Ecopath

Several mass-balance ecosystem models (Ecopath) for North Pacific regions have been generated. Mass-balance food web models provide a way for evaluating the importance of predator-prey relationships, the roles of top-down and bottom-up forcing in modeled ecosystems, and the changes in ecosystem structure resulting from environmental perturbations (natural or anthropogenic). In addition, the models may provide a way to compare natural predation mortality with respect to predator biomass and fishing levels, and determine the quality of data available for a given system.

*Eastern Bering Sea Shelf Ecopath Model 1.* Although many of these models were done in the past for the Alaska region, the most up-to-date published model is the effort by Trites et al. (1999) for the Eastern Bering Sea. These models are highly aggregated across age groups and species groups and best highlight our gaps in understanding of how ecosystems function and our lack of data on certain ecosystem components. Walleye pollock is divided into two biomass groups: pollock age 0 to 1 and pollock age 2 and older. This model is useful for testing ecosystem hypotheses about bottom-up and top-down forcing and to examine system level properties and energy flow among trophic levels. The Eastern Bering Sea model extent includes the main shelf and slope areas north to about 61°N and excludes nearshore processes and ecosystem groups.

*Eastern Bering Sea Shelf Model 2 and Western Bering Sea Shelf Ecopath Model.* The second Eastern Bering Sea Shelf model breaks down the earlier model into more detailed species groupings to tease apart the dynamics of individual species, especially in the commercially important groundfish. Spatial extensions to the model include subdividing into inner, middle, and outer biophysical domains. The model will be calibrated with respect to top-down and bottom-up forcing with the use of “checkpoint” food webs for several years in the 1990s, the 1979-1998 time series of trawl data, and Multispecies Virtual Population Analysis (MSVPA)/other assessment analyses. The primary purpose of this model is to investigate the relative roles of natural and anthropogenic disturbances on the food web as a whole. A Western Bering Sea Shelf model, built as a joint U.S.-Russian project, is currently being completed.

*Gulf of Alaska, Continental Shelf, and Slope (Excluding Fjord, Estuarine, and Intertidal Areas) Ecopath Model.* Throughout the 1990s there were extensive commercial fisheries in the GOA for groundfish, as well as crab, herring, halibut, and salmon. Removals of both target species and bycatch by these (and historical) fisheries have been suggested as a possible cause for the decline of the western stock of Steller sea lions, which are now listed as endangered species. An Ecopath/Ecosim model for the GOA could test the hypothesis that fishery removals of groundfish and bycatch during the 1990s has contributed to the continued decline of Steller sea lions.

In addition, a community restructuring, in which shrimp populations declined dramatically and commercial fish populations increased between the 1960s and the 1990s, may have taken place, according to small mesh trawl surveys conducted by the National Marine Fisheries Service and Alaska Department of Fish and Game. An additional hypothesis, which could be tested with this model, is that this trophic reorganization has had a negative impact on marine mammal and bird populations in the GOA. Finally, the effects of an apparent increase in shark populations on their prey and the relative importance of these effects in the whole system could be evaluated with an Ecopath model.

*The Aleutian Island and Pribilof Islands Ecopath Models.* While the Eastern Bering Sea and GOA model may capture broad-scale dynamics of widespread fish stocks, their scale is too large to address local depletion. This issue may be important for island-based fish such as Atka mackerel, and may be critical for determining the effect that changes in the food web may have on the endangered Steller sea lion. This smaller-scale Ecopath model will be used in conjunction with larger-scale models to examine the possibility of linking the models across scales.

*Prince William Sound Ecopath Models.* An Ecopath model of Prince William Sound was constructed by a collaboration of experts from the region during 1988-1999 (Okey and Pauly 1999). The Exxon Valdez Oil Spill Trustee Council funded this effort for the purpose of “ecosystem synthesis.” The project was coordinated by the University of British Columbia Fisheries Centre and overseen by the National Marine Fisheries Service Office of Oil Spill Damage Assessment and Restoration. Prince William Sound is well defined geographically; spatial definition of the system consisted of drawing lines across Hinchinbrook Entrance, Montague Strait, and smaller entrances. The time period represented by the model,
1994-1996, is the post-spill period with the broadest and most complete set of ecosystem information. This food web model consists of 48 functional groups ranging from single ontogenetic stages of special-interest species to highly aggregated groupings. A variety of hypotheses are being addressed with the PWS model—most relate to the 1989 Exxon Valdez oil spill and the fisheries in the area.