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Network of Conservation Educators and Practitioners
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Lessons in Conservation (LinC) is the official journal of the Network of Conservation Educators and Practitioners and is published as issues become available. The Network of Conservation Educators and Practitioners (NCEP) is a collaborative project of the American Museum of Natural History's Center for Biodiversity and Conservation and a number of institutions and individuals around the world. The vision of NCEP is a highly trained network of individuals effectively managing and sustaining the world's biological and cultural diversity. Teaching modules presented here in LinC are available in modifiable form for teachers on the NCEP website (http://ncep.amnh.org). All materials are distributed free of charge. Any opinions, findings and conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the American Museum of Natural History or the funders of this project. All components (Syntheses, Exercises, and Case Studies) have been peer-reviewed and approved for publication by NCEP.

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Lessons in Conservation (LinC)
Developing the capacity to sustain the earth's diversity

Dear Reader,

We welcome you to the second issue of LinC, Lessons in Conservation, the official journal of the Network of Conservation Educators and Practitioners (NCEP, http://ncep.amnh.org) of the Center for Biodiversity and Conservation (CBC) of the American Museum of Natural History. On these pages, you will find selected NCEP teaching modules, presented in an easy-to-browse PDF format. LinC is designed to introduce NCEP teaching materials to a broad audience. After browsing through LinC, we hope that university faculty members and other teachers and trainers will be inspired to visit and download additional materials from the NCEP site, and to try them in the classroom. We welcome feedback on our modules and we especially welcome those wishing to become further involved in the project!

Topics in this first issue of LinC range from marine conservation biology to ecosystem loss and fragmentation to assessing threats, and include both Synthesis summary documents and Exercises for classroom or field use. Future issues will be released semi-annually, and will include Case Studies to complement our Syntheses and Exercises. Future issues will also include brief reports from teachers and trainers using and testing the modules.

Many people from the CBC and the NCEP network of collaborators have contributed to the development of LinC over the past year. On our back cover, we are pleased to acknowledge the foundations and individuals that have supported this project. Special thanks go to Dr. Kathryn Hearst for providing the funding needed to bring this inaugural issue to completion.

We look forward to your input and comments, and to seeing you again soon on these pages!

Eleanor Sterling — Co-Editor

Nora Bynum — Co-Editor

NCEP Workshops and activities in (from left to right) Rwanda, Bolivia, and California.

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Source: E. Sterling and K. Frey

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Monitoring for Adaptive Management in Conservation Biology

James P. Gibbs

Introduction

As conservationists, we devote a great deal of effort and resources to preserving biological diversity. While we pour a lot of energy into developing and implementing management plans, we rarely assess whether our labors have helped us to achieve our goals. In recent years, however, many of us have taken a growing interest in measuring the outcome of our conservation projects and in defining conservation success. Donor agencies and non-governmental organizations have also recognized the need to make conservation and development projects more effective and accountable (World Bank, 1998; Margoluis and Salafsky, 1998; Kleiman et al., 2000). Monitoring, if carefully executed, can provide these kinds of insights.

Elzinga et al. (2001) define *monitoring* as "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective." Margoluis and Salafsky (1998) broadened this definition to include the periodic collection of data relative to stated project goals, objectives and activities. Monitoring is critical, for example, in managing harvested and endangered species, measuring the effects of management activities and natural perturbations, and documenting compliance with regulatory requirements or contractual agreements. Through monitoring, we can determine whether management was a success and should be continued or whether it was a failure and should be abandoned or altered. In most situations, significant amounts of funding are applied to conserve the biological diversity of particular areas. An effective monitoring program is a vital part of determining if those resources are well spent.

According to Salafsky and Margoluis (1998), the three components that comprise any conservation project can be monitored: the state of the target condition (species, ecosystems, protected areas etc.), the success in mitigating threats to the target condition, and the process of implementing interventions. These three types of monitoring are as follows:

(i) *Monitoring the status of the target condition*: Monitoring efforts that are focused on the biological state of the target condition have been referred to as ecological or biological monitoring. Many of these approaches measure conservation outcome using biological indicators of success (e.g. Noss, 1990; Spellerberg, 1991; Sparrow et al., 1994). This is best known as "*biological monitoring*."

(ii) *Monitoring the status of threats to the target condition*: A second approach to monitoring involves focusing on threats to the target condition. Are the most critical threats that affect the target condition changing in their severity or geographic scope as a result of conservation strategies (or lack thereof)? Monitoring threat status has recently gained increasing attention (e.g. Salafsky and Margoluis, 1999; Hockings et al., 2000; Margoluis and Salafsky, 2001; Ervin, 2003). This topic has been addressed in detail in an accompanying module ("Threat Assessment in Conservation Planning and Management") and is very briefly reviewed in the latter section of this overview. This is best known as "*threats monitoring*."

(iii) *Monitoring the process of implementing interventions*: This type of monitoring involves tracking progress in accomplishing project activities to ensure that project activities are getting done. Assessing whether an activity has been completed could involve developing a checklist for recording when activities are completed (Margoluis and Salafsky, 1998). This is best known as "*implementation* *monitoring*."

In most contexts, "*adaptive management*" (Holling, 1978; Ringold et al., 1996) provides a useful framework for monitoring conservation effectiveness. Within an adaptive management milieu, monitoring measures progress toward or success at meeting an objective, providing the evidence necessary for deciding whether to change or continue a specific management practice. More succinctly, adaptive management in conjunction with monitoring is a "learning by doing" process. It is a way of thinking about and implementing natural resource management that states that we should view any management we impose on a system as an experiment from which we can learn (Walters and Holling, 1990; Grumbine, 1994, Gunderson, 1999, Meffe et al., 2002).

Adaptive management is about systematically implementing management in order to achieve a desired outcome. It involves several specific steps as outlined below:

1. Establishment of a clear management goal to describe the desired condition of a species, ecosystem, protected area or other conservation interest.
2. Development of a management plan to clearly identify both threats to the target condition and activities that will reduce these threats, thus achieving the project goal. Threats might include invasive species or poaching, for example.
3. Development of a monitoring plan, to focus (assess) on these target conditions, threats and activities.
4. Implementation of the management and monitoring plans.
5. Data analysis and communication of results.
6. Iterative use of results to adapt and learn. Only by carefully tracking a system in response to management actions can we learn how our actions affect it. Management is adapted (changed) if objectives are not reached or if the new knowledge from monitoring suggests a better course of action.

This overview will primarily focus on monitoring the state of the target condition, which could be a particular species, a suite of species, a protected area, an ecosystem type or a landscape comprising all of these components. Specifically, it describes: (1) how to articulate clear management goals; (2) how to convert these into explicit monitoring goals; (3) how to estimate sampling necessary to meet those monitoring goals; (4) how to analyze monitoring data to determine if change has occurred; and (5) how to report results to stakeholders in a timely and effective fashion.

Monitoring the Status of the Target Condition in Biodiversity Conservation

Conservationists must meet several criteria in order to successfully monitor their work within an adaptive management context. From the outset, conservationists must translate general aims into clear management goals, which they must then further refine into precise and measurable monitoring objectives. This process may seem obvious, but often managers fail to address it! If useful targets are not identified and progress toward them tracked, it cannot be known if management succeeded, nor can management practices evolve and improve.

Determining whether or not we have met monitoring objectives depends on sampling the resource before and after the management has been completed. Proper sampling involves deciding on the amount of data collection necessary to track a resource. Because sampling always includes some uncertainty, estimation is also required of the precise number of samples needed to confidently conclude that management did or did not work. A common problem in monitoring is either undersampling or oversampling the conservation target. Undersampling (taking too few samples) prevents one from detecting a change even if a change has occurred. Oversampling will let one identify a change in response to management but results in an unnecessary waste of effort. Because monitoring in the field is often very expensive and time consuming, it is important to optimize sampling. This can only be done if monitoring objectives are clear.

Keep in mind that the concepts introduced here can be applied to any conservation context. Perhaps you wish to determine if an incentive program actually changed people's behavior, or whether recovery efforts actually increased a population of a rare species. Or perhaps you are concerned with whether or not a law or prohibition is working in terms of the resource it was designed to protect. All of these issues can be assessed by following variations of the basic steps outlined below.

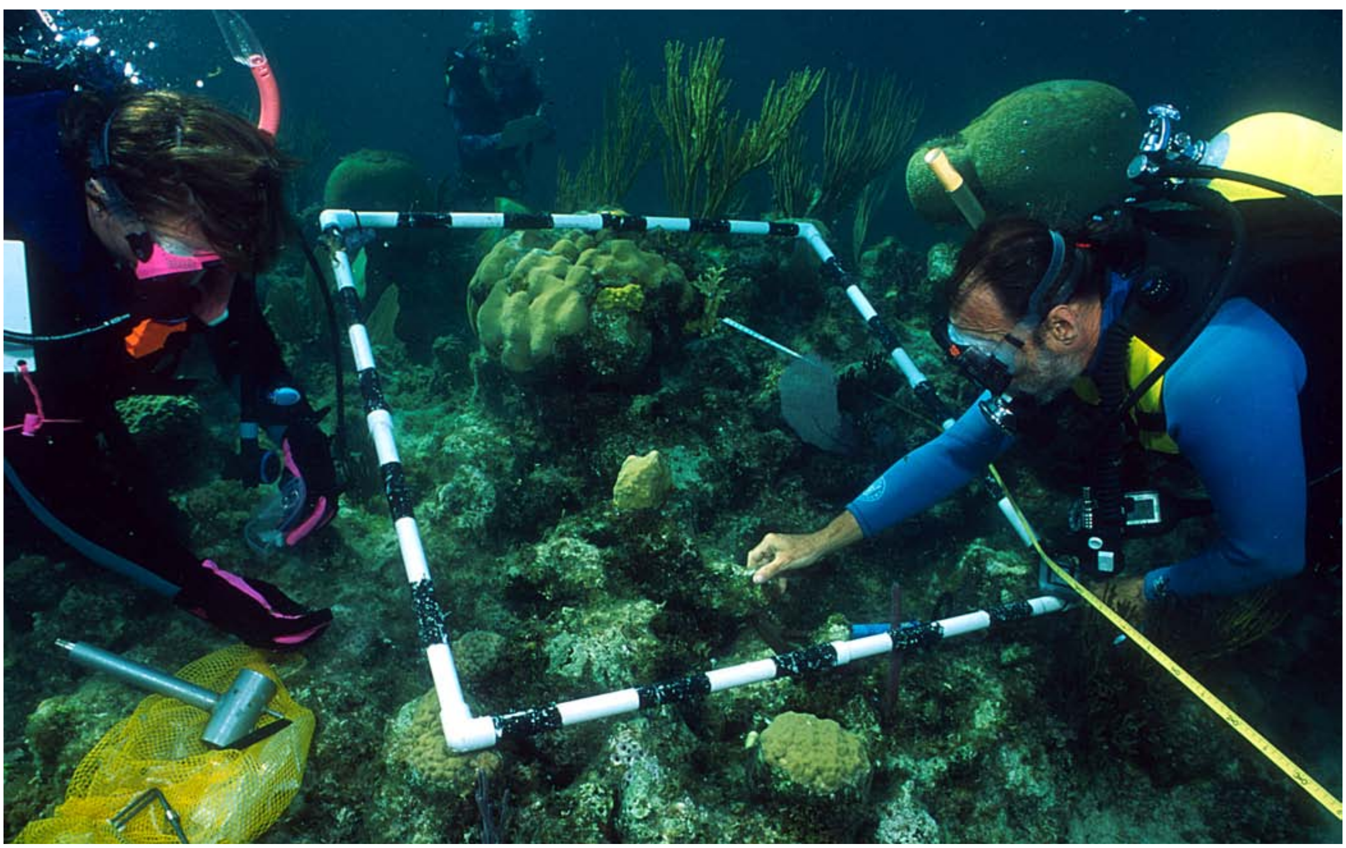
Translating General Management Goals into Specific Management Objectives

Components

Before you can set up a robust monitoring program, you first need to be clear about your general *management goals*. These goals guide resource management by specifying the types of conditions or trends desired in resource conditions. These goals might come from existing management plans and environmental regulations, ecological models of how a system should best function, reference sites or comparison areas, expert opinion, or perhaps even historic records and photographs. Management objectives can take many forms but a complete one has the following components:

The Entity to be Measured

This might be a direct measurement of species/community or an indirect measure of a habitat indicator. Monitoring may involve measuring the change or condition of some aspect of the species itself. If you are monitoring the species, the objective should include its scientific name. If the objective will address a subset of the species (e.g., only flowering individuals, only females), this should also be specified. Monitoring may also measure indicators that function as surrogate measures of species success. There are four classes of indicators: 1) indicator species that correlate with the success of the target species and are easier to measure; 2) characteristics of the ecosystem



Taxonomists Paula Mikkelsen and Gordon Hendler survey a patch reef in the Bahamas (Source: D. Brumbaugh) the species inhabits; 3) threats; and 4) indices of abundance. Monitoring indicators may be less expensive, provide more immediate monitoring feedback to management, and focus on the aspect of the species or community over which you actually have management control, such as habitat quality or intensity of threat. Monitoring indicators may also be problematic, however, because the relationship between an indicator and a particular species is usually hypothetical, or at best only partially understood. Monitoring an indicator may thus result in false conclusions about the condition of a biological resource.

Attribute to be Measured
This is the specific attribute of the entity to be measured. Often this will be a parameter such as size, density, cover, or frequency. It might also be condition or a qualitative measure (e.g., many, few, none). The best attribute to use in monitoring depends on the management situation, the species, and the monitoring resources available.

Action is the Desired Change in the Entity's Attribute, Usually to:

1. **Maintain.** Use when you believe the current condition is acceptable or when you want to set a threshold desired condition (e.g., maintain a population of 200 individuals).
2. **Limit.** Use when you wish to set a threshold on an undesirable condition or state of the species or habitat (e.g., limit Noxious Weed A cover to 50%; limit mortality to 50% per year).
3. **Increase.** Use when you want to improve some aspect of the species or indicator (e.g., increase the average density by 20%; increase the number of populations to 16).
4. **Decrease.** Use when you want to reduce some negative aspect of the species or indicator (e.g., decrease livestock utilization of inflorescences (the buddings and flowerings of plants) to 50% or less; decrease cover of Noxious Weed A by 20%).

Managers working to recover rare species usually seek to increase the population. Some populations, however, may already be at the maximum potential for their habitat, or they suffer from no apparent threats. For these, a more realistic objective would be to maintain current conditions. For other populations you may wish to set a threshold that will trigger a management action if the population falls below it.

Quantity/ Status
This is the measurable status or degree of change for the entity's attribute. For example, you might want to specify not only that numbers of an endangered species increase, but also by what degree. Determining these quantities or states requires consideration of a number of factors:

1. How much can the species respond? Populations of long-lived species (like tortoises or trees) may be very slow to respond to management changes. Responses may be small and difficult to detect, or take many years to express. In this situation, consider using an indicator as an alternative.
2. What is necessary to ensure species or population viability? How much change, what population size, what qualitative state is required to ensure the survival of a species or population?
3. How much change is biologically meaningful? Populations of annual plant species, for example, can vary dramatically from year to year. An objective that specifies increase or decrease in density for such populations is meaningless.
4. What is the intensity of management? Will you continue existing management, remove current threats, or implement a radical alternative?
5. What is the implementation schedule of management? If the monitoring project is scheduled to last 5 years, but new management will not be implemented until the second year of the study, the change results from only 3 years of management.
6. What are the economic costs or other associated considerations associated with measuring the mount of change specified? Small changes are often difficult and expensive

to detect.

Location of Interest
This defines the geographic area to which management and monitoring pertains. Clear delineation of the specific entity or geographic area of management concern allows all interested parties to know the limits to which management and monitoring results will be applied. The spatial bounds of interest defined in a management objective will vary depending on land management responsibilities and particular management activities. For example, you may only have access to a portion of a particular population due to multiple land ownership patterns, or you may only be interested in individuals located within recently logged forests. Location will also vary in relation to the scale at which monitoring will occur. Conservation goals and responsibilities, the biology of the species or ecosystem, and the extent of limited monitoring resources all affect the scale at which monitoring will take place. For example, adaptively managing a population of threatened orchids might require monitoring on a single site within one ownership, whereas tracking the change in wolf populations in response to anti-poaching measures may be a region-wide undertaking involving many hundreds of land ownerships.

Time Frame
This identifies the amount of time that must pass before the effects of management can be accurately monitored and assessed. The biology of the species, the intensity of management, and the amount of change desired all influence the time required to meet a management objective. Populations of short-lived species that reproduce annually may respond quickly, but long-lived species and those with episodic reproduction may require more time. High intensity management will result in more rapid changes than low intensity or no special management. Large changes will require a shorter time frame to detect than smaller changes. In general, the shorter the time frame for monitoring the effects of management, the better, because: (1) changes in agency budgets and personnel often doom long-term monitoring projects; (2) short-term objectives promote regular reassessment of management and implementation of management changes; and (3) the adaptive management cycle must occur within a short enough period that opportunities for species recovery or alternative management are not lost.

Many adaptive management projects concern endangered species for which we lack information. Gathering information over the long-term assists scientists in making adaptive management decisions as they learn more about population cycles, reproductive cycles, longevity, and general adaptability of the species and its food resources or habitat needs to environmental variation. For these reasons a long-term perspective on monitoring is valuable. Moreover, the designated time frame must be sufficient to permit the project to adapt to new information gathered. In reality, short-tem objectives often prevail because of the short-term and cyclical availability of funds for monitoring but long-term monitoring, whenever feasible, can be valuable.

When defining any of the above six types of management objectives, you may need to develop new definitions or unique indicators to meet the needs of a project. For example, your management goal may be to maintain a "healthy and diverse forest ecosystem." To identify monitoring objectives, however, you would need to identify some functional component of the ecosystem as an indicator of "healthy." Similarly, you would need to choose some indicator(s) of "diversity." Keep in mind that these need to be specific, measurable entities and attributes. Were all of the essential components included? If not, what was missing?

We have emphasized the importance of setting and defining management objectives here because managers often fail to identify one or more of them when defining their management objectives. We recognize the difficulties involved in converting general goals for management to specific measurable objectives for monitoring. Without doing so, however, we cannot gauge whether management activities are effective and if management goals are met. Below we provide an example of how to develop specific management objectives for a general management goal.

An Example of Translating a General Management Goal Into Specific Management Objectives

General Management Goal: Sustain and maintain a healthy and diverse forest ecosystem.

Some Possible Specific Management Objectives and Related Monitoring Objectives in Support of this Goal:

1. By the beginning of next year, reduce by 50% silt loads in the main river originating in the forest.
2. Within each forest ecosystem type, maintain 2000-2001 compositions of native grass, shrub, and tree cover from 2010-2015.
3. Prevent fragmentation in the southern block by maintaining the road network at 2000 levels from 2000-2015.
4. In forest interior areas within buffer zone, maintain current (2000-2002) densities of harvested mammals from 2002-2010.

Defining Sampling Objectives From Monitoring Objectives

Complete management objectives (the "what, where, and when" of a project) make a foundation from which monitoring objectives can be defined. Once you have identified your monitoring objectives, you will then have to collect some data. Unless you plan to conduct a complete census, most monitoring will require some sampling of the environment. To sample, you repeatedly measure the environment in a quantitative fashion to determine if your management plan has succeeded in changing (or maintaining) the state of the resource in question. In other words, the sampling objective for a monitoring objective is to estimate the parameter in the population (the "what, where, when") under management and compare this estimated value to the threshold value desired.

Sampling always involves some uncertainty because with sampling we are never entirely sure that we have properly estimated the true value of the parameter for the population. We have to consider the possibility that any difference that we see between two estimated parameters (before and after) could result from sampling errors. A *Type I statistical error* occurs when two populations sampled by chance give the incorrect appearance of being different when, in fact, they are not. It happens when our random sample is not representative of a population as a whole. We also want to be careful about committing a *Type II statistical error,* which involves wrongly concluding that there is no difference among data sets when in fact we simply failed to sample adequately to detect it. We guard against both of these kinds of errors by using increasingly smaller and more stringent levels of alpha or "significance levels."

Increasing the alpha level comes at a cost, however, because it generally involves more sampling to get higher confidence, and gathering samples takes time and money. In addition to balancing cost versus confidence we also need to worry about precision when formulating sampling objectives. How accurate do we really want or need to be? To some extent, the answer to this question depends on the importance of what we are monitoring. Resources of high value, such as quality timber and endangered species, may need to be estimated with greater precision than less critical resources like forage levels or water quality. General estimates, and hence less precision, may suffice for these latter two because the consequences of incorrectly estimating them are less dire (e.g., a slightly thinner cow versus an extinct species).

So when we translate specific management objectives into monitoring objectives, we also need to define how statistically powerful we want our sampling to be. We need to specify information such as the confidence level (false change error rate), the power (the probability that we will detect a change if it occurs), and the precision of the measurements we will take. Without specified targets for these parameters, estimates of population parameters might have excessively large *confidence intervals* or *low power* (e.g., only a 20% chance of detecting the magnitude of change that was desired). We need to specify these parameters so that we know how much sampling we need to do to monitor adequately. More specifically, setting sampling objectives for target/threshold management objectives will help avoid studies that provide unreliable measurements. No one is willing to apply to management decisions to a population estimated at 1200±1300.

Example of a Sampling Objective for a Target Management Objective

General management goal: Improve the health of the elephant herd.

Management objective: Increase the density of young elephants to 1 per 1,000 hectares at site A by 2005.

Sampling objective for monitoring: Estimate with 90% confidence the density of young elephants to within 10% of its estimated true value.

The sampling objective here is to determine if the resource has attained a particular threshold state. We want the true value and the measured value of the resource to fall within a set confidence interval.

Detecting Change

Detecting Change With Confidence Intervals

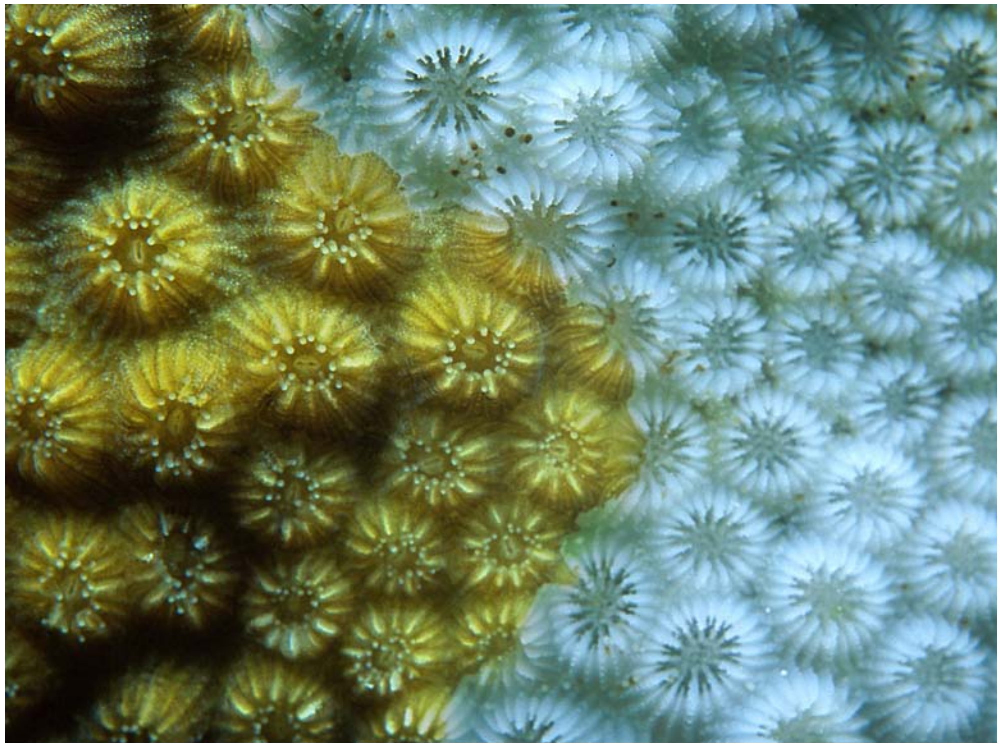
Once you have collected your monitoring data, you can compare it to the baseline data you collected earlier—presumably before management actions occurred. By contrasting conditions before and after management, you can evaluate whether your have met your management objectives, and hence whether you should continue or alter your management practices.

If you are estimating a quantity based on a single independent sample (i.e., you are not trying to relate the sample to another year or another site) then calculating the precision of your estimate using confidence intervals is the correct approach. Confidence intervals can be calculated for a mean, proportion, or a population estimate. Examples include total number of individuals within the sampled area, mean number of individuals per unit area, the proportion of quadrats (generally rectangular plots used in ecological and population studies) occupied by the species, the mean height or weight of individuals within your sampled population, the proportion of occupied nesting boxes, the mean number of motorcycle tracks per unit area, etc.

If your management objective is a target or threshold objective, it is sufficient to estimate the parameter (mean, total, or proportion) and construct a confidence interval around the estimate. The analysis required is to calculate the sample statistic (mean, total, or proportion) and the confidence interval (the desired confidence level should be specified in your sampling objective). Any basic statistics book will instruct you on how to construct confidence intervals. Once the confidence intervals are calculated, the mean and confidence interval of each sample can be compared to the target or threshold to determine if action is necessary or if the objective has been reached.

For example, your management objective is to maintain a population of at least 2000 individuals of *Nectophrynoides asperginis* (the Kihansi Spray Toad) in the Upper Spray Wetland of the Lower Kihansi Gorge over the next 5 years. Your sampling objective is to annually estimate the population size of *Nectophrynoides asperginis* at the Upper Spray Wetland and be 95% confident that the estimate is within 250 toads of the true population total. This is a threshold objective, because you are concerned with the population falling below the threshold. Therefore, data analysis consists of estimating the population size from the sample mean (by multiplying the total number of possible sampling units by the sample mean) and calculating the confidence interval for this estimate.

The estimated total and confidence interval are then compared to the threshold of 2000 toads. If both the estimated total and lower bound of the confidence interval are above the threshold, you can be confident (relative to the alpha level chosen) that you have met your objective. If both the estimated total and upper bound of the confidence interval are below 2000 toads, you can be confident (again relative to the selected alpha level) that you have failed to meet your objective. Less clear are situations where the threshold value is included within the confidence interval, with the estimated total either above or below the threshold. One way to address this problem is to decide that if any part of the confidence interval crosses the threshold you will take action, based on the possibility that the true parameter has crossed the threshold. This minimizes the risk that one will fail to take action when action is needed.



Bleached coral due to warming waters (Source: D. Brumbaugh)

Remember, however, that the size of the confidence interval depends on the confidence level you choose, the degree of variability in your sampling data (as expressed by the standard deviation), and your sample size. Thus, an inefficient sampling design and small sample size will result in much wider confidence intervals, which in turn will result in complicated situations. Good sampling design and reasonable sample sizes will facilitate interpretation by making narrower confidence intervals and reducing the likelihood that threshold values will fall within the confidence interval. These are complicated concepts so do not hesitate to consult with someone with statistical training if you need help with confidence interval estimation or data interpretation.

Detecting Change With Significance Tests

If your management objective requires detecting change in some average value (such as a mean or proportion from one time period to another), then your statistical analysis should consist of a significance test, also called a *hypothesis test*. This situation often occurs in monitoring and involves analysis of two or more samples from the same monitoring site at different times (usually in different years, before and after management). The hypothesis of interest is that of no change; it is called the *null hypothesis*.

The major question asked in hypothesis testing is whether there has been change in the parameter of interest over a particular period. This parameter is often the mean, but we will also look at situations where the parameter is a proportion. If a change has occurred, the direction of change is a question usually (but not always) of equal importance. Significance tests are used to assess the probability of an observed difference being real or simply the result of the random variation that comes from taking different samples to estimate the parameter of interest. You can apply the material in this section in conjunction with any standard statistics book and, in particular, any computer software package that performs simple

Table 1. Summary of statistical tests available to analyze typical monitoring data		
Purpose of text	**Parametric Test**	**Nonparametric Test**
Testing for change between two years; samples independent; not frequency data	Independent sample t-test	Mann-Whitney U test
Testing for change between two years; samples paired (permanent sampling units); not frequency data	Paired t-test	Wilcoxon's signed rank test
Testing for change between two years; samples independent; frequency data	None available	Chi-square Test (2x2 contingency table)
Testing for change between two years: samples paired (permanent sampling units); frequency data	None available	McNemar's Test
Testing for change between 3 or more years; samples independent; not frequency data	Analysis of Variance; Independent-sample t-tests with Bonferroni correction	Kruskal-Wallis test; Mann Whitney U test with Bonferroni correction
Testing for change between 3 or more years; permanent sampling units; not frequency data	Repeated Measures Analysis of Variance; paired t-tests with Bonferroni correction	Friedman's test; Wilcoxon signed rank test with Bonferroni correction
Testing for change between 3 or more years; samples independent; frequency data	None available	Chi-square test (2 x 3 contingency table)

statistical tests. We have not presented detailed formulas in the interest of focusing on concepts.

One important distinction to make is whether the significance tests are for independent vs. paired samples. *Independent samples* are ones in which different sets of sampling units are selected randomly (or systematically with random starts) in each year of measurement. *Paired samples* are those in which sampling units are randomly selected only in the first year of measurement. The sampling units are then permanently marked, and the same (or at least approximately the same) sampling units are measured in the subsequent monitoring year. We make this distinction because different significance tests are used for independent versus paired samples.

Another important distinction to make is whether the data are *parametric* or *nonparametric*. Data that are parametric are typically those that form an approximately "bell-shaped curve" when their frequencies are plotted. Non-parametric do not display this characteristic pattern, e.g., count data that have many zeros and a few counts > 0. This distinction is important because different kinds of statistics are used to analyze parametric versus nonparametric data.

The approaches described above are basic ones used for detecting change in monitoring data as well as estimating sampling needed for effective monitoring at a given point in time and for detecting change over time if some pilot data are available. There are many other approaches to sample size and change estimation more suited to complex monitoring designs (e.g., see Elzinga et al., 2001, Table 1); however, the basic methods presented here will suffice for most situations.

Data Management and Communicating Monitoring Data

A successful monitoring project, be it a biological- or threats-based program, is characterized by three traits. First, it is well designed, and technically feasible and defensible. Second, it is implemented as planned in spite of changes in personnel, funding, and priorities. Third, the information from a successful monitoring program is organized, archived, analyzed and communicated. In the end, the information is applied, resulting in management changes or validation of existing management.

All three of these traits depend on clear communication and adequate documentation over the life of the project. Good design is usually a product of collaboration with stakeholders, other specialists, and help from experts. Consistent implementation requires the support and knowledge of managers and documentation of methods to survive personnel changes. Finally, application to management decisions requires communication of results. A monitoring project that simply provides additional insights into the natural history of a species, or that languishes in a file read only by the specialist, does not meet the intent of monitoring. Not incidentally, extensive monitoring programs rapidly accumulate vast amounts of information. Organizing these data so that they can be analyzed and quickly communicated is a substantial task that involves considerable planning unto itself.

To communicate effectively, results of monitoring should be analyzed each year (or each year data are collected) and reported in a short summary. Analyzing data as soon as they are collected has several benefits. The most important is that analysis is completed while the fieldwork is still fresh. Questions always arise during analysis, and the sooner analysis takes place after the field work the more likely those questions can be answered. Analysis after each data collection episode also means that the monitoring approach will be assessed periodically. Periodic assessment insures a long-term monitoring project against problems of inadequate precision and power, and problems of interpretation (Elzinga et al., 2001). Cooperators should create a management plan and schedule times to get together periodically to review data as a project moves along. The timings of these meetings should be outlined in the project goals to ensure that the meetings transpire.

At the end of the specified monitoring period, or when objectives are reached, results should be presented in a formal monitoring report. This report provides a complete document that describes monitoring methods and results, and should be distributed to interested parties. It offers a complete summary of the monitoring activity for successors, avoiding needless repetition or misunderstanding of the work of the predecessor. Finally, a professional summary lends credibility to the recommended management changes by presenting all of the evidence in a single document.

Terms of Use

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Glossary

Adaptive management: a way of thinking about and implementing natural resource management that recognizes that any management we impose on the system can be viewed as an experiment that we can learn from.

Biological monitoring: tracking the biological state of the target condition.

Confidence interval: an interval used to estimate the likely size of a population parameter.

Hypothesis test: a statistical test designed to measure the likelihood that observed results occurred because a hypothesis was valid as opposed to due to random chance (compare with Null hypothesis).

Implementation monitoring: tracking progress in accomplishing project activities to ensure that project activities are being completed.

Independent sample: sample in which different sets of sampling units are selected randomly (or systematically with random starts) in each year of measurement.Management goals: specification of the general types of conditions or trends desired in resource conditions.

Monitoring: the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective.

Nonparametric: Data that do not form an approximately "bell-shaped curve" ("normal curve") when their frequencies are plotted.

Null hypothesis: the hypothesis that an observed difference (as between the means of two samples) is due to chance alone and not due to a systematic cause. (Merriam-Webster Online Dictionary: www.m-w.com)

Paired sample: sample in which sampling units are randomly selected only in the first year of measurement.

Parametric: Data that form an approximately "bell-shaped curve" ("normal curve") when their frequencies are plotted.

Power: the ability of a statistical test to reject the null hypothesis (see below) when it is actually false. The power measures the probability of not committing a type II statistical error. (Adapted from Statistics Glossary: http://www.cas.lancs.ac.uk/glossary_v1.1/main.html)

Threats monitoring: tracking of threats to the target condition.

Type I statistical error: concluding incorrectly that the populations we sampled do not actually differ because we drew unrepresentative samples by chance giving the mistaken appearance of a difference.

Type II statistical error: wrongly concluding that there is no difference between sampled populations when in fact we simply failed to sample adequately enough to detect it.

Protected Areas and Biodiversity Conservation I: Reserve Planning and Design

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Source: K. Frey

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Protected Areas and Biodiversity Conservation I: Reserve Planning and Design

Eugenia Naro-Maciel, Eleanor J. Sterling, and Madhu Rao

This module is the first in a two-part series entitled *Protected Areas and Biodiversity Conservation*. The objective of this module is to introduce the topic with a theoretical focus, covering the rich and extensive body of literature focusing on protected area (PA) objectives, design, and planning. Ultimately, however, the implementation and effectiveness of PAs are influenced by diverse social, economic, and political factors. Therefore, the second module in the series, *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*, elaborates on management and human aspects of PAs, including policy, governance, financing, enforcement, efficacy, monitoring, and the future of protected areas. For complementary information pertaining to PAs in the marine *realm*, please see the NCEP module *Marine Protected Areas and MPA Networks*.

Introduction

A protected area is a "clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values", according to the definition of the *World Conservation Union (IUCN*) (Dudley, 2008). While other concepts may have been adopted by individual states or organizations, the IUCN definition of a protected area is generally accepted around the world. Protected areas, also known as parks or reserves, have been established at international, regional, national, state, and municipal scales, and many are linked as *networks* or systems.

Historical Origins of Protected Areas

Protected areas have deep historical roots: they have existed in varied forms in diverse ancient cultures, dating back to early pre-agrarian societies in Asia and the Near East (Allin, 1990; Runte, 1997). Chinese and South American civilizations from 3000 years before present have recorded decrees setting aside land to protect plants and animals (Sterling, 2002). Sacred forest groves that prohibited all forms of extractive use represent an early manifestation of protected areas (Chandrashekara and Sankar, 1998). Royalty created reserves, such as land set aside for game hunting, to exclude commoners. The unparalleled scale of ecological change stemming from the rise of colonialism and European expansion spurred conservation action and protected area establishment. Many of these colonial European measures and philosophies were built on early Indian and Chinese principles of conservation (Sterling, 2002). The establishment of the first national parks in the United States, such as Yosemite and Yellowstone, stemmed from a philosophy that valued these areas as grand monuments (Runte, 1997). The rise of this "national parks movement" in the United States is believed by some to have occurred in response to the industrial revolution that set humankind upon a course altering natural *landscapes* at a prodigious rate. The rapid and unprecedented transformation of the land provoked a call for the preservation of what was so rapidly lost (Runte 1997).

Protected Areas Today: Type and Extent of Coverage

Protected areas form the cornerstone of biodiversity conservation efforts worldwide (Margules and Pressey, 2000). A global system of PAs currently protects more than 105,000 sites over approximately 20 million km2, covering close to 13 percent of the planet's land area (Chape et al., 2005). In contrast, in 1982 this network was reported to encompass only 3.5% of the planet's earth surface. Most of the current PAs are terrestrial, while marine areas protect some 2 million km2, only about 0.5 - 0.6 percent of the world's oceans (Chape et al., 2005). The United Nations List of Protected Areas contains updated information on these protected areas (http://www.unep-wcmc.org/protected_areas/UN_list/index.htm), as does the World Database on Protected Areas (http://www.wdpa.org./Default.aspx).

More than 4,500 PAs have been established under various global treaties and conventions, including World Heritage Sites and Man and Biosphere Reserves (Table 1). PAs are also a focus of other international agreements, including the Convention on Biological Diversity (CBD), the Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar), and the Convention on the Conservation of Migratory Species of Wild Animals (CMS). The United Nations Convention on the Law of the Sea (UNCLOS) defines national rights to territorial seas, a necessary precursor to Marine Protected Area (MPA) establishment (see also NCEP module *International Treaties for Marine Conservation and Management*).

On a regional level, there are transboundary protected areas and networks. The transnational Turtle Islands Heritage Protected Area in the Philippines and Malaysia, for example, was implemented to protect regional populations of highly migratory sea turtles. Recognizing that conservation issues often transcend state borders, the Association of South East Asian (ASEAN) Declaration on Heritage Parks and Reserves (Bangkok, 1984) is designed to protect eleven sites in the nations of Brunei Darussalam, Indonesia, Malaysia, the Philip-

Table 1. Types of Protected Areas Included in the Global System (UNEP, 2003)
Each entry in the United Nations List of Protected Areas typically includes information for each country regarding PA name, geographic coordinates, size, IUCN category if applicable, and year of designation.

PA Type	Examples (Chape et al., 2003)
National Sites - areas of national designation	National parks, nature reserves, wildlife sanctuaries
International Sites - areas designated by international instruments, or treaties	**World Heritage Sites.** The Convention Concerning the Protection of the World Cultural and Natural Heritage aims to protect areas of outstanding cultural, natural, or mixed value, fostering international cooperation in safeguarding these important areas. The Convention was established in Paris in 1972, and entered into force in 1975.
	Man Biosphere Reserves. The United Nations Educational, Scientific and Cultural Organization's Man and Biosphere (UNESCO-MAB) Reserves are globally recognized ecosystems where biodiversity conservation and sustainable use are joint goals. These terrestrial and marine sites are "designed to promote and demonstrate a balanced relationship between people and nature". Reserves are nominated by national governments and remain under their sovereign jurisdiction.
	Wetlands of International Importance (Ramsar Sites). The Convention on Wetlands of International Importance Especially as Waterfowl Habitat (Ramsar, Iran, 1971) provides a framework for international cooperation in the conservation of wetland habitats in signatory states' territories. The Convention was signed in Ramsar, Iran, in 1971, and entered into force in 1975 (Box 2).
	European Commission Directive on the Conservation of Wild Birds (Birds Directive, 1979). Designates Special Protected Areas (SPAs) declared by European Union Member States in response to the Birds Directive to protect avian fauna and their habitats. The Birds Directive entered into force in 1981 and imposes legal obligations on European Union states to maintain populations of naturally occurring wild birds at levels corresponding to ecological requirements, to regulate trade in birds, to limit hunting of species able to sustain exploitation, and to prohibit certain methods of capture and killing.
	Other PA-related regional agreements entailing park establishment. Biogenetic Reserves (Council of Europe); Specially Protected Areas of Mediterranean Importance (Barcelona Convention); Special Areas for Conservation (EC Habitats Directive), Baltic Sea Protected Areas (Helsinki Convention), Association of Southeast Asian Nations (ASEAN) Heritage Parks and Reserves (ASEAN Declaration on Heritage Parks and Reserves).

pines, and Thailand (www.aseansec.org/1491.htm). In addition, there are PA-related regional agreements for European sites, such as the Protocol Concerning Specially Protected Areas and Biological Diversity in the Mediterranean governed through the Barcelona Convention (1976), which designates Specially Protected Areas of Mediterranean Interest (www.rac-spa.org).

Protected area coverage varies greatly by nation. Within individual countries, areas may be designated for federal, state, or local protection with varying objectives. In the United States, for example, Nature Reserves, Wilderness Areas, National Parks, Natural Monuments, Species Management Seascapes, and Areas Managed for Sustainable Use together protect about 15.8 % of the total land area (World Resources Institute 2003, based on data from UNEP-WCMC 2003). For more information about the different types of PAs worldwide, please see Table 1, or consult the World Database on Protected Areas (http://www.wdpa.org./Default.aspx).

Reserves can be managed by governments, private entities, communities, or through cooperative arrangements. To learn more about the governance, effectiveness, and human aspects of PAs, please see our companion NCEP module *Protected areas and Biodiversity Conservation II: Management and Effectiveness*.

Protected Area Objectives

Biodiversity conservation is one major objective in protected area planning, and is the main focus of this module. An essential role of PAs is protecting biodiversity from extinction or threats. Protected areas may be implemented to conserve populations, species, or genetic diversity. They can protect habitats at *community, ecosystem*, *landscape*, *biogeographic*, and ecoregional scales, and safeguard vital *ecological processes*. PAs may also be designed to act as buffers against anthropogenic or natural uncertainty, including catastrophes and climate change.

Many parks are established for purposes other than protecting biodiversity. Parks have been chosen to protect *features of special interest*, such as water or scenery. Alternately, the goal of biological conservation can be coupled with diverse aims. Common *sustainable use* objectives include provision of *ecosystem services,* such as clean water and carbon sinks, and extraction of biological resources for subsistence or commercial use. Extractive Reserves in Brazil are one particularly well-known example, although there are others, where conservation and development are combined goals. These reserves were initially proposed by The Rubber Tapper's National Council, led by Chico Mendes until his widely condemned assassination (Ruiz-Perez et al., 2005). *Separation of conflicting activities* is the goal of the "Parks for Peace" initiative, which employs *transboundary reserves* as a tool in conflict resolution (IUCN, 2003). Protecting *cultural heritage* and *indigenous peoples, alleviating poverty*, and providing *recreation*, *education* and *spiritual benefits* are additional goals of PAs. Increasingly, parks are being designed to achieve multiple objectives and take the needs of stakeholders into account (see NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*).

IUCN Categories

The IUCN has defined six categories of terrestrial and marine protected areas according to management objectives (IUCN, 1994; Dudley, 2008). They range from **Category I,** aimed mainly at conservation of biological or geological diversity, to Category VI, managed principally for sustainable resource use (Table 2). In the global PA system, different categories of reserves are unequally represented in size and number, with smaller and less strict areas being more common (Chape et al., 2005). The IUCN categories were originally developed as a 'common language', to help communications and reporting about PAs. These categories serve the useful and needed function of standardizing designations that may vary by country, improving communication and enabling comparisons. The categorization further aims to help protected area agencies plan their systems, by describing a suite of different management approaches, and also more generally to publicize the importance and diversity of PAs.

IUCN and other organizations supported the two-year

Table 2. IUCN Categories of Protected Areas (Excerpted from Dudley, 2008)	
Category Ia	Strict nature reserve. Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.
Category Ib	Wilderness area. Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition
Category II	National park. Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
Category III	Natural monument or feature. Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.
Category IV	Habitat/species management area. Category IV protected areas aim to protect particular species or habitats and management reflects this priority. Many category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.
Category V	Protected landscape/seascape. A protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
Category VI	Protected area with sustainable use of natural resources. Category VI protected areas conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

'Speaking a Common Language' (SaCL) project to: 1) evaluate the impacts and effectiveness of the 1994 IUCN category system; and 2) examine what needs to be done to refine and promote the objectives-based PA categorization. Overall, the project has reaffirmed the conservation values and importance of the 1994 system. In some countries such as Australia, it has been relatively successful. However, the categories have been less well understood in other states.

A number of issues were found to warrant further clarification (Bishop et al., 2004):

1. It is not clear how to classify large PAs containing a range of *zones*, each with different management objectives;
2. Application of the category system in certain *biomes*, such as forest or marine areas, has proven problematic. This issue is especially acute in large marine protected areas where ecosystem scale management is sought;
3. Where one protected area lies within another (e.g. a strict reserve exists within broader landscape or seascape categories), each with its own category, 'double counting' may occur: for example, in the United Kingdom, some Category IV nature reserves are nested within Category V national parks; and
4. There is also some confusion about how to report transboundary protected areas. The SaCL project identified a number of potential improvements in the interpretation and the application of this system, and suggested the need to develop an updated edition of the 1994 guidelines to the category system (Bishop et al., 2004; NCEP module

Box 1. A Transboundary Protected Area Network

The proposed El Condor-Kutuku Conservation *Corridor* is an innovative transboundary network that includes-PAs of various IUCN categories. Located in long-contested areas in the "Cordillera del Condor " mountain range along the border of Peru and Ecuador, the initial project was conceived as a means of attaining cooperation and minimizing disputes. In the late 1990's, adjacent PAs were established on both sides of the border: the "El Condor Park" in Ecuador and the "Zone of Ecological Protection" and "Santiago-Comaina Reserved Zone" in Peru. The cross-boundary effort enabled protection of endangered, endemic, and migratory species, as well as ecosystem processes, while furthering peace through cooperation on conservation and sustainable development initiatives (Ponce and Ghersi, 2005).

Protected Areas and Biodiversity Conservation II: Management and Effectiveness).

More recently, questions have been raised about the interpretation of the IUCN PA definition, the relative importance and necessity of protecting biodiversity in PAs as an objective, issues of balancing reserves of different categories, and IUCN roles in governmental use of these categories

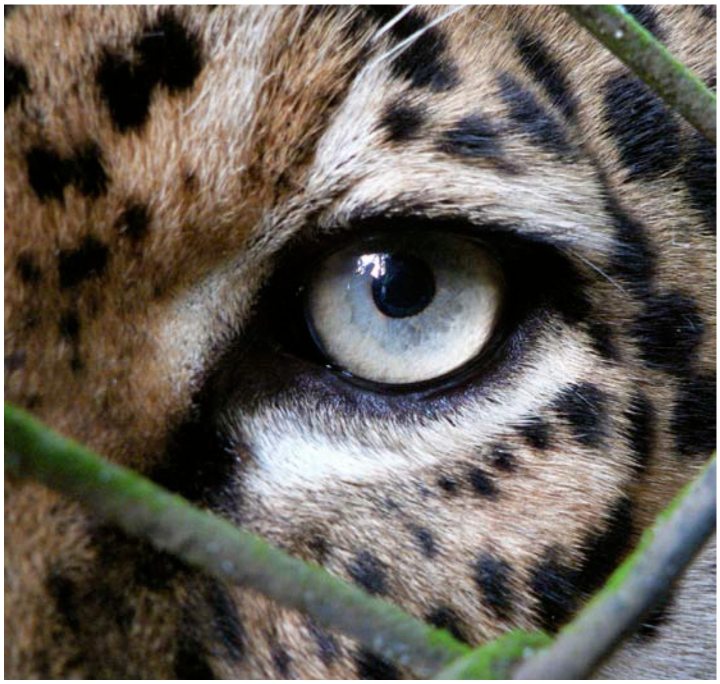
All of these issues have led to the formulation of revised IUCN definitions both for what is a protected area, as well as the various PA categories (Dudley, 2008; Table 2; see also see also NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*).

PA Networks

Separate protected areas can be linked into a network unified by common goals, shared management, and/or biophysical connections. Networks can be designed to increase the biogeographic representation of habitats and area of coverage. They can also be created to preserve key linkages, maintain genetic diversity, and as a buffer against environmental variation. In the marine realm, PA networks commonly consist of individual sites connected by *dispersal* or migration of marine organisms, ocean currents, or ecosystem processes (NAS, 2001). The conservation value of a network is often greater than if each PA were ecologically isolated. Linking reserves into networks can expand the potential of individual sites to achieve diverse management objectives over a broader area. This also accommodates competing interests and socioeconomic constraints, facilitates enforcement, and precludes all reserves in a country from being no-take. Brazil's National System of Nature Conservation Units (SNUC) is an example of a national effort to protect threatened and biologically diverse areas (Silva, 2005), and international PA networks (Box 1) can also be effective.

Surrogates for Reserve Selection

Many parks are designed to conserve specific threatened organisms. Sites may be chosen to protect taxa listed on the IUCN Red List, which includes species at risk of extinction (http://www.redlist.org). Focal species may also be used as surrogates, or tools, to conserve other groups and ecosystems as well. Charismatic taxa may serve as *flagship species*, garnering public attention and support that can then be used to protect their ecosystems (Caro and Doherty, 1999). These flagship species are often charismatic mega-vertebrates, such as jaguars, that attract public support (see NCEP module *The Management of Conservation Breeding Programs in Zoos and Aquariums*). In Belize, for example, the Cockscomb Basin area was set aside as a Jaguar Preserve and a wildlife sanctuary. Another option is to focus protection on *indicator species*, or "organism[s] whose characteristics (e.g., presence or absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest" (Landres et al., 1988). Protection of communities or habitats can also be achieved by conserving *umbrella species*. These are organisms, such as migratory wildebeest (*Connochaetes taurinus*), whose habitat requirements and range also encompass the needs of other conservation targets (Caro and Doherty, 1999). Multiple species are likely to serve as better "umbrellas" than individual taxa (Lambeck, 1997). PAs may also be designed to protect organisms that are important to ecosystems. *Keystone species* such as figs (Moraceae), mast-fruiting dipterocarps (Dipterocarpaceae) in Asia, or habitat-forming organisms like corals, have important ecological roles that are greater than would be expected based on their abundance (see NCEP module *Why is Biodiversity Important?*; Caro and Doherty, 1999). A related but different concept is that of *landscape species* such as forest elephants, which "use large, ecologically diverse areas and often have significant impacts on the structure and function of natural ecosystems" (Redford et al., 2000). Conservation of these organisms aims to protect additional species and habitats, however in this case the species' requirements are employed to define the target conservation landscape (Sanderson et al., 2002). Landscape species are sensitive and susceptible to human impacts, and use of multiple taxa may enhance effectiveness of this strategy (Copolillo et al., 2004).



The Jaguar, *Panthera onca*, is a flagship species for the conservation of its habitat in the Amazon (Source: F. Laso)

Reserves to Protect Specific Habitats

Certain habitats with exceptional characteristics and/or threats may be chosen for protection in PAs. Coral reefs, the rocky intertidal, mudflats, seagrass beds, and wetlands (Box 2) can be considered at-risk marine systems worthy of conservation in PAs (Airame et al., 2003). Significant natural communities, for example pine barrens, freshwater tidal marshes, floodplain forests, chestnut oak forests, and talus cave communities in New York (Howard et al., 2002), may be chosen for protection in reserves. Site choice may be based on habitat characteristics, including substrates, such as hard or soft sediments, and coastline features, for example sandy beach or rocky coast (Airame et al., 2003). Depending on data availability and scale, aspects of species distributions and demography, such as abundance, distribution, and population growth, are also considered in selecting habitats for protection (see Airame et al., 2003). In the absence of reliable comprehensive data, environmental, climatic or physiographic surrogates such as rainfall, temperature, and vegetation structure can be employed. It is important to consider how well selected sites represent the spatial area and resources used by a community of species.

Reserves to Protect Ecological Processes

Maintaining or restoring *ecological processes* or *ecosystem functionality* are important considerations in conservation planning. Ecological processes, such as streamflow, floodplain, fire, and erosion processes, are those that create, build, or shape habitats and systems. Maintaining community-level interactions, such as between producers and consumers or partners in mutualism, and addressing natural levels of disturbance, are key elements of an ecological approach to foster natural processes and change in a reserve (Scott and Csuti, 1997).

Box 2. Convention on Wetlands of International Importance (Ramsar)

The Convention on Wetlands of International Importance (Ramsar, Iran, 1971) addresses the conservation of exceptional and/or threatened wetland habitats and sites. Wetlands are defined by the Convention as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres"… and "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands", as well as human-made wetlands (www.ramsar.org). The Ramsar Convention provides a framework for the protection and responsible use of wetlands at national and international levels. It places general obligations on contracting Parties, or signatory states, relating to the conservation of wetlands throughout their territories, with special emphasis on wetlands of the List of Wetlands of International Importance. Ramsar was signed in Iran in 1971, and entered into force in 1975. Currently, there are 153 contracting parties to the Convention, which covers 1629 wetland sites protecting about 1,456,204 km2 (www.ramsar.org). For additional information on other treaties, please see Table 1 and the NCEP module *International Treaties for Marine Conservation and Management*.

Protection of an area of appropriate size and shape, as well as adequate number of individuals, is important for population viability. Large PAs may be required to maintain metapopulation dynamics, preserve intact and/or functioning ecosystems, and to accommodate wide-ranging species.

Areas of High Taxanomic Diversity

Priority areas may be selected to preserve *species richness* or *species diversity*. Species richness refers to the number of species present at a site, while species diversity is the species number weighted by an indicator of abundance, for example population size or biomass (see also NCEP module *What is Biodiversity?*). Conservation priorities can be based on abundance, rarity, threat levels, *phylogenetic* or *evolutionary distinctiveness*, the extent to which assemblages represent regional diversity, or *endemism*. Combinations of these criteria are also employed; for example, conservation planners are increasingly interested in taxonomically rich and threatened sites that could be chosen to maximize cost-effectiveness. Concentrated, long-term and careful effort focused on such high priority areas may ensure that a large proportion of the world's biodiversity will escape extinction.

Currently, there are several global conservation priority-setting methods based on species distributions, threat levels, and financial considerations (Figure 1; reviewed by Brooks et al., 2006). These approaches tend to focus on irreplaceability, targeting areas with highly diverse and endemic plant, bird, or terrestrial vertebrate taxa. *Biodiversity Hotspots* have been identified that occupy only one to two percent of the earth's land surface, but are the exclusive home of one fifth of the world's plant species (www.conservation.org; Myers et al., 2000; Sechrest et al., 2002). Sites were designated terrestrial biodiversity hotspots if they contained at least 0.5 percent of the world's plant species and had lost at least 70 percent of their primary vegetation. The resulting 25 hotspots are home to 20 percent of the world's human population (IUCN, 2003), and on average 10 percent of these hotspots are a part of protected areas.

Some of these priority-setting approaches are considered proactive, focusing on sites with low threat but high irreplaceability, and others are reactive, prioritizing both threat and irreplaceability (Brooks et al., 2006). One example of a reactive approach is the Wildlife Conservation Society's (WCS) *Last Wild Places* (Sanderson et al., 2002). Last Wild Places are identified using biodiversity indices in combination with threat indicators, such as human population density, accessibility of the regions to human development, and land transformation

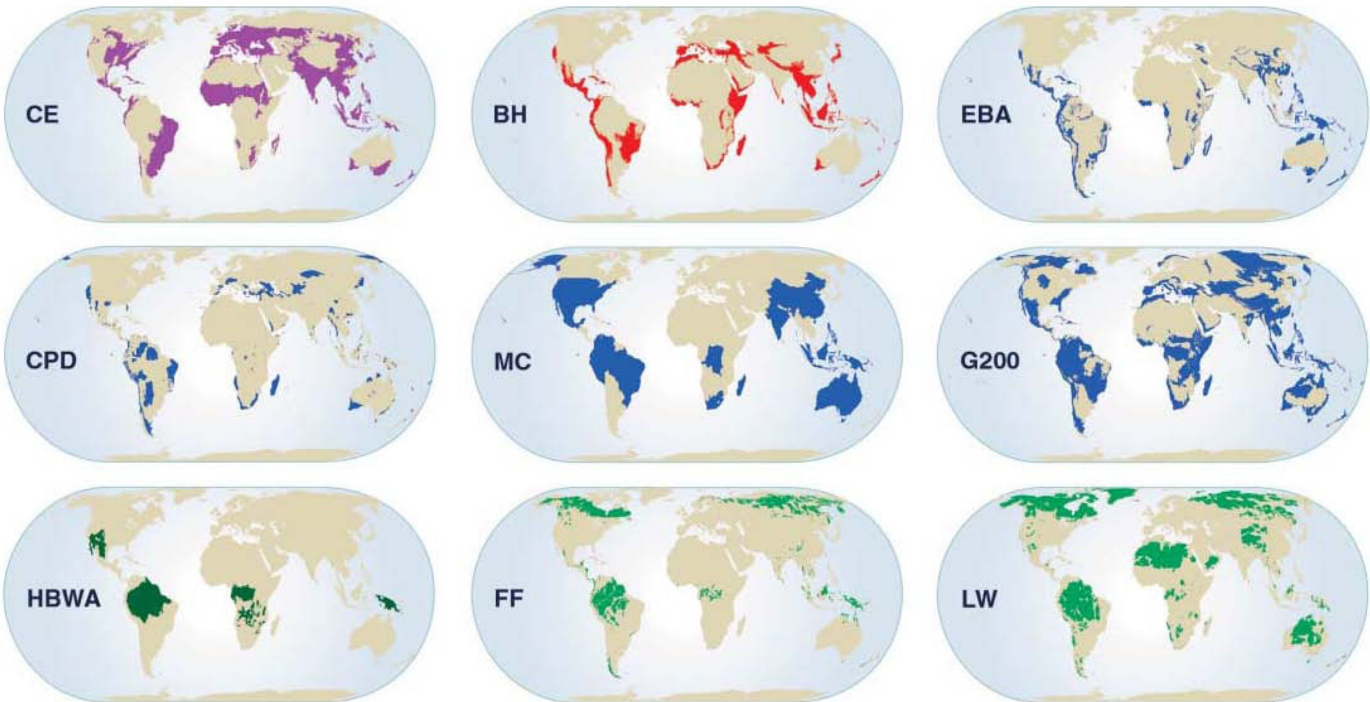


Figure 1. Maps of the nine global biodiversity conservation priority templates: CE, crisis ecoregions; BH, biodiversity hot spots; EBA, endemic bird areas; CPD, centers of plant diversity; MC, megadiversity countries; G200, Global 200 ecoregions; HBWA, high-biodiversity wilderness areas; FF, frontier forests; LW, last of the wild. (Source: Brooks et al., 2006)

(Sanderson et al., 2002).

For some purposes, the level at which conservation priority areas are defined may be too coarse for effective conservation planning, possibly failing to capture finer-scale variation (Olson et al., 2001). The entire Caribbean, for example, is considered one Biodiversity Hotspot (Myers et al., 2000). To address this, a hierarchical approach may be employed whereby smaller sites are evaluated for protection, sometimes within these larger areas. The World Wildlife Fund (WWF), for example, focuses on priority "*ecoregions*" (www.wwf.org; Olson et al. 2001). An ecoregion is "a large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (www.wwf.org). The *Global 200 Ecoregions* are the subset of terrestrial and aquatic ecoregions with exceptional biodiversity and ecosystem representation that are considered high priorities for conservation (Figure 1; http://assets.panda.org/downloads/ecoregions_map.jpg; Olson and Dinerstein, 2002). Recently, the WWF selected 19 Priority Places, including the Amazon rainforest, the Galapagos, the Congo Basin, the Coral Triangle, and Madagascar, of top conservation priority (www.wwf.org).

Methodological Limitations of Priority-Setting Exercises

Although such exercises are promising, it is important to consider their methodological limitations (reviewed in Brooks et al., 2006). One contentious issue is the difficulty in measuring taxonomic richness (Pimm and Lawton, 1998). Quantifying biodiversity requires expensive, expert inventories that are often not feasible (Howard et al., 1998). In practice, selected indicator groups, such as vascular plants, birds and butterflies, are assessed. Pimm and Lawton (1998) question how well patterns coincide between indicators and other elements of biodiversity. A site that contains many plant species, for example, may not be rich in other taxa, or contain rare organisms. Prendergast et al. (1993) found limited spatial congruence between taxonomic groups in Great Britain: areas rich for one taxon, such as butterflies, were not hotspots for others, such as birds. Similar limited overlap is reported for temperate and tropical areas (Kerr, 1997; Howard et al., 1998). Another controversial question pertains to which criteria are best suited to define hotspots. A comprehensive global study of birds assessed overlap of different hotspots defined by species richness, threat, or endemism, and found only limited congruence (Orme et al., 2005). In another approach, many rare species were found in "cold spots," sites of relatively low biological diversity that harbor threatened or uncommon ecosystems or species (Kareiva and Marvier, 2003). The additional question of source-*sink*, dynamics was raised by Hansen and Rotella (2002). A sink population requires net immigration to sustain itself. These individuals may come from a source population, characterized by net emigration. Protecting areas that are sinks, despite apparent abundance, may be counterproductive if the sources are threatened.

In reviewing the different priority setting methods, Brooks et al., (2006) acknowledge many of these issues, while emphasizing the importance of worldwide conservation planning to determine how financial resources should best be channeled. There are overlapping areas, such as in the tropics, identified in many of these distinct efforts, and Brooks et al. (2006) suggest these as promising initial recipients of global donor funds. The authors further highlight the need to focus conservation prioritization efforts at increasingly finer spatial scales, such as at the level of sites where PAs can be established.

Representation

Sites may be selected for protection because they are representative of biodiversity. Analyses of the global protected area system have been carried out to determine to what extent biodiversity targets are currently represented, and where new PAs should be established to achieve representative coverage (Box 3, Brooks et al., 2004; Box 11, Rodrigues et al., 2004a; 2004b). Although many land biomes and habitats are included in this system, others, such as lake systems and temperate grasslands, are not well represented (Box 3; Brooks et al., 2004). Over 90 percent of the existing parks are terrestrial, with MPAs protecting only 0.5 percent of the world's oceans. The largest nationally designated PA in the world is the North-East Greenland National Park, a site measuring 972,000 km2 and covered in large part by snow (UNEP-WCMC, 2003). In the United States, most of the productive and low elevation land is privately owned, so that many habitats and species occur outside of reserves (Scott et al., 2001). In a study of terrestrial vertebrates, 12 percent of species were not found in parks (Rodrigues et al., 2004a; Box 11).

In 1992, the Fourth World Congress on National Parks and Protected Areas, held in Caracas, Venezuela, established a target for conserving biodiversity by recommending "that pro-

Box 3. Representativeness of the Global PA Network

Twelve to thirteen percent of the planet is protected in reserves, but is this network representative? Brooks et al. (2004) summarized protected area coverage across each of the terrestrial biomes and biogeographic *realms* to identify bioregional gaps in the global PA network. Temperate conifer forests (25%), flooded grasslands and savannas (18%), and tropical or subtropical moist broadleaf forests (18%) are the most protected biomes. However, if only PAs in IUCN categories I through IV (Table 2) are considered, tundra (12%) emerges as the most protected biome. Temperate grasslands, savannas, and shrublands (5%), Mediterranean forests, woodland and scrub (6%) and tropical or subtropical conifer forest (6%) are the least protected biomes. Protection also varies among biogeographic realms. In relation to total area, habitat protection has been most substantial in the Neotropical (16%), Nearctic (16%), and Afrotropic (15%) realms, but less so in the Indo-Malay (10%), Palearctic (9%), Australasian (8%) and Oceanian (8%) realms.

tected areas cover at least 10 percent of each biome by the year 2000" (McNeely 1993). This target has been generalized to apply to individual countries and to the entire planet, and is commonly referred to as "the 10 percent rule". However, since biodiversity is not evenly distributed worldwide, the scientific basis and conservation value of uniform targets based on the percentage of the planet or its biomes that is protected have been questioned (Soule and Sanjayan 1998; Pressey et al., 2003). Contrary to frequent recommendations, current protection levels should not be used as a significant criterion to guide priorities for allocation of future conservation investments, as the percentage of area already protected in a given country or biome is a very poor indicator of additional conservation needs.

There are two broad emergent issues in PA design related to representation: 1) The global protected area system is far from representative, and filling the gaps in the existing system should be a high priority for conservation (Box 3; Box 11); 2) The percentage of the planet or its biomes that is protected is less important than PA location and management. Overall, uniform targets based on the percentage of area protected cannot be used to distinguish between regions that are sufficiently protected, and those that need additional conservation.

Climate Change

Protected areas may be planned to serve as buffers against unpredictable or catastrophic events. Climate change has been identified as an important emerging issue for protected area planning (Lemieux and Scott, 2005). Over the past 100 years, the global average temperature has increased, and is projected to continue to rise at a rapid rate. Although species have responded to climatic changes throughout their evolutionary history, a primary concern for wild species and their ecosystems today is the rapid rate of change. The synergism of rapid temperature rise and other stresses, in particular habitat destruction, could easily disrupt the connectedness among groups, potentially leading to a reformulation of species communities, and to numerous extirpations and possibly extinctions (Peters and Darling, 1985; Root et al., 2003). In many regions, in addition to climate change, human populations and the resulting pressures on ecosystems will continue to evolve, often in ways unfavorable to biodiversity. The interactions between these multiple changes will ultimately have major implications for conservation and protected area planning.

As climate changes, species might move into or out of parks and reserves, likely altering the species composition of PAs, with important implications for conservation (Peters and Darling, 1985). Recently, shifting range boundaries as a result of contemporary climate change have been observed for multiple species, underscoring the potential for climate change effects on species composition at fixed geographical points such as protected areas (Parmesan and Yohe, 2003; Root et al., 2003). It is likely that the amount of range under protection in PAs will change, depending on the new species' occurrence relative to the geographic location of PAs. Overall, the present ranges and the present degree of protection of many species will likely rapidly erode as a result of climate change. Many studies use bioclimatic models to calculate the effect of climate change on species representation in protected areas (Box 4).

Designing Reserves for Biodiversity Conservation

Once PA objectives have been defined, a subsequent step in the systematic planning process is reserve design. This encompasses size, shape, *replication,* complementarity, and connectivity of PAs. The Theory of Island Biogeography, developed initially for true oceanic islands (MacArthur and Wilson, 1967), has substantially impacted PA design especially as regards reserve size and connectivity (Box 5). The theory postulates that, as the area of an island becomes larger, the number of species increases, while extinction rates decrease. The number of species results from a balance between the colonization rate of new taxa, and the extinction rate of resident groups. The

Box 4. Modeling Effects of Climate Change in PAs

Current and future modeled ranges may be used to calculate the area of a species' range under protection at a given time, keeping in mind that a species' modeled potential range may not precisely match its actual range (Pearson and Dawson, 2003).

In a study based in the Cape Floristic Region of South Africa, Hannah et al., (2005) show that a substantial number of species may lose all suitable range if climate changes. Many species may lose all representation in PAs as a result, while a much larger number may experience major loss in the amount of their range that is protected. The spatial distribution of PAs, particularly between lowlands and uplands, is an important determinant of the likely conservation consequences of climate change.

A study by Lemieux and Scott (2005) examined potential impacts of climate change in Canada's protected area network, which consists of 2,979 PAs. Their vegetation-modeling results project that 37 to 48 percent of Canada's reserves could experience a change in terrestrial biome type under doubled atmospheric carbon dioxide conditions.

In another study, Tellez-Valdes and Davila-Aranda (2003) examined the effects of climate change on the future distribution patterns of 20 species of Cacti in a protected area of Mexico. They used a floristic database and a bioclimatic modeling approach to examine 19 climatic parameters, and to obtain the current potential distribution pattern of each species. Their main findings include a drastic distribution contraction in which most of the remaining populations will inhabit restricted areas outside of reserve boundaries or will become extinct.

In a fourth study, Thomas et al., (2004) model species-distribution responses to a range of climate-warming scenarios, and use a novel application of the species–area relationship. They estimate that 15 to 37percent of modeled species in various regions of the world will be committed to extinction by 2050.

number of species tends to decline in fragmented or isolated habitats, as immigration rates are lowered due to barriers, and extinction rates tend to increase as areas diminish.

Size

Heated debates over optimal PA size permeated the literature of the mid-1970's, dwindling by the mid-80's (Soulé and Simberloff, 1986; Bierregaard et al., 2001). Controversy centered on the benefits of "**S**ingle **L**arge **O**r **S**everal **S**mall" parks, commonly referred to as SLOSS. Given limited resources, should we choose one large reserve or several small ones of the same total size? SLOSS is currently less of a point of argument, partly because the answer depends on the context, and partly because political and fiscal realities, rather than ecological models, often determine reserve size - today, about 60% of PAs are smaller than 100 km2 (Chape et al., 2003).

Larger parks are typically advantageous because contiguous areas are often better able to preserve intact communities of interdependent taxa and maintain viable populations of species that occur at low population densities, especially large vertebrates. Large PAs tend to include more organisms and generally house a greater diversity of species and habitats than individual small reserves. Larger PAs can also accommodate population growth, and support bigger groups in which the deleterious effects of small populations are countered. These harmful factors include inbreeding, loss of genetic diversity,

Box 5. The Biological Dynamics of Forest Fragments Project

This seminal empirical reserve design study is a classic example of how Island Biogeography Theory has been applied to conservation. The project stemmed from Thomas E. Lovejoy's idea to research forest fragmentation in the Brazilian Amazon, where landowners were required by law to maintain forests on half of their property. Within an area planned for cattle ranching, plots of various sizes and degrees of isolation were designed to assess dynamics of forest fragments, mostly in the early 1980's (Bierregaard Jr. et al., 2001). Major findings included the generally negative effects of land fragmentation, isolation, and small patch size on many species over time. To minimize harmful effects of fragmentation, it was suggested that roads be avoided, simple land-use guidelines be employed throughout the deforestation process, and that the human context of deforestation be considered in planning conservation strategies (Bierregaard Jr. et al., 2001; NCEP module *Ecosystem Fragmentation and Loss*).

The shape, size, and degree of fragmetation/isolation of a forest patch restricts which species may inhabit it (Source: K. Frey)

and increased extinction risk (see NCEP module *Small Population Phenomena*). In western North American parks, for example, an inverse relationship between mammal extinction rates and park area, consistent with Island Biogeography Theory, was revealed (Newmark, 1995). The negative effects of environmental disturbance and catastrophes may be buffered in large areas. These may also be better able to support functioning ecosystems and accommodate shifts in species distributions caused by processes such as climate change. Large sites may be required to maintain meta-population dynamics and accommodate wide-ranging or low-density species.

A system containing several small PAs, on the other hand, also provides many benefits such as increased representation, replication, and feasibility. Multiple reserves are recommended to buffer against uncertainty and catastrophe, and replication of sites may be more feasible in a network of small parks. It may be possible to conserve a greater variety of taxa, including endemic species, in a system of small reserves that protects multiple heterogeneous ecosystems, than in a single large reserve (Soulé and Simberloff, 1986). This is true even though each individual small area may contain fewer species. Importantly, small sites may be sufficient to protect certain target species with small ranges, such as plants, small mammals, and insects. In fact, some groups characterized by low dispersal, such as amphibians and mollusks, naturally occur in small, isolated populations.

There is no single answer to the SLOSS debate, as optimal park size will vary depending on organismal and habitat characteristics, and what constitutes a small or large reserve can depend on the circumstances. Many current approaches to reserve size choice are therefore goal-based. A combination strategy, in which large PAs maintain functional ecosystems and large-scale processes, while small reserves protect rare elements such as certain species, may work best. This is the essence of the "coarse filter-fine filter" strategy advocated by The Nature Conservancy. In a "course filter" approach, many species are automatically conserved as a result of protecting their ecosystems. However, some taxa are not necessarily conserved in this approach, requiring a complementary "fine-filter" strategy targeted to their specific needs.

Shape

PAs can be designed in shapes that maximize compactness, minimizing boundary length (Andelman et al., 1999). This is desirable to counter potentially harmful "*edge* effects", the physical, biological, synergistic, or anthropogenic (Box 6) processes that occur in edge environments. Edges are border areas, or ecotones, that mark the transition between two different habitats (see NCEP module *Ecosystem Loss and Fragmentation*). Edge effects can include alterations in microclimate, species composition, abundance, and distribution, and species interactions such as predation and competition (Matlack and Litvaitis 1999; NCEP module *Ecosystem Loss and Fragmentation*). Biodiversity and habitat quality may be negatively affected in these areas, and extinction has been linked to edge effects at park borders, especially for wide-ranging species (Woodroffe and Ginsberg, 1998). Although edge environments may be beneficial to invasive or certain generalist species, a general PA design principle is to avoid them because of their generally harmful effects on conservation targets. Therefore, because edge effects tend to be more extensive in areas where the perimeter to area ratio is higher, such as in reserves of elongated shape, and lessened in areas of rounder shape, the latter may be favored in reserve design.

Replication

An important design criterion is to represent key features more than once. Multiple representation of species or ecosystems in reserves safeguards conservation targets from environmental change and catastrophic stochastic events, such

Box 6. Edge Effects of Eurasian Badgers in Spain

Carnivores such as the Eurasian Badger (*Meles meles*) are particularly vulnerable to anthropogenic edge effects such as road kills, hunting, poaching, or incidental trapping (Revilla et al., 2001). These badgers were monitored using radio telemetry to study edge effects at the Doñana National Park, Spain. This reserve was chosen because of its extensive biological diversity, its geographic location, and historical preservation from development as a game preserve. Causes and rates of mortality were studied for two badger populations, one of which occurred near the park border, while the other was further away. The study revealed that most badger mortality (about 85%) was due to poaching and road kills. Of the two populations studied, the one closer to the edge of the park suffered the most mortality, and population density was about three times higher in the interior population. Statistical analyses revealed that distance from the park's boundary affected the likelihood of survival. The researchers therefore concluded that, although reserves are beneficial to the species, their effectiveness is reduced because of the mortality along the edges. Therefore, it was recommended that reserves be enlarged, and human activities contributing to these edge effects be curtailed (Revilla et al., 2001).

Box 7. Complementary Reserve Systems in Africa

The forest reserve network in Uganda was planned to maximize habitat and species representation through complementarity. By alternately adding sites, it was possible to design a network capable of protecting about 96 percent of indicator groups. Despite the limited spatial overlap in species richness of butterflies, moths, and plants, sets of complementary forests chosen using one indicator taxon generally represented the species richness of other groups as well (Howard et al., 1998; 2000).

In South Africa, however, low congruence was detected in complementary networks selected for different taxa, such as birds and mammals, as well as butterflies, plants, and various other invertebrates (Van Jaarsveld et al., 1998). Neither did complementary networks there overlap with areas of high and/or low species richness, species rarity, or indicator species.

Although complementary networks and use of indicators may be promising if, for example, most organisms share similar biogeographical patterns (i.e. large numbers of species are restricted to northern or southern sites (Pimm and Lawton, 1998; Howard et al., 1998), they are not representative in all cases. Therefore, PA networks designed to be complementary should probably include multiple species and the full range of available or necessary data, unless evidence indicates that indicator species capture patterns of overall diversity and threats.

as storms, hurricanes, fire, and oil spills, that could destroy the last remaining site or population. Most Kemp's Ridley sea turtles (*Lepidochelys kempii*), for example, nest at a single site in Rancho Nuevo, Mexico. This species is thus considered highly vulnerable to extinction due to the severe consequences to the species if any natural or human disturbance affects that breeding colony. Efforts were therefore undertaken to establish a companion nesting beach at the Padre Island National Seashore, Texas, USA (Shaver, 1989). Replication is also important for assessment purposes, providing increased sample sizes and lowering the potential for analytical error due to over-reliance on any one site. Human use of protected areas also supports replication as a design principle. If, for example, people heavily use one particular habitat, such as a lakeshore, protection of additional similar sites may alleviate harmful anthropogenic effects.

Complementarity

Conserving groups of sites selected to maximize complementary species distributions or habitats is a promising strategy for increasing overall representation (Howard et al., 1998; Howard et al., 2000). Complementarity is measured as the extent to which a reserve advances the goal of representing biodiversity in a network, by contributing unique elements. Networks are designed so that targets, such as species, absent at one site are present at another, thus resulting in a set that together (rather than individually) maximizes species richness. The process involves selecting the area with the highest species diversity (or other selected criterion), then discounting groups present there in the choice of the next most species-rich area, for example, and so on (Brooks et al., 2001). Complementarity has been applied at continental and national levels in Africa (Box 7; Howard et al., 1998; 2000; Brooks et al., 2001).

Isolation and Connectivity

Dispersal and migration are processes that connect populations. Movement is often a natural part of organismal development, such as dispersal from nursery grounds to feeding areas, and finally to breeding sites. Daily movements, annual migrations, and range shifts in response to climate change are additional kinds of movements. In addition, certain groups may constitute a metapopulation, in which some areas are "sources" of dispersing individuals, while others are "sinks" characterized by net immigration or mortality.

Natural patterns of dispersal and migration are increasingly disrupted, and protected areas are a promising way of countering fragmentation and ensuring population connectivity. Fragmentation, for instance caused by roads in a terrestrial environment, can directly cause mortality and block access to sites essential for different phases of organismal life cycles. Disruption of movement may be especially harmful when groups become small and isolated (see NCEP module *Biology of Small Populations*). Therefore, maintaining natural linkages among populations is an important consideration in reserve design. Considering the movements of organisms throughout their life cycles is necessary to ensure that reserves are placed to protect connections and all stages of development. Protecting sources is desirable for their contribution to population structure and abundance. Sinks, on the other hand, are potential candidates for sustainable resource extraction.

A common application of PA networks is using multiple reserves as stepping-stones for wide-ranging and migratory species, such as butterflies (Schultz, 1998). Genetic analysis of historical and contemporary red squirrels, for example, revealed that gene flow occurred between patches of pine forest in Great Britain (Hale et al., 2001). A stepping-stone approach, however, may be challenging for whales and other highly migratory species in which home ranges are vast, with much of the life cycle spent in unprotected high seas. To protect such species, PAs can be located in sites essential to their life cycles, such as nursery or breeding grounds. For some organisms, species-level legal protection might be necessary (see NCEP module *Endangered Species Management*). Other tools available include integrating areas outside the PA system into landscape-level planning for conservation (see NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*), or using corridors.

There has been much debate about the use of *corridors*, or protected strips of land designed to connect otherwise isolated habitat fragments (Hobbs, 1992; Beier and Noss, 1998). Joining separate areas using corridors may allow movement of organisms among habitats, potentially resulting in genetic exchange, increased species diversity, and interactions between taxa (Tewksbury et al., 2002). Corridors in fragmented pine forests, for example, facilitate plant-animal interactions (Tewksbury et al., 2002), as well as dispersal of birds, butterflies, and small mammals (Haddad et al., 2003). However at this stage, the corridor concept is more theoretical than proven in fact. The research results are considered insufficient in scale, taxonomic and ecological comprehensiveness, and susceptible to confounding effects (Hobbs, 1992; Tewksbury et al., 2002). Functional connectivity differs between species, and in some cases corridors have not convincingly enhanced linkages among groups (Haddad and Baum, 1999; Collinge, 2000). Further, corridors may serve as sinks, attracting organ-

Box 8. Large Mammals in African Parks

Various large mammals, including primates, elephants, carnivores, and ungulates, are protected within parks in Tanzania, Africa. As is common in many other parts of the world, protected areas there are becoming more isolated from each other and from their surroundings as human activities dominate the landscape. These reserves increasingly appear as islands in an otherwise human-dominated landscape. Island Biogeography Theory predicts that species will be lost as isolation increases and area decreases (MacArthur and Wilson, 1967). Using this theory, Newmark (1996) considered extinctions of large mammals in protected areas of Tanzania. As expected, an inverse relationship between extinction rate and park area was revealed, consistent with extinctions resulting to some degree from PA isolation. Corridors of land linking separate parks were proposed as a promising measure for countering these effects (Newmark, 1996).

isms into edge-dominated, predator-rich areas. They may be of limited utility to some forest organisms, such as sedentary or interior species. Resources invested in corridors could preclude other options, or be better employed elsewhere (Hobbs, 1992). Additional potentially negative impacts include spread of disease, pests, predators, invasive species, or fire (Hobbs, 1992). Even so, the balance of empirical evidence points to effectiveness of corridors in connecting landscapes (Beier and Noss, 1998; Box 8). In the face of uncertainty, maintaining natural habitat structure in the landscape through a monitored approach is advisable. This may include restoring natural links and employing corridors that are as wide as possible.

Zoning

Zoning is the spatial definition of activities permitted within delimited areas of a PA (Table 3). UNESCO Man and Biosphere reserves (Table 1; URL), for example, may be divided into core and buffer zones, with heavier restrictions on human use placed within the core, and regulated activities allowed in buffer areas (Figure 2). Other major zoning categories include Strict Reserve, Restricted Area, General Reserve, and Multiple-use area (Table 3; NAS, 2001; Villa et al., 2002). Most human activities, such as fishing, boating, and swimming, are not allowed in strict reserves, core areas, or no-take zones. These restricted areas provide refuge for wildlife, and may serve as controls to assess human impacts in other zones (NAS, 2001; Agardy 2000). Conflicting activities, such as extraction and recreation, may be spatially separated using zoning. In cases where objectives are compatible, zoning a site for more than one use can result in greater geographic coverage than if permitted activities were kept separate. Various pursuits, such as recreation and limited take, may be allowed in some multiple-use areas. Comparative analysis of zones can provide valuable information for research and adaptive management purposes (Agardy, 2000; NAS, 2001). However, there is no consensus regarding optimal zone size and spatial arrangement, and it is challenging to incorporate biological and scientific uncertainty into fixed zoning plans (Carr and Raimondi, 1999; Agardy, 2000; Villa et al., 2002). Zoning can therefore be year-round or seasonal, permanent or temporary. Successful zoning can be used to equitably accommodate divergent user interests and to achieve management objectives flexibly. The Great Barrier Reef Marine Park zoning plan is one of the most representative and comprehensive in the world (Box 9).

Box 9. The Great Barrier Reef Marine Park

The Great Barrier Reef Marine Park (GBRMP), which is about the size of Japan, is one of the largest and most diverse MPAs in the world. Zoning in the GBRMP is used to achieve biodiversity conservation, fishery management, sustainable use, tourism, shipping, and other goals (NCEP module *Marine Protected Areas and MPA Networks*; Fernandes et al., 2005). Recently, the Park developed a new zoning plan. As a result, about 33 percent of the entire area is now zoned as no-take, enhancing biodiversity conservation (Fernandes et al., 2005). Various activities are allowed in other zones, including boating, diving, photography, and permitted study in the 'Scientific Research' zones, and all of these uses as well as bait netting, crabbing, limited collecting, spear fishing, line fishing, netting, shipping, trawling, and trolling in the 'General Use' zones (www.gbrmpa.gov.au/corp_site/management/zoning). Throughout the re-zoning process, there was extensive communication with and participation of the public, and key reserve planning and design principles from the literature were applied. The new zoning plan, for example, employs strategies to build resilience against possible future effects of climate change by protecting against biodiversity loss and overfishing. At least 20 percent of each bioregion is protected, and a minimum size was established for no-take areas (Fernandes et al., 2005; see also NCEP module *Marine Protected Areas and MPA Networks*). This successful process has resulted in international recognition of the GBRMP and its zoning plan.

Table 3. Zoning in Marine Protected Areas				
Zone	**Synonyms**	**Activities Allowed**	**Activities Prohibited**	**Purposes**
Marine Reserve	No-take, no-access	Limited	Take, access	Counter harmful processes; address conservation and fishery management objectives; provide insurance against management failure (NAS 2001; Agardy 2000).
Restricted Access	Sanctuaries, no-take areas	Limited public activity, such as swimming, diving, and ecotourism	Extraction, take	Meet sustainable use goals, attract public attention and support; household or park income from ecotourism; pride in community involvement; fishery and conservation benefits
General Reserve		Regulated access and take; ecotourism, restricted fishing, research, education; recreation	Destructive practices	Address stakeholder interests
Buffer Area	Traditional use areas; partial reserves	Entry, take	Destructive practices	Buffer between the park and surroundings; potentially capable of protecting core areas from pollutants and other threats; Integrated conservation and development projects (ICDPs), as well as educational and administrative facilities, are often housed in the buffer zone.

Stakeholders

Stakeholder goals have significant impacts on PA planning and implementation, many times overriding biological considerations (see NCEP module *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*). Adequate incorporation of the reserve design factors discussed above is often constrained by socioeconomic and political issues (Pressey, 1994; Prendergast et al., 1999). Human use of areas surrounding parks can greatly influence their effectiveness, and there is no consensus as to how much human activity should be permitted within parks (Western and Wright, 1994; Oates, 1999; Hulme and Murphee, 2001; Terborgh et al., 2002). It is becoming increasingly obvious that the human context of biodiversity conservation must be seriously considered when planning PAs, including comprehensive assessment of legislative, cultural, societal, political, and economic factors.

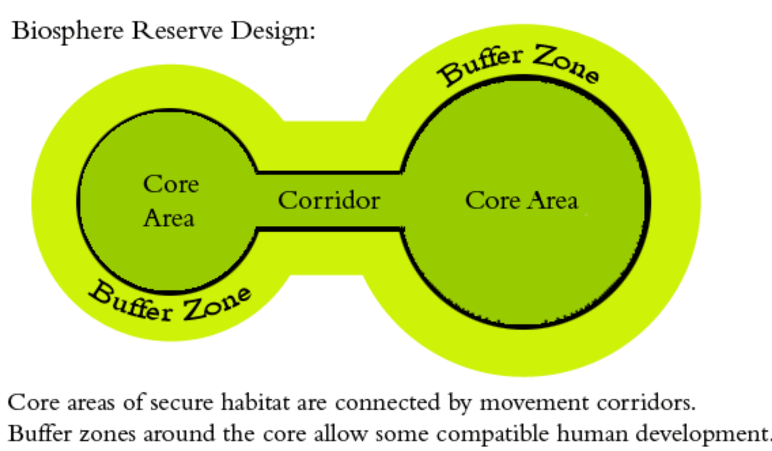


Figure 2. Zoning diagram of reserve design

Setting aside a site as a protected area can result in costs and benefits for the various stakeholders. There are numerous potential benefits to society from conserving biodiversity, including spiritual, educational, recreational, and economic factors (see NCEP module *Why is Biodiversity Important?*). Reserves, for example, are often established to protect resources used by people for hunting or recreation. Often, however, PAs are viewed as impediments or hindrances. It is easier to establish a park in a remote area with few conflicting uses than where land has economic value (Margules and Pressey, 2000). PAs bordering or within areas being developed for tourism, for example, may be viewed as costly by entrepreneurs, due to restrictions on commercial enterprise. Prohibiting activities, such as driving on beaches, may result in a view of PAs as obstacles to recreation. Establishing a strict reserve at a site where resources were previously used may result in loss of income or residence. For additional consideration of these and other points, please see the companion NCEP module *Conserving Biodiversity in Protected Areas II: Management and Effectiveness*.

Methods of Reserve Selection

Gap analysis and *reserve selection algorithms* are prominent methods employed in reserve selection. In gap analysis, a GIS approach is used to identify gaps in existing PA coverage. Alternately or in combination with gap analysis, reserves and networks can be designed using computer algorithms that incorporate biological and socioeconomic factors. These reserve selection algorithms find the minimum area that protects the most diversity, often minimizing the financial cost. These methods can be used singly or in combination, for example by using reserve selection algorithms to design parks in areas identified through Gap Analysis (Pressey and Cowling, 2001). Both methods can incorporate biological and socioeconomic factors, although the full complexity of land ownership, use, and constraints is often not captured (Prendergast et al. 1999). Software and tutorials are available online free of charge, and benefits of using the methods include transparency, clarity, comprehensiveness, and objectivity. Commonly used reserve selection algorithm tools that are freely available include: **SITES** (Andelman et al., 1999; http://www.biogeog.ucsb.edu/projects/tnc/toolbox.html), **MARXAN** (Ball and Possingham, undated; http://www.ecology.uq.edu.au/marxan.htm), and **C-Plan** (http://www.uq.edu.au/~uqmwatts/cplan.html).

In practice, selecting reserves can be a complex process, however these new procedures can provide a planning framework that is helpful in uniting and facilitating communication between different constituencies and agendas. Even so, many reserves to date have been planned through pragmatism, expert knowledge, or participatory approaches, and without referring to gap analysis or reserve selection algorithms (Pressey, 1994). This may be because theoreticians and conservation planning practitioners do not always communicate (Salafsky et al., 2002). There are also concerns over the feasibility of implementation, as well as the appropriateness of surrogates and the scale of analysis (Prendergast et al., 1999). Necessary resources (time, expensive data collection, a specialist, and computer equipment) may be prohibitive. In a conciliatory approach, analytical results can be used as a starting point for stakeholder and expert conversations (Pressey and Cowling, 2001). Marine PA planning in the Gulf of Mexico, for example, integrated results of the SITES reserve selection software (Andelman et al., 1999; see below) with participant interviews and a workshop (Beck and Odaya, 2001).

Reserve Selection Algorithms

Reserve selection algorithms are flexible tools that allow users to test different scenarios and combinations of factors to achieve different goals. When using reserve selection algorithm software, users first enter the relevant data on selected species, habitats, or other biodiversity elements into the program. The sites being considered are divided into planning units, such as hexagons or cells of varying sizes. Care must be taken to select planning units appropriately according to case-specific requirements (Andelman et al., 1999). The minimum area needed to maintain certain species can be entered into these programs, which are also capable of considering the closeness of areas for metapopulation persistence. Outputs can be constrained to minimize size or cost, and to maximize complementarity. Complex programs can minimize boundary lengths to achieve compactness and contiguity, thus decreasing edge. Emphasizing shared boundaries and adjacency can minimize isolation. The risk of catastrophes can be addressed by stipulating a minimum distance separating parks designed to protect the same target. Socioeconomic factors, such as cost and conflict minimization, can also be included. Threats can be incorporated by focusing on endangered species or habitats. Savings may be gained by selecting larger, complementary areas in a PA network, excluding highly priced sites as possible (Ando et al., 1998). Howard et al. (2000) used an iterative algorithm that included biological criteria and minimized opportunity costs and land-use conflicts. Combinations of constraints can be explored as scenarios to assess effects on goal achievement of tweaking different variables. Various solutions are then offered, and users may select their preferred option.

The choice of the best-performing algorithm is case-specific (Pressey et al., 1997). The MARXAN software was designed in response to reserve design needs in the Great Barrier Reef, Australia. Recently, MARXAN was employed to identify priority areas and management strategies for the conservation of 4795 terrestrial mammal species worldwide (Ceballos et al., 2005). Many of these "flagship" species, such as the orangutan (*Pongo pygmeus*), face extinction. The analysis indicated that about 11 percent of terrestrial areas worldwide would need to be protected using various methods to conserve one tenth of the land mammal ranges. A multi-faceted strategy, focusing on existing PAs, establishment of new parks, and management of areas occupied by people, would be necessary to achieve even minimal conservation goals for these taxa (Ceballos et al., 2005). MARXAN's precursor program, SPEXAN, was integrated with ArcView to make SITES (Andelman et al., 1999). Both programs incorporate spatial criteria in site selection and provide decision support for PA design; SITES has a GIS interface. SITES was employed in The Nature Conservancy's ecoregional conservation efforts at the Idaho Batholith and in the Northern Sierra Nevada. The program was also used to design the Channel Islands National Marine Sanctuary (Airamé et al., 2003). C-plan was employed to design a reserve system in the Cape-Floristic region of South Africa (Box 10).

Gap Analysis

Gap analysis is a biogeographic approach to biodiversity conservation planning that uses satellite remote sensing and geographic information systems (GIS) to identify and bridge gaps in existing protection efforts (Scott et al., 1993). Gap analysis consists of identifying and classifying the: 1) distribution of biotic communities, such as vegetation cover or natural features. Other important data include elevation, slope, aspect, soils, aquatic features, and climate; 2) biodiversity, such as plant, vertebrate or invertebrate distributions; 3) management regimes and socio-economic considerations for focal areas; 4) biodiversity that is not adequately represented in areas managed for conservation; and 5) priorities for conservation action (Figure 3). Once candidate areas are identified through gap analysis, other principles of conservation biology, such as population

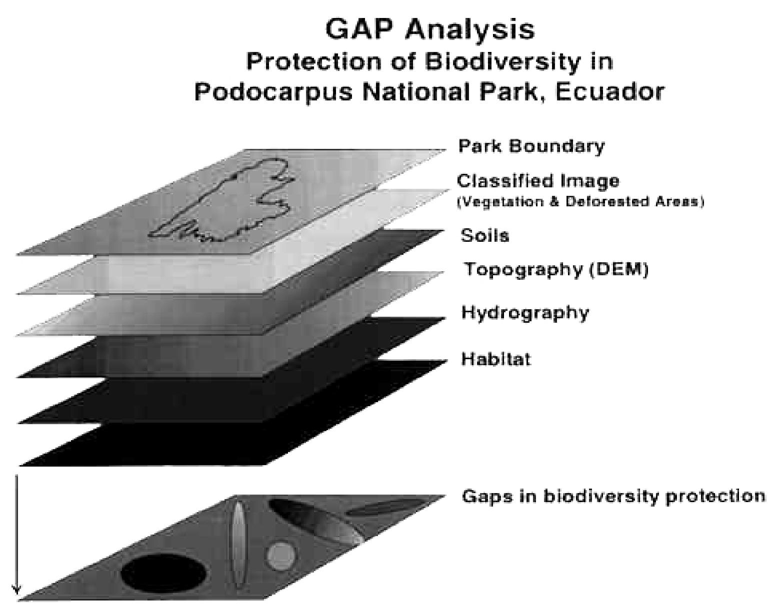


Figure 3. Gap Analysis (Source: http://libraries.maine.edu/Spatial/gisweb/spatdb/gis-lis/gi94030.html)

Box 10. Reserve Design in the Cape Floristic Region, South Africa

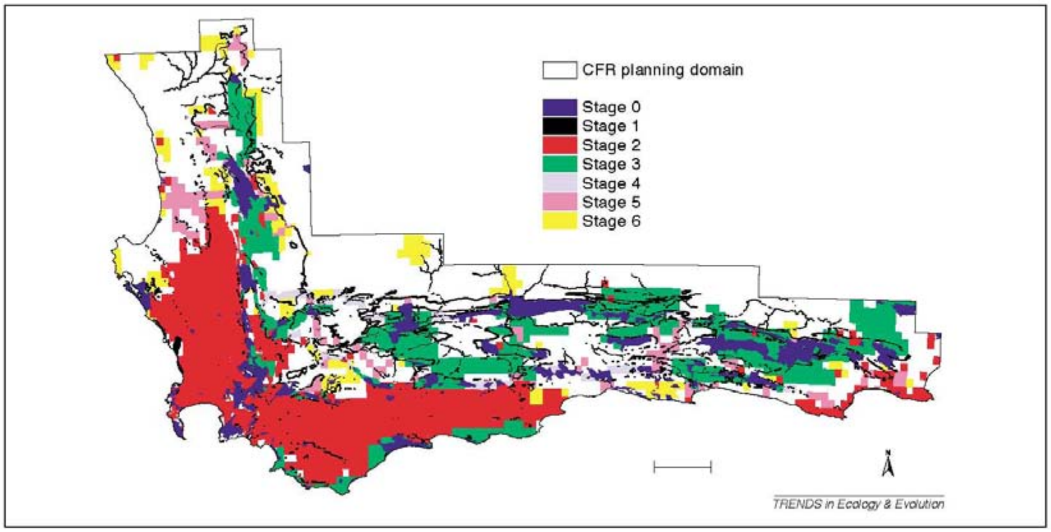


Figure 4. Protected Area Planning in the Cape Floristic Region (Source : Reprinted from Trends in Ecology and Evolution 18(9), Balmford, A., Conservation planning in the real world: South Africa shows the way, 435-438, © 2003, with permission from Elsevier.)

One of the best-known examples of the PA planning process is in the Cape Floristic region of South Africa (Balmford, 2003). This area is a Biodiversity Hotspot and a priority Ecoregion, widely recognized for its endangered and endemic plant diversity. A conservation planning program based on the framework of Margules and Pressey (2000) was instituted there, focusing on biodiversity protection, sustainable use, and capacity building. This framework consists of six stages that incorporate feedback and revision. Elements of biodiversity, such as species or vegetation types, are initially chosen as surrogates for overall patterns. Targets and goals for protection of these elements are then defined. In the third stage, the extent to which these goals have been met by existing PAs is determined. In Stage Four, additional sites are selected to achieve the remaining objectives. The final two steps consist of reserve implementation and monitoring (Margules and Pressey, 2000).

Following Margules and Pressey's framework, biological and spatial data about the Cape-Floristic region were obtained, and a comprehensive threat assessment was conducted. Challenges to conservation planning there include agriculture, cattle grazing, urbanization and invasive species. Goals were then defined for short- and long-term persistence of the target elements; specific but mutable targets were devised to conserve species, habitats, and ecological processes. Analyses carried out using the 'C-Plan' program revealed that most of the targets were not adequately met through the existing PA system. Much of the additional land being considered for protection was privately owned, although about one fifth was part of a regional protected area system. Rather than buying all of the necessary land, land-use agreements were entered into with private owners. This strategy had the additional benefit of increasing stakeholder involvement and addressing funding limitations. Throughout the process, landowners, government agencies, non-government organizations (NGOs), local communities, and scientists were involved in formulating the conservation plan. The resulting proposed plan included established reserves, and also required that conservation efforts be carried out in over half of the area outside existing parks (Figure 4). Recommendations from this effort included employing all available species and habitat data of acceptable quality, and filling gaps with expert judgments. The formulation of case-specific quantitative targets, protecting both patterns and processes, and subject to change following evaluation, was also suggested. Success was found to depend largely on stakeholder involvement and a feeling of joint ownership.

Box 11. Gap Analysis of the Global PA System

Gap analysis was used to assess the effectiveness of the global PA network for species-level conservation (Rodrigues et al., 2004a), and to suggest areas for network expansion (Rodrigues et al., 2004b). The analyses focused on mammals, amphibians, turtles and freshwater tortoises, and threatened birds, the four terrestrial vertebrate groups for which global assessments were available. Many other species, such as aquatic, plant, and invertebrate taxa, were not assessed due to data limitations. Of the 11,633 species analyzed, at least 1,424 (12.2 percent) were not included in any protected area. Gap analysis was then used to begin identifying specific sites for future network expansion, focusing on irreplaceability and threats among these vertebrates (Rodrigues et al., 2004b). Unprotected areas of the world that have remarkably high conservation value and are under serious threat were identified, concentrated overwhelmingly in tropical and subtropical moist forests, particularly on tropical mountains and islands.

viability analysis, ecosystem patch dynamics, complementarity, and habitat quality can be used to select specific sites and determine appropriate management area boundaries.

Gap analysis is considered promising for its practicality and simplicity, however there are some limitations. Gap analysis has been useful in identifying ways to improve the global PA network (Box 11), and provides a way of ranking the conservation needs of species and communities. The data layers also furnish information about the context of areas being managed for different values, as well as opportunities to maintain connectivity through landscape linkages. However, given the limited availability of species' distribution data, gap analyses have been conducted using indicators of biodiversity, such as particular species or groups of species (Terborgh and Winter, 1983; Pearson and Cassola, 1992; Bibby et al., 1992; Kremen et al., 1993; Launer and Murphy, 1994), physical attributes of the environment (Mackey et al., 1988; Kirkpatrick and Brown, 1994) or habitat types (Nilsson and Gotmark, 1992; Dinerstein and Wikramanayake, 1993; Keel et al., 1993), which are more likely to have been mapped. The assumption inherent in these analyses, that plant communities or other indicators accurately reflect physical factors (soil, moisture regime, aspect, elevation, temperature), may be violated. Vegetation cover, for example, is presumed to predict the distribution of target taxa accurately, and vertebrate distribution is assumed to be a good surrogate for diversity in other groups. In addition, specimen locality records or confirmed observations are used to refine or produce distribution maps, in combination with overlays of biotic or abiotic factors that may drive distributions. Gap analysis relies on distribution maps that may not be accurate because patterns are generally not well known, may not be representative, and may vary over time.

Concluding Remarks

This module has described ways in which protected areas, the "single most important conservation tool" (Rodrigues et al., 2004b), can be designed to conserve biodiversity. Currently, there is a global system of protected areas that covers about 12 - 13% of the Earth's terrestrial surface through diverse international, regional, and national initiatives. This system may not be optimal, however many parks do achieve biodiversity conservation, sustainable development, and multiple use objectives. Sites can be chosen to protect specific taxa, enabling also the conservation of the ecosystems they occupy. International treaties or other initiatives serve to protect target habitats, such as wetlands, or ecological processes. Reserves can be designed to protect areas of high species diversity, to include representative species or habitats, or to protect against environmental variation such as climate change. PAs can be planned to optimize size, shape, complementarity, replication, and connectivity according to specific conservation goals. Zoning and stakeholder involvement can be effective tools for accommodating human objectives throughout the design process. Methods such as gap analysis and reserve selection algorithms provide a level of objectivity, consistency, and transparency to reserve planning.

However, many PAs are threatened or situated and planned in ways that fail to match conservation priorities (Chape et al., 2005), and questions remain regarding the implementation, management, and effectiveness of protected areas worldwide. To investigate ways in which the theoretical aspects of reserve planning play out in the real world, consider referring to the second NCEP module in this series *Protected Areas and Biodiversity Conservation II: Management and Effectiveness*.

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Glossary

Biogeographic: A geographic range delineated using the presence of various species, both living and fossilized.

Biomes: Represent global-scale ecological variation in the structure, dynamics, and complexity of biological communities and ecosystems.

Community: A group of plants or animals that occupy a shared environment and interact.

Corridor: A strip of vegetation or other habitat that connects fragmented areas, which may have been historically connected. The intention is to enable movement between the two fragments.

Dispersal: The spreading of organisms across a physical scale, such as seeds or individuals, or movement away from the birth site.

Ecological process: The interactions between organisms, between communities, and between organisms and abiotic resources.

Ecosystem: An assemblage of organisms and the physical environment in which it exchanges energy and matter.

Edge: The area of transition between two different habitats.

Endemism: When an organism is native to, or found, only in one area.

Flagship species: Animals or plants that generate a large amount of popular interest; often used in conservation to protect less charismatic species that share habitat with the flagship species.

Gap analysis: An effort to use mapping (mainly using Geographic Information Systems - GIS) to uncover areas that are not being protected through existing conservation efforts.

Indicator species: A species whose well-being is taken to be reflective of the condition of some more general ecological or environmental condition/process.

IUCN: The International Union for the Conservation of Nature and Natural Resources, also known as the World Conservation Union (www.iucn.org).

Keystone species: A species that has an exceptionally important role in preserving the functionality and diversity of their community.

Landscapes: Areas that contain heterogeneous collections of ecosystems.

Network: A group of protected areas that are linked.
Phylogenetic distinctiveness: A measure of the evolutionary uniqueness of a taxon relative to others.

Realms: Continent-scale regions distinguished by characteristic biota that reflect shared evolutionary histories.

Replication: The inclusion of several areas of similar habitat within a reserve or network.

Reserve selection algorithm: Rule-based (heuristic), statistical, or mathematical algorithms used to build reserves, systems and networks according to user specifications.

Sink: A population that is not self-sustaining and relies on immigration to survive.

Source: A population from which individuals emigrate to other areas.

Species diversity: A measure of the species richness, but weighted to express abundance either based on the number of individuals or biomass of each species.

Species richness: The number of different species in an area.

Stakeholder: A person or group of people with an interest in any impact that an action might have.

Umbrella species: A species whose protection will also provide protection for other species, usually through habitat preservation.

Zones: Areas within a protected area that have different levels of protection.

Marine Reserves and Local Fisheries: An Interactive Simulation

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Source: C. Roberts and J. Hawkins

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Eugenia Naro-Maciel and Daniel R. Brumbaugh

Introduction

In many tropical marine areas such as the Caribbean, one finds productive ecosystems harboring a large diversity of organisms. People also live in these places, and harvest marine organisms for their livelihoods. The complex question arises: How to balance marine biodiversity conservation and local fishery activities? Marine protected areas, including marine reserves that completely ban fishing and other extractive activities, are a promising approach for addressing both of these factors.

This simulation-based exercise is an educational tool that allows users to:

1. Explore various factors that influence fish population viability and fishery sustainability; and

Fishers and conservationists using simulation software at workshop in Ecuador (Source: A. Walton / S. Lozano. © NOAA NMSP)

2. Experiment with the use of marine reserves as tools in fisheries management.

Highlights

The exercise allows:

- Interactive experimentation by users with marine reserve configurations and species and fishing parameters;
- Visualization of habitat suitability for three Caribbean fisheries species;
- Visualization of species abundances and fishing profits over time;
- Visualization of average harvest catch, effort, profits, and the source of these profits across space; and
- Saving of all input parameters and simulation results.

Why is this Important?

Although the total amount of fisheries catches appears to have a reached a global maximum over the last decade (Watson and Pauly 2001), many local fisheries are known to be declining worldwide. Whereas industrial scale commercial fisheries often switch to new stocks and species after depleting a resource (sometimes leading to a pattern of serial depletions), people in smaller scale, coastal fisheries are much more vulnerable to fisheries collapses. Coral-reef fisheries, due to their relatively small areas, the slow growth and maturation rates of many reef fishes, and the complex community interactions in reef ecosystems, are especially susceptible to overfishing and habitat degradation (Birkeland 2001). Moreover, overexploitation of key reef species has contributed to the instability and decline of coral reefs, leading to threats to the biological diversity of these rich, biodiverse ecosystems (Hughes et al. 2003, Mumby et al. 2006).

Marine protected areas (MPAs), including marine reserves that restrict all take (or harvest), provide tools for addressing threats from overfishing to both the sustainability of local fisheries and the conservation of biodiversity (NRC 2001). A protected area has been defined as an "area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (IUCN 1994). Protected areas, also known as parks, reserves, and a suite of other names, have been established at international, regional, national, state, and local scales, and many are linked as networks or other systems. Marine resource managers may opt for different combinations of MPA size, number, location, and other factors, depending on the specific objectives of a marine reserve or other MPA. This may include whether, for example, it is primarily designed for conservation or fisheries, for which target species, and in the context of what kind of fishery (e.g., gear type).

This exercise allows users to explore issues related to marine reserves and local fisheries via interactive simulations. Users are able to control (1) some attributes of a local fishery, including population dynamics and mobility of the target species as well as aspects of fisher behavior and economic factors, and (2) the extent and placement of marine reserves. By exploring the contributions of these issues to fisheries productivity over time, users should gain some understanding of the factors contributing to how reserves can interact with local fisheries. Of course, although many of the factors and dynamics in this exercise are based on actual interdisciplinary research conducted in The Bahamas (see http://bbp.amnh.org), the simulation represents a simplification of the real complexities of population dynamics, fisheries economics, and marine resource management. Adding these additional complexities, such as more variable population dynamics, more dynamic pricing of catches, and additional fishing regulations outside of marine reserves, would likely lead to different quantitative outcomes. Nevertheless, qualitative results deriving from controlled comparisons across different scenarios (e.g., species life-history, fleet, and reserve characteristics) are likely to be more general.

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Local Fisheries

In the Caribbean, three important fisheries species, for economic, cultural, and ecological reasons, are the queen conch (*Strombus gigas*), the Nassau grouper (*Epinephelus striatus*), and the spiny lobster (*Panulirus argus*).

Queen Conch

The queen conch, a large snail (gastropod mollusk) in the *Strombidae* family, is found throughout and beyond the greater Caribbean, including as far north as Bermuda and as far south as Venezuela and Brazil (FAO 1977). The conch fishery is one of the most important in the region, though the species' biology makes it rather susceptible to overfishing, and it has declined throughout its range in recent decades. Trade in queen conch is now restricted following regulations of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES), where S. gigas is listed on

Appendix II (CITES undated, Acosta 2006). The species is also listed in Annex III of the Protocol Concerning Specially Protected Areas and Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (SPAW, UNEP undated).

Economically, the conch fishery in the Caribbean is worth millions of U.S. dollars each year. Although harvest dates to prehistoric times, high levels of commercial take are relatively recent. The meat can be prepared in a variety of ways (e.g., raw ceviche-type salad, stews and chowder, or cooked in innumerable customary ways), while shells are used to make jewelry, and as a local construction material. Fishing methods include capture by hand, use of simple gear such as forked poles, or SCUBA, which is generally illegal (Catarci 2004). These methods do not greatly negatively affect habitats or ecosystems, or other species through incidental by-catch (Cascorbi 2004). In some areas, like The Bahamas, conch is harvested during the lobster fishery closed season, or as part of a multiple species effort (Catarci 2004). Management is coordinated regionally by the International Queen Conch Initiative. The fishery is regulated through temporal or spatial closures, as well as by level of maturity, size limits, gear restrictions, and catch quotas. Conch fishing in Florida – both commercial and recreational – has been prohibited since 1985, though stocks have not recovered subsequently. In 1991, the state recognized *S. gigas* as a "protected species" (Schlesinger 2006). In many nations, fisheries management measures are not effective due to factors such as illegal fishing and inadequate enforcement (Cascorbi 2004, Acosta 2006).

Aspects of this species' biology contribute to its vulnerability to overharvest (Gascoigne 2002, Gascoigne and Lipcius 2004, Cascorbi 2004). Queen conchs are relatively long-lived, slow growing, and have delayed sexual reproduction, with a reproductive output that increases with age (CHC CIC 2003). *S. gigas* live up to about 25 years, mature at around 3-4 years, and are highly fecund. Reproduction occurs through internal fertilization, when large numbers of conch migrate to shallow waters for breeding. Females lay individual masses containing ~300,000 fertilized eggs. After about 5 days, larvae called veligers hatch from these egg masses and start a 3-4 week period in the plankton before settling onto shallow sand and algae, where they metamorphose into tiny snails. The conch's life history is characterized by high mortality at younger ages; however, older individuals are naturally protected from predators by their strong shells. This species is, however, relatively easy for humans to capture. It lives in accessible shallow waters, is clearly visible, and moves slowly. *S. gigas* occur mainly in shallow sea grass beds linked to coral reefs, with the youngest being found closest to shore. Queen conch forage on plankton as larvae, and algae, sea grass, and other plants as adults (Ray and Stoner 1995, CHN CIC 2003). Vulnerability increases when conch aggregate in large numbers to spawn. This anthropogenic mortality of the later life stages, combined with habitat loss and pollution, are likely to be driving population declines. Further, reproduction in *S. gigas* may fail below certain density thresholds, inhibiting recovery (Stoner and Ray-Culp 2000, Gascoigne and Lipcius 2004).

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Nassau Grouper

The Nassau grouper, *Epinephelus striatus,* a member of the sea bass family (Serranidae), was historically found throughout the tropical western Atlantic Ocean, including the Caribbean Sea, the Gulf of Mexico, the southeastern U.S., Bermuda, and northern South America (Sadovy and Eklund 1999). Currently, this species occupies only a fraction of its previous range, and is classified as Endangered according to the World Conservation Union (IUCN 2006). Under this definition, endangered taxa are those that have suffered a high rate of population decline and are at risk of extinction; *E. striatus* has declined by about 60% over the last three decades (IUCN 2006). Historically, the grouper fishery has been one of the most important and valuable throughout its range (Sadovy and Eklund 1999, Gascoigne 2002). Grouper is used in traditional dishes, such as boiled fish and grouper fingers, where it is valued for having relatively few bones and being easy to eat. In The Bahamas, one of the few countries where stocks remain commercially viable (though much less abundant than in previous decades) and whose capital is the namesake of the fish, Nassau grouper has been the most valuable finfish in recent years. Commercial landings there were valued at over BSD$ 2.7 million in 2003 (Department of Fisheries [now, Marine Resources], The Bahamas undated).

Nassau grouper grow slowly and have delayed reproduction, reaching sexual maturity from 4-8 years of age when they reach 40-50 cm in length (Ray and McCormick-Ray 2004). These characteristics hinder population recovery from low densities, enhancing vulnerability to overfishing. These groupers are long-lived, capable of surviving over 20 years in the wild, and have naturally low adult mortality (Sadovy and Eklund 1999). Reproductive rates and number of eggs per reproductive event increase with age in this species, with large fish producing 5-6 million eggs per season. Most groupers change sexes with age, although this may not be the case for *E. striatus.* Fishing often targets larger individuals, eliminating those with highest reproductive capacity and skewing the age class distribution to juveniles with lower survivorship (Gascoigne 2002). During the winter months (e.g., November to February in The Bahamas, and December to March in Belize), adults undergo breeding migrations to specific offshore areas, either locally or up to hundreds of kilometers away from their resident habitats, where they form ephemeral spawning aggregations during the week around the full moon (Starr et al. 2007). These groups, historically numbering in the tens of thousands, form for reproductive and courtship purposes (Sadovy and Eklund 1999). Because there aggregations are predictable and often known to local fishermen, large numbers of fish can be readily caught during spawning. Uncontrolled exploitation has completely extirpated or reduced many spawning aggregations to a few dozens to thousands of fish, rendering many stocks commercially extinct, and disrupting spawning behavior (Sala et al. 2001, Gascoigne 2002, Sadovy 2002, Ray and McCormick-Ray 2004, Sadovy and Domeier 2005). Once eliminated, spawning aggregations have not been observed to form again, suggesting that knowledge of spawning sites depends on cultural transmission (Bolden 1980). Young groupers, in the absence of enough older, reproductively experienced individuals, seem unable to locate their spawning site. As a consequence, small aggregations with too few experienced individuals to facilitate enough new recruits to the aggregation may be doomed to extinction (Sadovy and Eklund 1999, Starr et al. 2007).

Measures have been instituted to limit fisheries in response to the observed decline in grouper numbers. These include seasonal closures (e.g., during the winter spawning months) and spatial closures around known spawning sites. In place also are gear restrictions and harvest limits for fish size and number. Commonly employed fishing methods include handline, traps, and spear guns. Marine protected areas have been hailed as one of the most promising methods for protecting Nassau Grouper (Sadovy and Eklund 1999, Gascoigne 2002). Taxation based on vessel or harvesting characteristics is another possible measure.

Habitat use, diet, and ecological role vary throughout the grouper life cycle (Sadovy and Eklund 1999, Perry Institute undated). Larvae hatch from pelagic eggs within a day after fertilization. After about 30–50 days, small juveniles leave the water column, shifting to inshore benthic nursery areas such as algal beds, seagrass, or reefs, where they will start life as relatively sedentary, demersal organisms. As they grow, they gradually shift their residences, to deeper reef habitats containing adequately sized holes, cracks, and other concavities (Ray and McCormick-Ray 2004). As adults, with the exception of the annual breeding migrations, Nassau grouper rarely disperse from their territories. They also shift their diets as they age, with juveniles feeding mainly on crustaceans, and adults feeding on a mix of invertebrates and fishes. Nassau grouper are among the larger reef fish, reaching up to 120 cm (3.9 feet) in length and approximately 25 kg (55 lbs.) in weight (Ray and McCormick-Ray 2004). A predator whose diet includes crustaceans, reef fishes, and octopuses, *E. striatus* plays a key role in reef communities (Mumby et al. 2006). Throughout its life cycle, this species also serves as prey for reef sharks, barracuda, dolphins, and humans. In addition, as with other reef fishes, *E. striatus* acts in a suite of symbiotic relationships, visiting cleaning stations, for example, where various species of small fishes (especially certain wrasses and gobies) or shrimps remove parasites from their exterior and inside their mouths. Thus, Nassau groupers are functionally linked to reef communities in numerous ways, and decreases in their populations will have community-wide impacts.

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Spiny Lobster

The Caribbean spiny lobster (*Panulirus argus*), found in the Gulf of Mexico, the Caribbean Sea, and the Western Atlantic Ocean from North Carolina, U.S.A., to Rio de Janeiro, Brazil (FAO 2004), is a member of the ecologically and economically important rock or spiny lobster family, Panuliridae. Apart from supporting lucrative commercial and recreational fisheries, these gregarious crustaceans are known for their migratory behavior, which can involve single-file group movements of juveniles and adults from shallow to deeper waters, related to seasonal, severe weather, or other factors (Herrnkind et al. undated). Larvae often disperse across national territories, so that management in one country may affect populations in others. This arthropod is omnivorous, scavenging mainly nocturnally on diverse kinds of plant and animal matter, including crustaceans and mollusks (Bliss 1982, Briones-Fourzan et al. 2003). Lobsters, in turn, are prey for various organisms, including sharks, groupers, snappers, sea turtles, octopuses, and humans.

(Source: T. McClanahan)

Spiny lobsters, commonly known as crawfish, are harvested throughout their range. This multi-million dollar fishery is one of the most valuable in the Caribbean (Cascorbi 2004, Bene and Tewfik 2001). Capture methods include free diving, use of traps, spears, and trawls (Bene and Tewfik 2001, FAO 2004). Spiny lobster fisheries in Florida and The Bahamas are intense, but do not result in notable harm to habitats and ecosystems, and levels of by-catch are low (Davis 1977, Davis and Dodrill 1989, Eggleston et al. 2003, Cascorbi 2004). In some areas, such as the Turks and Caicos, *Panulirus argus* may be harvested jointly with the Queen Conch (Bene and Tewfik 2001). Caribbean spiny lobsters are not classified as endangered or threatened, although they are listed on the SPAW protocol (UNEP undated). Aspects of their biology, such as rapid growth, a relatively early age of sexual maturity, high reproductive potential, and the potential for long-distance dispersal, may contribute to a relatively low susceptibility to extirpation from overfishing (Cascorbi 2004). Fisheries are regulated, including measures such as closures during spawning season, trap-reduction programs, and legal size and bag limits. Also illegal in some countries is harvesting of egg-bearing females, and fishing with firearms or explosives. Effectiveness of enforcement varies regionally (Cascorbi 2004). Marine reserves protect lobsters and their habitats, although very small protected areas may be inadequate (Eggleston and Dahlgren 2001).

Spiny lobsters occupy a variety of environments throughout their life cycle, which spans up to 30 years. Reproduction and fertilization occur in offshore reef areas, generally during late spring or early summer. During the mating process, males deposit a sticky fluid containing sperm onto the female's abdomen; this fertilizes the eggs upon release (Herrnkind et al. undated, Bliss 1982). Fertilized eggs remain under the female's tail until they hatch, and clutch size varies with location and fishing pressure. In the Dry Tortugas, for example, lobsters became reproductively active at larger sizes, and the average number of eggs is higher than in a south Florida fishery (Bertelsen and Matthews 2001). Eggs hatch into transparent phyllosome larvae that drift offshore with the surface currents. This pelagic stage generally lasts 6-12 months, resulting in long distance dispersal spanning hundreds of kilometers (Herrnkind et al. undated). They next molt into free-swimming puerulus postlarvae, which leave the open ocean to settle in nearshore vegetated benthic areas such as sea grasses, algal beds, or mangroves (Acosta et al. 1997, Acosta 1999, Butler et al. 1997). This process is thought to vary with characteristics of the nursery habitat, postlarval supply, environmental factors, fishing pressure, and oceanographic circulation (Lipcius et al. 1997, Butler et al. 2001, 1997, Cruz et al. 2001, Lipcius et al. 2001, Yeung et al. 2001). Postlarvae metamorphose into juveniles, whose movements are asocial and initially restricted to sheltered areas such as algal beds (Butler et al. 1997, Herrnkind et al. undated). As time goes on they become increasingly vagile and social, living in small aggregations inside crevices, under rocks, seaweeds, sponges and corals (Eggleston and Dahlgren 2001). As lobsters approach maturity, which may occur around 2-3 years of age, they move to deeper waters in coral reef systems where reproduction occurs (Herrnkind et al. undated).

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Fishery Management and Biodiversity Conservation

Despite its extraordinary value, the marine environment faces myriad threats from local to global sources. The world's oceans encompass about three quarters of the earth's surface. In addition to supporting critical natural processes, oceanic resources are important for maintaining human economies, amenities, and cultures along the world's coastlines. For example, oceans play a key role in climate regulation, harbor a substantial amount of the planet's biodiversity (especially in coral reefs), and host fisheries, tourism, and shipping industrial sectors.

Marine organisms and habitats are under intense stress, which has resulted in worldwide biodiversity loss (Agardy 2000a). Systems are strained principally by unsustainable fishing practices, as well as other factors such as habitat degradation, coastal development, and climate change (Jackson et al. 2001, Pauly et al. 2002). These factors impact not only the marine environment, but humans as well. Many of the world's commercial fisheries are currently overexploited. World fisheries landings have been slowly declining since the late 1980s, by about 0.7 million tons per year (Pauly et al. 2002). Importantly, fishery operations typically have targeted large, long-lived predatory fishes. With the depletion of these top predators, fisheries have shifted their focus to organisms lower on the food web. This phenomenon, known as "fishing down food webs", may lead to fishery collapses and negative cascading effects that alter the entire system (Pauly et al. 2002). Overexploitation degrades fish stocks and ultimately threatens food security in coastal populations.

There are different ways to address these issues, ranging from single-species to ecosystems-based fishery or biodiversity management. Traditional fishery management has focused on Maximum Sustainable Yield (MSY), calculated for target stocks using population dynamic models (Agardy 2006). This can be employed to determine harvest restrictions, such as size/age limits, quotas, restrictions on numbers of boats, maximum harvest and gear limits, and closures. By setting a size limit above which organisms can be harvested, younger members of the population are protected. Quotas set a maximum limit to capture, which may be essential in curbing efficient fishery operations capable of harvesting above sustainable levels. Closed seasons may ban fishing during times key to organismal life cycles. In parts of the Nassau Grouper range, for example, fishing is prohibited during spawning season to prevent the detrimental effects discussed previously (Sadovy 2002). Traditional measures alone, however, are insufficient to counter the hazards mentioned above (Pauly et al. 2002, Botsford et al. 1997). Management based on MSY, for example, may suffer from uncertainty, imperfect models, insufficient data, and inadequate consideration of ecosystem effects (Stergiou 2002, Pauly et al. 2002). Improved technology and the open-access nature of the sea further contribute to resource depletion.

Marine protected areas (MPAs) are a promising tool for sustaining ocean ecosystems through biodiversity conservation and fishery enhancement (Agardy and Staub 2006, and references therein). MPAs embody a precautionary and ecosystems-based approach to marine management. They protect biodiversity from genes to ecosystems by safeguarding vital processes. An increase in diversity, density, biomass, and size of organisms within marine reserves has been demonstrated in areas protected from resource extraction and habitat damage. This may lead to increased reproduction, as older individuals often make greater reproductive contributions. Closed areas may enhance fisheries by increasing the size and abundance of important target species, replenishing fished areas. The term "spillover" refers to increased production outside reserve boundaries attributed to emigration from within the MPA (Agardy and Staub 2006, and references therein). MPAs also present a solution for management difficulties in working with species of vastly different life histories (Roberts 1997a). Further, they provide a safety valve against inherent uncertainty (Roberts 1997a).

Use of MPAs or reserves alone, however, may be insufficient to protect target stocks from overexploitation (Agardy and Staub 2006). These areas, for example, are often not as large as the focal species' home range. In addition, the ecology and life history of many organisms remain insufficiently understood. Chances of success for marine reserves to protect target groups may be greater if managed adaptively, in combination with other conventional methods. Of note, reserves designed to protect focal taxa may not result in ecosystem conservation. Ecosystem-based fisheries management is a promising means of addressing this limitation. This approach focuses on interactions among multiple species and habitats used throughout their life cycles. This strategy recognizes that marine elements are not isolated, and that changes may affect the whole system. The greatest benefits to fishers and biodiversity may accrue from participatory approaches involving multiple stake-holders (Villa et al. 2002).

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Table 1. Summary of default values employed in the simulation exercise

	Grouper	Conch	Lobster
Initial population	50,000	150,000	110,000
Lifespan (days)	3285	3102	2920
Intrinsic growth rate	0.2	0.4	0.5
Carrying capacity	10000	15000	12500
Average catch rate (kg)	5	0.4	1
Dispersal rate	8	1	6
Fishing efficiency	0.02	0.09	0.04
Speed (km/hr)	20	20	20
Travel cost ($/km)	1	1	1
Boat cost ($/day)	12	12	12
Maximum boats/port	35	35	35
Maximum harvest (kg)	200	40	100
Price ($/kg)	5	6	8

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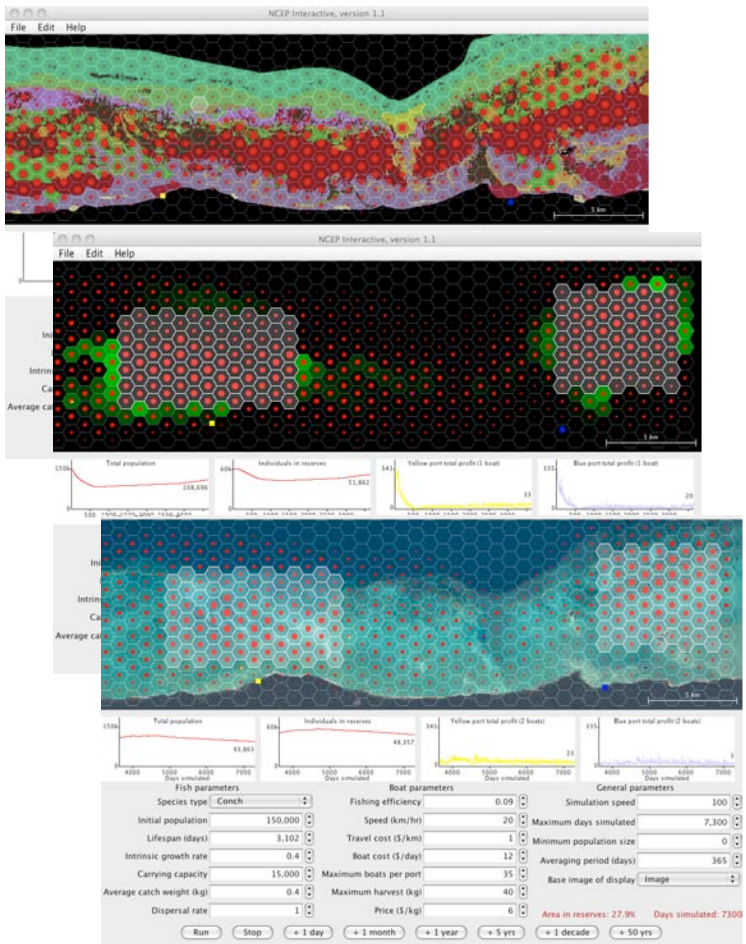
Download the Simulation

If you do not already have the simulation installed on your computer:

1. To run the simulation, you will need to have Java version 1.4 or later on your computer. This is available for download free of charge at http://java.sun.com/j2se/1.5.0/download.jsp. Please note that if you are working on a Macintosh computer, the version of Java used should be 1.4.2.
2. Download the exercise onto your computer by clicking on the file or simulation icon. **Note**: To run the simulation, you will need to have a recent version of the Java Runtime Environment on your computer, available for free download at http://java.sun.com/j2se/1.5.0/download.jsp. If your operating system is MacOSX, click on the Apple icon on the upper left part of your screen. Then click on "Software Update". If no Java Runtime Environment update is required, quit Software Update and proceed.
3. Save the program to your directory of choice.



Images of MPA interactive simulation software

Interactive Simulation

1. Double-click on the simulation icon to start the exercise.
2. After a few seconds, a window will appear. This includes a satellite image, as well as several variables describing fishery biology and economics, and simulation general parameters (see Glossary).
3. There are three species-types to choose from. These are Grouper, Conch, and Lobster. Their characteristics are based on those of real organisms.
4. Each variable (for example: lifespan) is set to default values that are within ranges published in the literature for the focal species, when these are known (Table 1). It is important to note that the exercise simulates "species types" and their fisheries. As such, the simulated organisms and their fisheries, although generally similar to grouper, conch, and spiny lobsters, are not intended to represent real world situations. Consider that this is a single-life stage model, which inflates this simplified composite number. To simulate other organisms of your choice, you can alter these numbers by selecting them and typing in your own values.
5. Pointing at each parameter with your cursor causes tool tips to appear. These explain each parameter, and provide minimum and maximum values. Parameters are also described in the Glossary. Please note: these tool tips will

only appear if your mouse is rolled over the value legend (such as "Initial population" or "Lifespan (days)". The tool tips will not appear if the mouse is rolled over the value field, or boxes where the variables are set.

6. You will see that the base image is overlaid by a hexagonal grid. In conservation planning, landscapes or seascapes are often subdivided into such units for planning purposes.
7. The red dots in each hexagon reflect the relative abundance of adult organisms within each planning unit. Pointing at a planning unit with your cursor will cause the number of organisms present in the hexagon, as well as the habitat type (see below), to appear.
8. Later on in the exercise, you will be able to construct a reserve system by clicking on hexagonal planning units of your choice. This will cause the hexagon to become outlined in white. No fishing will occur in protected hexagons, although boats may transit through without fishing.
9. You will also be able to follow boat movements along the seascape. Boats belong to one of two ports (Yellow or Blue), and are represented by small dots of the corresponding colors.
10. Pressing the Run button will start the simulation.
11. You may interrupt the run by pressing the Stop button. The speed of the simulation can also be changed in the appropriate field. Please note that 100 is the maximum available speed (as noted in the tool tips). There are additional buttons to speed up the simulation by the chosen time period (for example, "+1 decade").
12. While the simulation is running, the base image will depict changes in numbers of adults through corresponding alterations in size of the red dots.
13. Changes in population numbers (total and within reserves), as well as economic aspects of the fishery are shown in 4 graphs. Please note that the scale of the graphs changes as the data warrant. Clicking on a graph will cause a larger version to appear in a separate window. The graphs can also be saved using the "Save" option in the "File" menu.
14. Boats exit the simulation if their profits are negative, so that boat numbers may vary throughout the run. **This simulation assumes there will be at least one boat from each port participating in the fishery, even at negative profits.** The model for the behavior of fishermen is that if all boats from a given port have negative profit one day, then one boat drops out of service. One or more boats can be making a profit, even while the average profit (shown in the graphs) is negative. Thus, the average profit can go negative for a while, before boats start dropping out of service, and more than one boat may be present even at negative profits.
15. The percentage of total area in reserves at any given time is shown on the bottom right of the panel, as are the number of days simulated. Both are highlighted in red.
16. The simulation will end automatically when either the maximum days simulated or the minimum population size are reached. The default value for maximum days simulated is 20 years (7300 days). These variables can be specified in the column headed "General Parameters" on the right hand side of the panel.
17. You may alter the base image of the simulation using the "Base image of display" button on the bottom right. Toggle between a satellite image, an image showing habitat classifications, and an image reflecting habitat suitability for each species type. Species occurrence in each kind of habitat is based on its biology. Sea grass is appropriate habitat for conch, for example, while coral reefs are more suitable for spiny lobsters and groupers. Pointing your cursor at any hexagon will cause these classifications to appear. In the suitability screen, the most suitable habitats are lighter in color. The habitats, classified as follows, are defined in the Glossary:
    - Unclassified (land or deep water)
    - Sparse seagrass
    - Medium density seagrass
    - Dense seagrass
    - Sand
    - Silt / mud
    - *Batophora* dominated
    - Sargassum on hardbottom

- Dead coral and *Microdictyon*
- Sparse gorgonians and algae
- Uncolonized pavement and sparse gorgonians
- *Montastraea* reef
- *Acropora palmata* reef
- *Porites* reef
- Patch reef
- Mangrove

18. The "Base image of display" menu also contains options that summarize the following simulation outputs: Average effort, Average harvest, Potential yellow or blue boat profits, and Yellow or Blue boat profit sources. Values corresponding to each cell are provided in the tool tips. The Average effort and Average harvest options output the average effort and catch over the last year of the simulation. The Potential profit displays reveal the projected profits for each color boat at the time. The profit source feature tracks the cells of origin (i.e., birth) for individuals that are caught by blue or yellow boats in fishable areas. The lighter colors indicate larger amounts, and the values corresponding to each cell are provided in the tool tips.
19. You can save your results by opening the File menu under the Save option, on the upper right hand side of the screen.
20. You will be able to Reset to Time 0, Clear reserves, or Reset default values by selecting these options under the Edit menu, on the upper left side of the screen.

Glossary

Acropora palmata reef: habitat classification. Reefs with the coral Acropora palmata, also called Elkhorn Coral, typically have high vertical relief. This habitat is found at the crest of the reef. Although *A. palmata* is generally the most common coral in this habitat, the bottom community also includes other stony corals, gorgonians, and algae. This habitat is found between approximately 1 and 5 meters depth.

Average catch weight (kg): simulation fish parameter. Average weight of fish caught (kg; 0.1 -1000.0).

Base image of display: simulation general parameter. Image that is used for the background of the simulation.

Batophora dominated: habitat classification. This habitat contains abundant patches of the club-like algae *Batophora* and is typically on a hard bottom with a small amount of sediment. This kind of algae is also often seen growing on conch shells. Other algae and some patches of seagrass are often present in this habitat, which is founding low energy lagoonal environments.

Boat cost ($/day): simulation boat parameter. Cost per day to operate a boat, excluding travel (0 - 1000).

Carrying capacity: simulation fish parameter: maximum population per hexagon, in optimal conditions (0 – 100,000).

Dead coral and *Microdictyon*: habitat classification. In some areas, the majority of corals have died, possibly during bleaching events. These habitats are in shallow waters and appear to have been similar to *Montastraea* reef communities. They still have the rough structure of a coral rich area. The mesh-like algae *Microdictyon* is seasonally common and covers the substrate, presumably flourishing after the loss of live coral colonies. This habitat is found in a limited number of areas just landward of the reef crest.

Dense seagrass: habitat classification. This habitat is dominated by the seagrass *Thalassia*, also called Turtle Grass, but may contain the tube-like seagrass *Syringodium*. Dense Seagrass habitats have high biomass (tall plants, high density) and a low amount of visible sand and silt. This habitat is found in lagoonal environments where sediment is deep enough for the seagrasses to take root.

Dispersal rate: simulation fish parameter: percent of fish that move to another cell per day (0.0 – 75.0).

Fishing efficiency: simulation boat parameter: fraction of a cell's fish that a boat can catch per day (0.0 – 1.0).

Initial population: simulation fish parameter: initial total fish population (0 - 10,000,000). For purposes of the simulation, some of the default values may be more representative of well-established and protected areas than initially unprotected systems. These can be changed at will.

Intrinsic growth rate: simulation fish parameter. Population growth rate per year, in optimal conditions (0.0 - 2.0).
Lifespan: Simulation fish parameter. Typical lifespan (days; 0 - 100,000).

Mangrove: habitat classification. Mangrove trees grow in shallow, brackish waters along coasts and up creeks of some islands. Their roots provide nursery habitat for many important fish species. Mangroves in and around estuaries also trap sediments that might otherwise flow onto reefs and smother corals to death.

Maximum boats per port: simulation boat parameter. Maximum number of boats per port (0 – 1000).

Maximum days simulated: simulation general parameter. Stop simulation after this number of days (1 – 1,000,000).

Maximum harvest (kg): simulation boat parameter. Maximum catch per day (kg; 0 – 10,000).

Medium density seagrass: habitat classification. This habitat is dominated by the seagrass *Thalassia*, also called Turtle Grass, but may contain the tube-like seagrass *Syringodium* and the thin-bladed seagrass *Halodule*. Occasionally one also finds small coral colonies within the seagrass. Medium Density Seagrass habitats have medium biomass (medium plant height, medium density) and a medium amount of substratum is visible, when compared to Dense and Sparse Seagrass. This habitat is found in lagoonal environments.

Minimum population size: simulation general parameter. Stop simulation if fish population drops below this number (0 – 10,000,000).

Montastraea reef: habitat classification. The coral species *Montastraea annularis*, also called Boulder Star Coral, is the dominant coral species in this habitat. This benthic community is diverse, including corals, sponges, gorgonians, and algae. *Montastraea* Reef also supports a diverse and abundant fish community. This habitat is found in some reef environments between approximately 5 and 15 meters deep.

Patch reef: habitat classification. Patch reefs are reef formations often found in lagoons and surrounded by seagrass beds. They commonly have a small 'halo' around them of relatively clear sand cleaned by grazing fish and invertebrates. They support much more diverse invertebrate and fish communities than surrounding habitats.

Porites reef: habitat classification. At some sites, there are unusual areas of extensive growth of the Finger Coral *Porites porites*. These areas typically support an abundant number of juvenile fish, particularly grunts, parrotfish, wrasse, and damselfish. These reefs are found in shallow water less than 2 meters deep.

Price ($/kg): simulation boat parameter. Price per kilogram received by fishermen (0.0 – 100.0).

Sand: habitat classification. This habitat includes both clean sand and sand with a sparse algal community. It is found in lagoonal areas and near reefs.

Sargassum on hardbottom: habitat classification. This habitat contains numerous *Sargassum* plants, typically on a hardbottom with a limited covering of sediment. In some areas, the *Sargassum* plants reach greater than 1 meter tall. Other algae often occur between the *Sargassum* plants. This habitat occurs in medium energy lagoonal environments.

Silt / mud: habitat classification. Silt, which is finer than sand, is often present near shore areas and creeks. Seagrass and algae are often present in this shallow water habitat.

Simulation speed: simulation general parameter. Number of days simulated per second of animation (1 - 100).

Sparse gorgonians and algae: habitat classification. Gorgonians include sea fans, sea feather plumes, sea whips, and sea rods. This habitat is composed of sparse gorgonians on a hardbottom with some algae. In some areas, this benthic community is found in shallow reef environments and on hardbottom in the lagoon area.

Sparse seagrass: habitat classification. This habitat is dominated by the seagrass *Thalassia,* also called Turtle Grass, but may contain the tube-like seagrass *Syringodium* and the thin-bladed seagrass *Halodule*. Occasionally one also finds small coral colonies within the seagrass. Sparse Seagrass habitats have relatively low biomass (short plants, low density) and a high amount of substratum is visible. This habitat is found in lagoonal environments where sediment is deep enough for the seagrasses to take root.

Speed (km/hr): simulation boat parameter. Speed of travel to fishing grounds (km/hr; 0 – 100).

Travel cost ($/day): cost per day to operate a boat to and from fishing grounds (0 - 1000).

Uncolonized pavement and sparse gorgonians: habitat classification. Uncolonized Pavement is found in one of the high energy 'cuts' through the *Acropora* reef crest. This habitat is similar to the Sparse Gorgonians and Algae habitat but it has very few gorgonians and algae.

Marine Reserves and Local Fisheries An Interactive Simulation

The Exercise

Eugenia Naro-Maciel and Daniel R. Brumbaugh

OBJECTIVES

In this simulation exercise, you will be able to explore various factors that influence fish population viability and fishery sustainability. You will also experiment with the use of marine reserves as tools in fisheries management.

Discussion Questions for All Seven Levels

As you complete each level, think about the major lessons you have learned, regarding marine populations, fishery management, and marine reserves. The simulations provide a useful heuristic tool for exploring many issues in marine reserve design, and are highly illustrative and useful for comparative and educational purposes. Even so, it is important to consider the limitations of the exercise. The simulation is based on a mathematical model describing organismal population dynamics and fishery economics. The main parameters of this model are the variables on the simulation panel. This model was written by Steven Phillips. The author himself, however, is the first to note that there are limitations to any model, which must be kept in mind when interpreting results. If you would like to learn more about the model, it can be found in Appendix I (see below). This model focuses mainly on the adult life stage.

Can you think of some important caveats, and reasons why, although theoretically useful, the results of this exercise cannot be applied directly to any specific area or species? It might be helpful to read over the introductory pages, as they contain relevant information on complexities in life cycles and fisheries of Nassau Grouper, Spiny Lobster, and Queen Conch.

Notes for All Seven Levels

In working through this exercise, you will notice there are many details. For example, rolling your mouse over each hexagon will cause the exact number of organisms within to be revealed. Keep in mind the overall amount of time your teacher has given you for each assignment, and before focusing on details, try to get an idea of the larger picture.

Although efforts have been made to provide a realistic scenario, due to necessary simplifications and model assumptions, simulation results are not intended to reflect reality.

LEVEL I
STARTING UP

Take a few minutes to familiarize yourself with the exercise, and to become comfortable with the simulation. This part of the exercise focuses on an unprotected system, where there are no reserves in place.

- Make sure that no part of the total area is protected in reserves, by selecting "Clear Reserves" under the "Edit" menu before you begin.
- Select any species-type.
- Press Run. The simulation will automatically run for 20 years.

When the simulation has ended, indicate the option/s that best describe/s overall trends observed. Click on the relevant graph to visualize trajectories over the course of the simulation.

Species: ___________________________________

Population size:	increase	decrease	remain stable
Yellow port total profits:	increase	decrease	remain stable
Blue port total profits:	increase	decrease	remain stable

LEVEL II
OPEN-ACCESS FISHERIES

Divide into groups of 3-6 students. Within each group, one or two students will focus on each species-type, so that all species-types are represented in one group. Make sure you are working on a different organism than you did for Level I. For your new species-type, explore the effects of fisheries on fish population size and fishery economics, when no areas are closed to fishing.

Ongoing fishery crisis. More than two thirds of the world's fisheries are considered fished beyond capacity, or in danger of this (FAO 1995). Increasingly efficient boats and fishery technology, combined with reduced fish population sizes, contribute to this phenomenon.

- To explore this, run the simulation for 20 years and fill out the table below. Use the default values, or the numbers that appear automatically for each species-type at the start of the simulation. The "+ year", "+ 5 years" and "+ decade" buttons may be useful in this regard.

Species: ___________________________________

Number	After 1 Year	After 5 Years	After 10 Years	After 15 Years	After 20 Years
Organisms					
Yellow Boats					
Yellow Total Profits					
Blue Boats					
Blue Total Profits					

Indicate the option/s that best describe/s overall trends:

Population size:	increase	decrease	remain stable
Yellow port total profits:	increase	decrease	remain stable
Blue port total profits:	increase	decrease	remain stable

Discussion points

After running your individual simulations, get together as a group. Discuss your results for the three species-types.

Do you have any thoughts about why patterns might be similar or different?

There are also many interesting points do discuss regarding historical over-fishing, shifting baselines, and trophic cascades (Jackson et al. 2001, Pauly et al. 1998). Overturning prior assumptions, Jackson et al. (2001) showed that many marine populations were overfished even in historical times, and occur today at fractions of their past levels. You may wish to explore this by running the simulations for longer than 20 years, starting at different initial population levels, or reducing fishery effectiveness and maximum harvest.

In related work, Pauly and colleagues coined the term "shifting baseline syndrome" to describe the arbitrary nature of some recovery targets. These authors noted that, in some cases, recovery targets are set at the size the fish population was at the start of the manager's career. On the other hand, if historical levels were considered, recovery targets would be set higher. In the simulation, shifting baselines can be modeled by using different initial population sizes and keeping other parameters constant.

One commonly used definition of an overfished stock is one that occurs at 20% of initial levels. Can you think of a limitation of such definitions, especially when considering history? Can you think of other ways to define overfishing? Of note, when one species becomes overfished, fishers tend to shift their attention to other species, resulting in trophic cascades (Pauly et al. 1998). How might the trends detectable in your simulations be affecting other organisms in the ecological community? Also, consider how different fishing methods might vary in the degree of harm caused to the environment, for example through by-catch, or accidental harvest of non-target species.

LEVEL III MARINE RESERVES AND SINGLE-SPECIES MANAGEMENT

You will now be able to design your own reserve networks for each species-type. Break up again into small groups, or work individually. One or two people will be assigned to work on each species-type within a 2 - 6 person group. You may also wish to have one student or group focus on biological issues, while the other concentrates on economic aspects.

Notes: Before you plan your reserve system, think about feasibility, enforceability, and effectiveness in a real-world scenario. Simpler reserve configurations, with easily understood boundaries and a degree of contiguity, are going to be more realistic. A system of various disconnected single-hexagon reserves, for example, could be ineffective or unenforceable. In most MPAs, in light of practical issues and constraints, boundaries are marked by buoys, signs, or aligned through landmarks offshore, and designed to be readily comprehended, complied with, and enforced.

When evaluating reserve placement, it may be helpful to look at the Average effort, Average harvest and Potential profits options under the "Base Image of Display" pull down menu. Also of interest in this pulldown menu are the habitat Suitability and Classes options.

a. Proportion of area in reserves

At the Fourth World Congress on National Parks and Protected Areas (Caracas, Venezuela, 1972), it was recommended that PAs protect at least 10 percent of each biome; however, this target has not been achieved for marine sites, among others. Over 90% of the world's existing parks are terrestrial, covering about 12% of the land surface. MPAs, however, protect only 0.5% of the global oceans. The Great Barrier Reef MPA in Australia is the largest in the world. In other places, however, reserves may be very small.

- Experiment with the amount of area set aside for protection in a reserve nework of your choice, for your species-type.
- Run the simulation for 20 years.

Species: ___________________________________

Reserves

	100%	50%	25%	10%	No reserves
Total organisms					
Fish in reserves					
Yellow boats					
Yellow profits					
Blue boats					
Bliue profits					

b. Reserve placement

A complex issue in conservation planning is placement of reserves. It has been noted that much of the terrestrial reserve system includes habitats unsuitable for many species (such as the large terrestrial reserve in Greenland, composed mainly of snow).

- Go to Edit, Reset defaults.
- Switch to the Suitability option for "Base Image of Display". The lighter habitats are the most suitable for your species-type. The tool tips will indicate how many organisms are in each hexagon.
- Place 10% of the total area in marine reserves situated in the most suitable habitat (the lightest colored habitat). You may distribute the MPAs as you wish, as long as they are within the specified kind of habitat (suitable or unsuitable). When designing your reserve system, however, think about enforcement and feasibility, as discussed above.
- Run the simulation for 20 years, the default value.
- After filling in the Suitable Habitat column in the table below, go to the Edit Menu and Clear Reserves.
- Next, taking feasibility into account, place 10% of the total area in marine reserves located in unsuitable habitat (hexagons that are black or contain small red dots), and write your answers in the chart below.

- To fill out the "no reserves" column, you may draw directly from your work on previous levels.

Species: ___________________________________

Number	Suitable habitat	Unsuitable habitat	No reserves
Total organisms			
Organisms in reserveves			
Yellow boats			
Yellow profits			
Blue boats			
Blue profits			

Indicate the option that best describes overall trends when reserves are in suitable habitat:

Population size:	increase	decrease	remain stable
Yellow port total profits:	increase	decrease	remain stable
Blue port total profits:	increase	decrease	remain stable

Indicate the option that best describes overall trends when reserves are in unsuitable habitat:

Population size:	increase	decrease	remain stable
Yellow port total profits:	increase	decrease	remain stable
Blue port total profits:	increase	decrease	remain stable

c. Reserve size and connectivity

The so-called SLOSS (Single large versus several small) debate centers around the benefits and costs of choosing a single large versus several small reserves. An important issue is connectivity among groups, which varies in nature. For populations that are naturally connected, for example, instituting a system of isolated reserves may not preserve natural linkages necessary for population processes. These are key factors to consider in reserve design.

- Explore these issues by selecting 6 small, isolated reserves encompassing 10% of the area in total. Each reserve should protect between 5 and 10 hexagons (1- 2% of the total; each hexagon represents about 0.2% of the total). Every reserve should be at least 8 hexagons away from the other reserves.
- Then design one large reserve protecting 10% of the area. Each hexagon in this reserve must be connected to at least one other, except where impossible, such as along the edges.
- In each case, run the simulation for 20 years and enter your results in the table below.

Species: ________________________________

Reserves

Number	Several small isolated	1 large	No reserve
Total organisms			
Organisms in reserve			
Yellow boats			
Yellow total profits			
Blue boats			
Blue total profits			

Indicate the option that best describes overall trends with…

Several Small Reserves:

Population size:	increase	decrease	remain stable
Yellow port total profits:	increase	decrease	remain stable
Blue port total profits:	increase	decrease	remain stable

Single Large Reserve:

Population size:	increase	decrease	remain stable
Yellow port total profits:	increase	decrease	remain stable

Blue port total profits: increase decrease remain stable

d. Reserves in combination with other methods

As noted by Dr. Tundi Agardy in the "Marine Protected Areas and Networks" module, reserves may work best in combination with other measures, such as harvest, gear, and boat limits.

- Enter the 10% reserve system of your choice from your results so far.
- Set the fishing efficiency, maximum boats per port, and maximum harvest levels to ½ their default values.
- Run the simulation for 20 years, then record your results.

Species: ________________________________

Number	Reserves only (from above)	Reserves and limits
Organisms		
In reserves		
Yellow boats		
Yellow total profits		
Blue boats		
Blue total profits		

Discussion Points

After running your individual simulations, get together as a group, to consider how results from different kinds of fisheries compare to each other, and why.

- Were you able to identify reserve networks that eventually increased or maintained stable both fishery rents and fish population sizes?
- Are the networks similar across species?

Although various elements of reserve design were explored separately in each section, in addressing the following questions consider also interactions among different factors, such as habitat suitability and proportion of area protected.

- What percentage of habitat would you recommend be set aside in reserves for each species type, and why? Can you think of limitations of using numerical percentage targets? Are there other criteria that might be important in designating sites for protection?

- How do results when there are no reserves, reserves in unsuitable habitat, and PAs in suitable habitat compare? Is habitat suitability important for effectiveness?
- How would you resolve the SLOSS debate as regards your marine organism? Can you think of a way to reconcile these two approaches? Can you think of specific cases where it would be essential to link sites into a network, and others where this might not be important? Are there local examples you view as models or that need improvement?
- Does your design account for environmental variation or catastrophes?
- What impacts do limiting gear, boats and harvest have on organismal population and fishery economics? What other measures might you employ, either singly or in combination with marine reserves, towards achieving sustainable resource use?
- Do you think your recommendation would be feasible in the real world, in particular as regards enforcement and funding? Is there a role for consumer choice?

Consider also that, in the real world and despite reserve placement, many populations, such as Conch, remain at low levels. Discuss the idea of possible thresholds below which reserve placement has little impact on population numbers, at least in the short-term.

LEVEL IV MARINE RESERVES AND MULTIPLE SPECIES

Working as a group, can you build a reserve network that keeps population numbers of all 3 species-types, as well as fishery profits, steady or increasing, after 20 years? Do you have a compromise solution to offer? Would use of other measures, perhaps in combination with marine reserves, be a useful option?

Discussion Points

Think about these results as regards ecosystem conservation, and the challenge of conserving multiple taxa or systems. Are there local examples of reserves to protect groups of interest? What are your opinions about single-species versus ecosystem level conservation? What are some ways to address controversial issues?

Other key concepts in reserve design are representation and duplication. In general, the former entails ensuring that most major habitat types are included in a reserve system. Switch to the "Classes" option under "Base image of display". Running the mouse over any hexagon will cause tip tools to appear, which will allow you to match habitat type to the color on your habitat map. How many of the 15 habitat types are included in your suggested reserve or network? Are all species and groups equally or fairly represented in your network?

LEVEL V MARINE RESERVES AND SOCIAL EQUITY

Reserve placement may affect the communities near the reserve. Fishers' costs, for example, might increase if they are obliged to fish further away because of the reserve. Place a large reserve (10% of the area) near one of the ports, for each species-type. Run the simulation for 20 years and save the results. Now clear this reserve and place a new one near the other port.

Discussion points

How does the reserve affect the economics of boats from each port? Which port community is likely to benefit from the effect of the reserve, and which is likely to experience the immediate economic costs? Think about implications of an open access fishery where people enter and exit depending on net earning relative to outside opportunities.

When you experimented in the exercises above with other conservation methods, such as fishery limits, you were in effect simulating reserves or zones where take is allowed within prescribed limits. What is your concept of a protected area? Do you think protected areas should be primarily strict, no-take reserves, or can they be sustainably used? Consider examples you may be familiar with. In either case, can you think of reserve planning strategies that could minimize conflict and allow users to voice their concerns? Do you know of any examples where this was successfully accomplished, or where important lessons were learned?

LEVEL VI PROFIT SOURCE

The "Profit Source" feature of this exercise was designed to track the cells of origin for the fish caught by boats from each port. This information can have significant impacts on reserve selection and design. It can also demonstrate the "spillover effect", whereby profits outside reserves are increased when fish protected within the reserve disperse and are harvested in unprotected waters. However, this feature significantly slows down the simulation, and was therefore not included in the exercises above. To use this feature,

- Turn on the profit source feature by going to "Edit", then "Track fish sources".
- Select a species-type. Each of the three species-types should be analyzed by a student group.
- Switch to the Yellow profit source option in "Base Image of Display". The lighter habitats are the greater profit sources for your species-type. The tool tips will indicate the profit source per hexagon.
- Run the simulation for five years, and save the results.
- Fill out the first column of the table below, then go to Edit, Reset to time 0.
- Place 10% of the total area in marine reserves. You may distribute the MPAs as you wish; however, when designing your reserve system, think about enforcement and feasibility, as discussed above. You may wish to look at the potential profit sources under the "Base Image of Display".

- Run the simulation for five years.
- Fill out the second column of the table below.
- To view the results for the blue port, switch to "Blue profit source" under "Base Image of Display".
- Go to File, Save, and save the results.

Species: ___________________________________

Number	No reserves	Reserves
Total organisms		
Organisms in reserves		
Yellow boats		
Yellow totap profits		
Blue boats		
Blue total profits		

Discussion points

Get together as a class to discuss these questions, referring to the profit source maps you saved. Can reserves be economically valuable as sources of individuals that "spillover" to surrounding areas? Do results vary by species-type, and if so, can you think of some biological characteristics that could explain this? How can choices about reserve placement and design affect biological and economic aspects of the fishery?

LEVEL VII SENSITIVITY TO DEMOGRAPHIC AND ECONOMIC VARIATION

In this section, you will explore how select variables contribute to population growth and fishery total profits by completing the table below, following the Initial Population Size example in the table.

- Break up into at least 4 groups.
- If you were working on Level VI, don't forget to turn off the Profit source feature. Go to "Edit", then "Don't track fish sources".
- Each group will be assigned or choose to work with the lobster species-type and a set of variables. One group will work with the first 5 values (biological) with no

reserves. The second group will work with the first 5 variables (biological) with 25% reserves. The third group will work with the last 5 (economic) variables from the table below, without reserves. The fourth group will work with the last 5 (economic) variables, with 25% reserves.

- Depending on the size of the group, one person can be assigned to one or two variables. If there are more than four groups, additional species-types can be worked with.
- Change one variable from the table below at a time to their minimum (a value of at least 10) or maximum values. The minimum and maximum values will appear in the tool tips and can also be found in the Glossary. Please remember that the tool tips will only appear when the mouse is rolled over the legend, not the value field.
- Before moving on to the next variable, remember to reset to: 1) time 0; and 2) to your previous values.
- Run the simulation for 20 years.

Discussion Points

Get together as a class for discussion. Now that you have explored the effects of fish and fishing characteristics on organismal populations and the fishery, consider the following questions.

What would the ideal species to protect using marine reserves be, in terms of demographic characteristics (lifespan: long vs. short; intrinsic growth rate: high versus low; dispersal rate)? What are the fishery characteristics most likely to produce a balanced system (fishing efficiency: high or low; costs: high or low)?

What combinations of factors produce better results in terms of larger fish populations, overall fishery statistics, and per capita earnings? What combinations tend to produce population crashes? Why might extreme values such as these not provide the full picture?

____No reserves
____Reserves

	Fish population		Economics Yellow		Economics Blue	
VARIABLES	Min.	Max.	Min.	Max.	Min.	Max..
Initial population						
Overall effect	A high initial population size results in rapid over-harvest, and therefore collapse of both population and profits. A very small population size results in negative profits.					
Lifespan						
Overall effect						
Intrinsic growth						
Overall effect						
Ave. catch weight						
Overall effect						
Dispersal rate						
Overall effect						
Fishing efficiency						
Overall effects						
Travel costs						
Overall effects						
Number of boats						
Overall effects						
Max. harvest						
Overall effects						
Price						
Overall effects						

Next Steps

Please feel free to explore the simulation further. You may wish to run the simulation using different time frames, for example to explore effects of historical overfishing. You may also choose to model other organisms by inputting new variables into the simulation panel. Make sure, however, that the habitat is appropriate to your organism. Consider visiting the following websites for more information on these and other species:

- www.fishbase.org
- www.arkive.org
- www.natureserve.org
- http://www.strombusgigas.com/
- http://marinebio.org

Additional Reading

Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity. 2005. Elliott A. Norse and Larry B. Crowder (Editors). Marine Conservation Biology Institute, Island Press.

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TERMS OF USE

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Appendix I: The Simulation Model (By Steven Phillips)

The map is divided into a set of (hexagonal) grid cells, and I'll use variables x and y to refer to cells. The basic population growth equation relates the population p_{i+1} on day $i+1$ to the population on day i:

$$p_{i+1} = p_i(x)(1 + g_x(p_i(x))) - \delta_x p_i(x) - h_i(x) + \sum_y \delta_{y,x} p_i(y)$$

where the terms represent population growth inside x, dispersal out of x, harvest from x, and dispersal into x, respectively. The dispersal rate out of x is just

$$\delta_x = \sum_y \delta_{x,y}.$$

Each cell x has a "habitat suitability" $H(x)$, between 0 and 1. Growth inside a cell is logistic growth, with some natural mortality. In symbols:

$$g_x(p) = -\mu + r\left(1 - \frac{p}{KH(x)}\right)$$

Here μ is the mortality, which we estimate as one over the typical lifespan of a fish, in days. The upper limit on the population size is $KH(x)$, where $H(x)$ is the habitat suitability of cell x, and K is the carrying capacity (maximum population) of a grid cell with perfect conditions for the species. The constant r is the rate of growth when the population in a cell is far from the maximum; this is called the "intrisic growth rate".

A fraction α of the fish in each cell swim to a neighbouring cell each day. The choice of which cell a fish moves to depends on the availability of resources. If we set

$$\sigma_x = \sum_{y \in \text{neighbours}(x)} H(y)/(1 + p(y))$$

then

$$\delta_{x,y} = \frac{\alpha H(y)}{(1 + p(y))\sigma_x}.$$

Now for the harvest term: it's the sum of the harvests of all boats currently in existence. I'll use the variable b to refer to a boat:

$$h_i(x) = \sum_b [\gamma_i(b) = x]\phi_b(x)$$

where $[\gamma_i(b) = x]$ is in indicator variable equal to 1 if boat b is in cell x on day i and 0 otherwise, and $\phi_b(x)$ is the number of fish b harvests if it does visit x. The latter term depends on the boat's efficiency $e(b)$, its maximum daily capacity $m(b)$, the commute time to get to x, and the population in x:

$$\phi_b(x) = \min\{m(b), e(b)p(x)t_b(x)\}$$

Here $t_b(x)$ is the fraction of a day that b can spend at x (considering commute time), which can be calculated from boat speed and distance, assuming an 8-hour working day:

$$t_b(x) = 1 - \frac{d_{x,\text{port}(b)}}{8 * \text{speed}(b)}.$$

Appendix I (Continued)

Finally, we need to specify the boat behaviour. Say that a boat b visited cell x one day and had profit ρ. If $\rho \leq 0$ or ρ is less than a third of the average profit of boats from the same port, or randomly (with probability 0.03), then the next day b visits a random cell, as described below. Otherwise, b visits either x or one of the (non-reserve) neighbours or x, with the choice made to maximize profit. Note that this assumes some prescience from the boats, as it assumes they know what the profit would be in each neighbour.

The profit of a boat depends on the harvest, the wholesale price of the fish (\$$f$ per kg), the average weight of a fish (w kg), travel costs (at a rate of $t(b)$ dollars per km) and daily boat cost, $\omega(b)$:

$$\text{profit}_b(x) = \phi_b(x) f w - 2t(b) d_{x,\text{port}(b)} - \omega(b)$$

If the boat chooses a random cell, it does so as follows. If there is any (nonreserve) cell in which it can make a profit, it chooses from all such cells with probability proportional to the profit. Otherwise, it chooses from all non-reserve cells with probability proportional to exponential profit, $e^{\text{profit}_b(x)}$. The latter rule biases the choice in favor of cells where the boat will make the smallest loss.

Lastly, this is an open fishery, so we need rules for when boats come and go. Each port has a maximum number of boats. If no boats from a port have any profit in any one day, and there are currently at least two boats operating from the port, then one boats stops fishing. If all the boats have at least \$50 profit per day for at least 30 days, and the current number of boats is less than the maximum, then another boat starts fishing.

For an initial configuration, the user picks an initial total population, i.e., number of fish. The initial population is divided between the cells in proportion to their suitability. Initially there are 2 boats per port.

Designing a Marine Reserve in the Mediterranean

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Source: C. Roberts and J. Hawkins

Designing a Marine Reserve in the Mediterranean

Eugenia Naro-Maciel

OVERVIEW

The Pelagos Sanctuary

The complexity, challenge, and promise of designing a marine protected area (MPA) are compellingly evident in the case of the Pelagos Sanctuary for Mediterranean Marine Mammals (Box 1; Notarbartolo di Sciara and Hyrenbach with Agardy, 2007).

Box 1. The Pelagos Sanctuary for Mediterranean Marine Animals

"The Pelagos Sanctuary for Mediterranean Marine Mammals is a large protected area covering more than 87,000 km2 of sea surface in the north-western Mediterranean Sea, between south-eastern France, the Principality of Monaco, north-western Italy and northern Sardinia. The waters of the Sanctuary contain the internal maritime and territorial waters of France, Monaco and Italy, as well as the adjacent high seas."

"The Pelagos Marine Sanctuary was established for three primary reasons: (1) the discovery of significant populations of fin whale (*Balaenoptera physalus*) and numerous other cetacean species in the Ligurian Sea; (2) the emergence of signs that significant threats to these cetaceans existed, based primarily on evidence of a striped dolphin (*Stenella coeruleoalba*) epizootic, or mass disease event, in 1989, and increasing numbers of strandings of marine mammals accidentally caught in the drift net fishery; and (3) no adequate legal framework existed to provide an adequate mechanism for the protection of marine wildlife in the Mediterranean high seas, where most of these cetaceans are found."

[In the Mediterranean during the late 1980s] "… public recognition of threats to marine biodiversity grew. In part this awareness was spurred by strandings caused by cetacean accidental catch, otherwise known as by-catch, in the Italian pelagic drift net fishery for swordfish. (Pelagic drift net fisheries are those that take place offshore involving large hanging nets through which fish and other marine life try to swim but become entangled.) The national and international media highlighted these by-catch impacts, leading to United Nations Resolution 44/225 of Dec. 1989. This established a global moratorium on large-scale pelagic drift net fishing (Scovazzi, 1998). In addition to fishing, other major anthropogenic impacts on the marine environment began affecting cetaceans. Maritime traffic, including high-speed passenger vessels, pleasure craft, naval ships and expanding commercial whale watching activity were all increasing, with the risk of disturbance and collisions (Notarbartolo di Sciara et al., in prep). Growing ship traffic also carried with it the risk of hazardous substance release, such as occurred during the 1994 oil spill caused by the blaze of the tanker Haven off Genoa. These threats slowly entered the public consciousness."

"The drive to protect the area was led by a few environmental champions, who recognized both the threats and the opportunities to promote large-scale marine conservation. These champions include Prince Rainier III, who mobilized Monaco and led the neighboring states into multilateral agreements, top diplomats, legal scholars and the founder of Tethys, a highly regarded Italian Non-Governmental Organization (NGO)."

"In spite of the difficulties posed by the formidable task of granting protection to cetacean populations in such a large area, and within such a heavily exploited environment, the Pelagos Sanctuary has already resulted in a number of positive outcomes. These include: raising public awareness; taking what for the region is the rare but necessary step of creating and implementing a management plan; catalyzing voluntary measures by the three governments to minimize environmental impacts on the area; and providing a demonstration model for large scale, ecosystem-based management, high seas MPAs, the utility of regional seas agreements, the use of umbrella species to protect whole ecological communities, and the role of individuals in carrying forward a conservation vision."

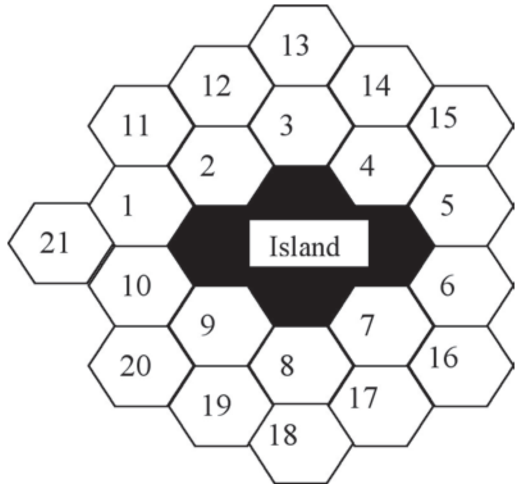
(Excerpted from the NCEP case study: *The Pelagos Sanctuary for Mediterranean Marine Mammals*).

THE EXERCISE

Although the Pelagos sanctuary does have a formal management plan, zoning measures are not included. Zoning is the spatial definition of activities permitted within areas of a reserve, and is a useful management tool worldwide. Zones can range from areas under strict protection to those where regulated human use is permitted. Notarbartolo di Sciara and Hyrenbach (2007) note that zoning could be helpful for management and conflict resolution at Pelagos as well, for example with respect to whale watching activities.

In this exercise, you have been invited to a meeting convened by interested parties to inform Mediterranean stakeholders about systematic reserve design and zoning. The meeting organizers hope that, by experiencing the simplified reserve planning process described below, participants will consider: 1) establishing a zoning plan at Pelagos; and 2) adopting a participatory process when designing other marine protected areas.

You will be part of a group that is designing a marine protected area and formulating a zoning plan. Your group will be composed of the major stakeholders in this case, and you will be undergoing a participatory reserve design process designed to fairly address concerns. The target site has been divided into 21 planning units surrounding a fictional island:



PROCEDURE

First, one or two students in your team will choose or be assigned a stakeholder category representing: 1) Biodiversity Conservation; 2) Fishing; or 3) Recreation and Tourism, so that all three categories are represented in each group by one or two students.

In the case of Pelagos, stakeholders interested in biodiversity conservation have focused on protecting fin whales and other cetaceans, as well as their ecosystems. These stakeholders may include NGOs such as Tethys, researchers, government representatives such as Prince Rainier III, or private citizens. However, there is also extensive commercial fishing in the Mediterranean, including long line and drift net fisheries, and these activities play an important role in the economy and in social welfare. As well, the Mediterranean is world famous for its beauty, and thus other stakeholders, such as entrepreneurs or governmental representatives, are interested in promoting the area for recreation and tourism.

Conservation Planning

Now consider that all of the data deemed necessary for the reserve design process have been input into a computer program which, based on clear and transparent criteria, has designated whether each site is a priority for each stakeholder group. If the site is a priority, "Y" was entered for yes, if not, "N" was entered for no (Table 1).

On three separate planning unit maps, students in each stakeholder category within each group are next asked to shade in the subset of sites that they consider priority areas for biodiversity protection, fishing, or recreational use according to Table 1. Thus, each student group will produce three separate maps, one per stakeholder category.

Compare and discuss your results with each other. What reserve design tools are available for reconciling differing biological and socio-economic needs?

Table 1. Priority Sites for Reserve Planning

Site	Biodiversity	Fishing	Recreation
1	N	Y	Y
2	N	N	Y
3	Y	N	Y
4	Y	N	N
5	N	Y	N
6	N	N	Y
7	N	Y	N
8	Y	N	Y
9	N	Y	N
10	Y	Y	Y
11	N	Y	N
12	Y	N	N
13	Y	Y	Y
14	Y	N	Y
15	N	Y	N
16	Y	N	Y
17	Y	Y	N
18	Y	N	N
19	N	N	Y
20	Y	Y	Y
21	N	Y	N

Zoning

The group agrees to designate three kinds of zones stipulating permitted activities at each site: 1) no-access/no-take (NN); 2) access/take (T); and 3) access/no-take (AN).

Which category of stakeholder would benefit primarily from each zone? It is important to note that these are overly simplified categories for the purposes of the exercise, and that in the real world multiple objectives can be reached within one zone.

Consensus Building

On an unmarked map, produce a preliminary zoning plan for each site in the park.

Start with the sites that are only important for one group. Tally up the number of sites for each kind of zone.

Next work on the sites that are priorities for two groups.

Propose a few strategies for accommodating both stakeholders. In the case of biodiversity, consider that there is a preference for adjacent sites because species with large home ranges, such as cetaceans, are present. Due to the characteristics of this area, it is important to include sites that are arranged in a row of three.

Now work with the sites that are priorities for all groups and devise strategies for a compromise.

DISCUSSION

It is essential to note that for the purposes of this exercise, issues have been simplified. In the "real world", creation of protected areas is a highly complex process. To explore this further, consider the following questions:

A. Consider the implications if:

- There had been more stakeholders with diverging interests.
- There had been fewer stakeholders because not all of the interested parties participated in the planning process.
- The preferences of particular stakeholder groups were valued more highly than others by the decision makers.
- The results of the computer program differed depending on stakeholder criteria.

Is a participatory MPA design process typical or an exception? Would you recommend this kind of process?

B. Consider enforcement and funding issues. Now that you have a good zoning plan, devise strategies to avoid this becoming a "paper park", or park in name only.

C. Now think about this case in a larger socio-economic context. How might decisions and recommendations vary depending on how the area surrounding the park is used? For example, what if the waters around all of the nearby islands were open to fishing and recreation, with no provision for biodiversity conservation? What if they were closed off to fishing because of conservation priorities?

TERMS OF USE

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The Pelagos Sanctuary for Mediterranean Marine Mammals

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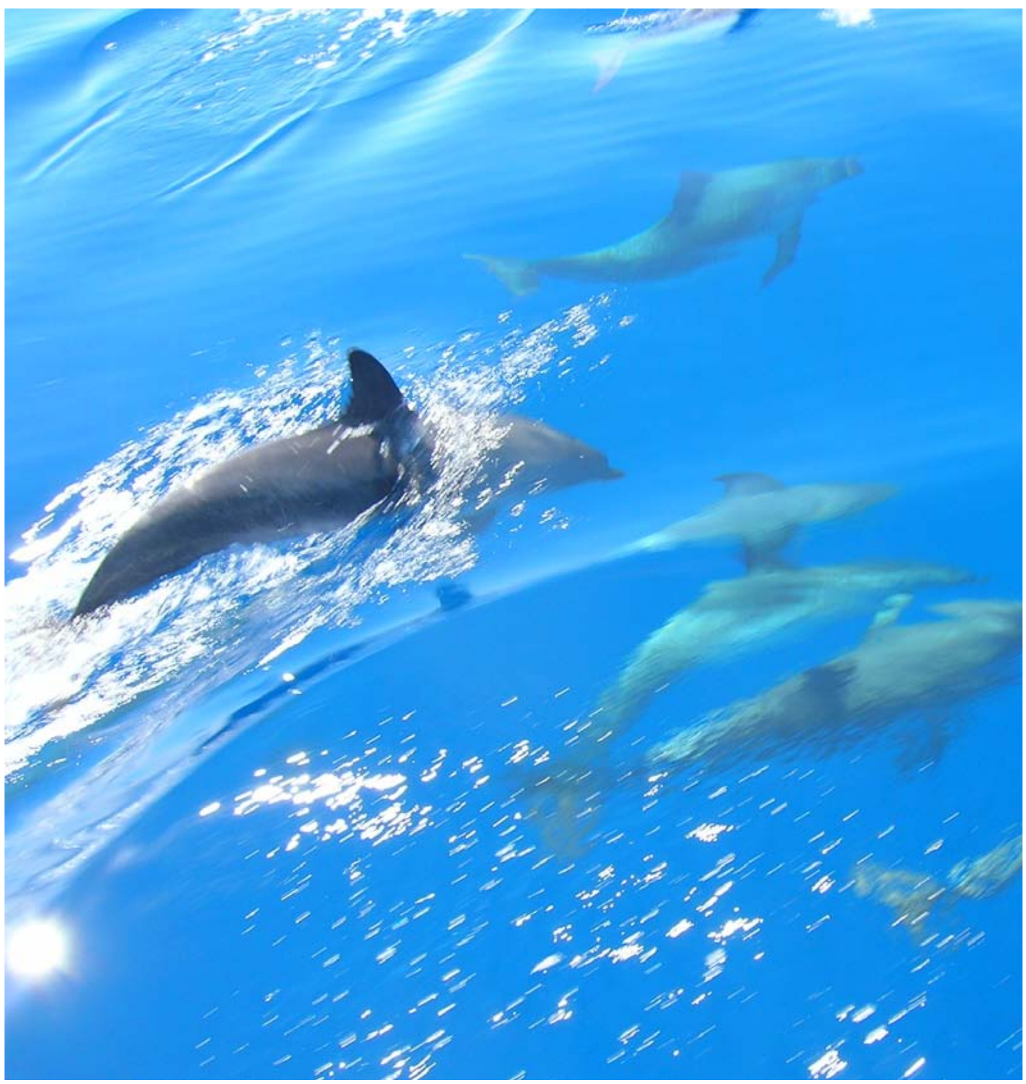

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The Pelagos Sanctuary for Mediterranean Marine Mammals

Text by Giuseppe Notarbartolo di Sciara and David Hyrenbach
Boxes by David Hyrenbach and Tundi Agardy

Overview

In the Mediterranean -- one of the best-known, heavily utilized bodies of water around the world -- a recent discovery provoked surprise and provided impetus for conservation. Large populations of eight marine mammal species, including several cetacean species, were discovered, supported by a permanent frontal system concentrating vast populations of zooplankton and other food sources. The presence of these spectacular mammals in such a heavily used area surprised the public and the scientific community alike. The confluence of this discovery, and heightened public awareness about a spate of marine mammal strandings resulting from disease and by-catch in the drift net fishery, has led to a drive to protect this newly discovered special feature. The governments of Italy, France, and Monaco made an unprecedented move to protect this high seas area by declaring it a marine mammal sanctuary called "Pelagos".

The drive to protect the area was led by a few environmental champions, who recognized both the threats and the opportunities to promote large-scale marine conservation. These champions include Prince Rainier III, who mobilized Monaco and led the neighboring states into multilateral agreements, top diplomats, legal scholars and the founder of Tethys, a highly regarded Italian Non-Governmental Organization (NGO). The opportunity to establish a tri-national marine protected area was, paradoxically, created by the lack of mechanisms for protecting the high seas, since Mediterranean countries have not yet declared 200-mile Exclusive Economic Zones (EEZs), and no legal framework existed for management of marine areas outside of the 12-mile territorial seas. The responsibility to successfully implement the Pelagos Sanctuary still rests on the three governments, but the conservation effort's success will likely rest on a committed drive by civil society to keep pressure on the public sector to live up to its commitments.

Historic, Conflicting Quotes on Whales in the Mediterranean

1985: *"The Mediterranean is not a very productive sea. [It]shows no appreciable upwelling… [and] visible blooms and red tides are of limited occurrence."*

-R. Margalef, 1985

but...

1989: *"The oligotrophy of the western Mediterranean: a fading paradigm?"*

-G. Jacques, 1989

1899: *"Concerning cetaceans, I had the opportunity of making interesting observations. For instance, it is generally believed that to find these animals one must travel to the Arctic seas … In those regions, during two campaigns at sea, I haven't been able to sight a single cetacean, whereas from my home in Monaco, from my window, I can often see some. In order to find cetaceans, and to find them in large numbers, one must visit the Mediterranean."*

-Albert 1 , Prince of Monaco,
(W.H. Kuehl, 1901)

but...

1965: "*The Fin whale pays a heavy tribute to the whaling industry, and therefore, although its catches are theoretically regulated, the species' population size appears to be compromised. Such industry, however, is practically inexistent in the Mediterranean due to the rarity of these Cetacea."*

-A. Toschi, 1965

Problem Statement

The Pelagos Marine Sanctuary (Figure 1) was established for three primary reasons: (1) the discovery of significant populations of fin whales (*Balaenoptera physalus*) and numerous other cetacean species in the Ligurian Sea (Figure 2); (2) the emergence of signs that significant threats to these cetaceans existed, based primarily on evidence of a striped dolphin (*Stenella coeruleoalba*) epizootic, or mass disease event, in 1989, and increasing numbers of strandings of marine mammals accidentally caught in the drift net fishery; and (3) no adequate legal framework existed to provide an adequate mechanism for the protection of marine wildlife in the Mediterranean high seas, where most of these cetaceans are found.

Figure 1. The Pelagos Marine Sanctuary (Source: Tethys Institute)

The significance of the Mediterranean for cetaceans was not unknown during the history of its many great civilizations. In fact, the Romans called the coastline facing this portion of the Mediterranean the "coast of the whale." Prince Albert 1er of Monaco stated in 1899 that he was more likely to see whales from the window of his palace in Monaco than during whale research cruises in the Arctic. However, the notion of cetacean abundance in the Mediterranean was subsequently largely forgotten. In the 20th Century, mainstream ecology asserted that the Mediterranean was oligotrophic, or of relatively low productivity, and could not support significant populations of top marine predators. This was the commonly held perception until the late 1980s, when dedicated research cruises provided a different view of marine productivity in the area (Jacques, 1989), while others surveyed the entire Mediterranean for cetaceans (Notarbartolo di Sciara et al., 1993). The data from ship-based transects highlighted the presence of important cetacean habitats and populations within a wide marine area between Corsica and the continental coasts of France and Italy, known as the Corsican-Ligurian-Provençal basin (Forcada et al., 1995, 1996).

During the same period, public recognition of threats to marine biodiversity grew. In part this awareness was spurred by strandings caused by cetacean accidental catch, otherwise known as by-catch, in the Italian pelagic driftnet fishery for swordfish. (Pelagic drift net fisheries are those that take place offshore involving large hanging nets through which fish and other marine life try to swim but become entangled.) The national and international media highlighted these by-catch impacts, leading to United Nations Resolution 44/225 of Dec. 1989. This established a global moratorium on large-scale pelagic drift net fishing (Scovazzi, 1998). In addition to fishing, other major anthropogenic impacts on the marine environment began affecting cetaceans. Maritime traffic, including high-speed passenger vessels, pleasure craft, naval ships and expanding commercial whale watching activity were all increasing, with the risk of disturbance and collisions (Notarbartolo di Sciara et al., 2007). Growing ship traffic also carried with it the risk of hazardous substance release, such as occurred during the 1994 oil spill caused by the blaze of the tanker *Haven* off Genoa. These threats slowly entered the public consciousness.

Box 1. High Seas

"One of the difficulties with dealing with the high seas is that even the concept of high seas is poorly understood and that their definition is more legal than biological in nature - though obviously their ecology is of considerable importance. Under the legal regime set up by the United Nations Convention on the Law of the Sea, which was adopted in 1982 and is commonly referred to as a constitution for the oceans, coastal States are responsible for the management of marine resources within their coastal waters, broadly defined as an area that extends from the coastline to 200 nautical miles (n.m.) offshore. These areas under coastal states jurisdiction include internal waters within the coastal baselines (e.g. bays, estuaries, etc.), territorial seas generally extending to 12 nautical miles offshore, and exclusive economic zones (EEZs) extending from the limits of the territorial sea to 200 n.m. from the coast. This is particularly important because coastal States could, theoretically at least, control and impose limits on exploitation of resources within their zone of jurisdiction. No single entity, however, has such power on the high seas and the regime that prevails is one of freedom of exploitation. This freedom is not absolute but is mainly constrained by the rights of other states to share in the exploitation of resources, and what is sorely missing is an emphasis on conservation, or at the very least sustainability." (Source: De Fontaubert, C. 2006. High seas: the last frontier for ocean management, The W2O Observer. Available at http://www.thew2o.net/archive_new.html?id=25)

Despite increased awareness of both the value and risk to the Ligurian Sea area and its wildlife, protection was limited by the legal regime of the Mediterranean states. Mediterranean riparian states (those with watersheds emptying into the Mediterranean Sea) have never declared EEZs extending to 200 nautical Miles (n. mi.; 370 km). Thus ocean areas beyond the 12 n. mi. (22 km) territorial sea are high seas, without the management regimes made possible by national jurisdictions (Box 1). In 1995, a revision of the Specially Protected Areas Protocol to the Barcelona Convention – the Mediterranean Regional Seas Agreement [see NCEP module: "*International Treaties for Marine Conservation*"] -- allowed consideration of high seas protected areas. This presented an opportunity to move forward with the strong public support for marine conservation felt in Italy, Monaco and France, and created a push for the establishment of a Ligurian Sea Marine Protected Area (MPA) (Notarbartolo di Sciara et al., 2007).

History

Growing public awareness led civil society to take on an active role in promoting an MPA in the area. In 1990, an Italian NGO called the Tethys Research Institute (Box 2) proposed a project to promote the establishment of a marine protected area in the high seas encompassing the most important habitat for cetaceans in the region (Venturino, 1997). This project was submitted to the "European Association Rotary for the Environment," which provided initial funding (Box 2). Thus "Project Pelagos" was born. Tethys' early work concentrated on examining the ecological representativeness of the area, its high species diversity, its intense biological activity, the presence of critical habitat for a number of pelagic species including cetaceans, and the opportunities that the area offered to baseline research.

"Project Pelagos" forged ahead into uncharted territory with its subsequent campaign for MPA establishment. At the time, the proponents of the project envisaged the creation of a Biosphere Reserve in the high seas of the Ligurian-Corsican-Provençal Basin – an area where it was thought that no legal regime could offer the high seas strict protection. It was anticipated that the international authority for this Biosphere Reserve would be headquartered in the Principality of Monaco, as the entirety of Monaco's coastline faces this region (Notarbartolo di Sciara, 1997).

When in March of 1991, Tethys presented "Project Pelagos" to the public in Monaco, it had the support of local businessmen

Box 2. NGOs
by Tundi Agardy

The Pelagos Sanctuary was initially promoted by two NGOs, the Tethys Research Institute and the European Association Rotary for the Environment, and subsequently supported by a number of environmental NGO, most notably the World Wildlife Fund (WWF).

The Tethys Research Institute (www.tethys.org) is a non-governmental research organization having as its main goal the promotion of the conservation of the marine environment through the collection of scientific knowledge. Tethys aims at protecting the Mediterranean biodiversity by promoting the adoption of a precautionary approach for the management of natural resources. Public awareness and conservation activities, coupled with education and capacity building, find their strength in Tethys' scientific background. The activities conducted by Tethys seek to prevent the decline of marine species – cetaceans in particular - and to encourage a sustainable use of the marine environment, particularly where habitat degradation makes it necessary. Founded in 1986 in Milan, Italy, by Giuseppe Notarbartolo di Sciara and Egidio Gavazzi, the institute is headquartered at the Milan's City Aquarium, and has offices in Venice hosted by the Civic Natural History Museum of that city. Tethys has conducted longitudinal studies of bottlenose dolphins in the northern Adriatic Sea since 1987, and on both common and bottlenose dolphins in the eastern Ionian Sea. Research methods used by Tethys included remote sensing and telemetry, relative abundance and line-transect population studies, the combined use of laser range-finding binoculars and GPS to passively track and record the horizontal movements of whales, bioacoustic research, photo-identification and behavioral sampling, remote biopsy sampling for genetic and toxicological analyses, and historical research. With a core of about 35 collaborators (largely marine biology professionals and students) and a membership averaging 300/year, the Tethys Research Institute has involved in its campaigns thousands of people from all over the world, and has developed a network that is constantly growing.

The European Association Rotary for the Environment (www.aera.it) is a non-profit organization which was founded in the early '90s in Milano by the Rotary Clubs of Districts 2030-2040-2050-2080-2110. The organization pursues its aim of social solidarity through educational activities, scholarships, and the development of environment-friendly technologies.

Strong support in promoting the Pelagos Sanctuary was provided in Italy and France by the Worldwide Fund for Nature (WWF). In particular, the Italian branch of WWF (www.wwf.it) worked in tandem with the Mediterranean Programme of WWF (www.panda.org/mediterranean) to catalyze the effort. The WWF Mediterranean Programme's goal is to conserve the natural wealth of the Mediterranean and to promote the sustainable use of natural resources for the benefit of all. It focuses primarily on the conservation of forest, freshwater and marine ecosystems, promoting the establishment of protected areas and resource use practices that maintain biodiversity and ecological functions. The Mediterranean Programme of WWF also works to promote a sustainable fisheries regime in the entire basin, to prevent nature loss from mass tourism development, to ensure that the European Union's Mediterranean policy is ecologically sustainable and socially equitable, and to improve and implement measures against marine pollution. WWF generally works to build the conservation capacity of individuals and organizations. Importance is given to communications and advocacy to inform people, to raise awareness and to persuade decision makers and stakeholders to act.

in the Rotary Club chapters in Italy (Milan), Monaco and France (Saint Tropez), and the European Association Rotary for the Environment. Prince Rainier III of Monaco received the proposal enthusiastically and granted support of the Principality. It was Prince Rainier III who then championed the idea that a sanctuary for cetaceans be eventually created in the Ligurian-Corsican-Provençal basin through a trilateral agreement among France, Italy and Monaco (Box 3).

Box 3. Champions of the Ocean Environment: The Role of Individuals in Establishing MPAs
by Tundi Agardy

The birth of the Pelagos Sanctuary would not have been possible, or even imaginable, without a few dedicated individuals who championed the idea and carried it forward.

The early conceptualization of a vast marine mammal sanctuary was partly the brainchild of Giuseppe Notarbartolo di Sciara, who continues his involvement with Pelagos to this day. Giuseppe is an Italian marine biologist, who is well known throughout Europe as a conservation leader and television personality. He was a guest of "*Noah's Ark*", a documentary series on wildlife of the world, and is the marine science advisor for "*Geo + Geo*," a live show televised daily throughout Italy; he is the recipient of the Golden Trident Award by the International Academy of Underwater Sciences and Techniques. Giuseppe's interest in marine mammals grew out of a lifelong love of the sea. His ancestors were mariners and his father was a founder of the Centro Velico di Caprera, which honed his interest in Italy's marine environs and pointed his childhood fascination with animals towards marine life.

Opportunities for research on marine mammals in Italy were non-existent in the 1970s, however, so when he finished his studies at University of Parma, working on gobies, he traveled to the U.S. At Hubbs-Sea World in San Diego, he worked on beluga whales and whale sharks, and ended up doing his Ph.D. at Scripps Institution of Oceanography on manta rays in the Gulf of California (where he discovered a new species that he named after his good friend and mentor Walter Munk). Returning to Italy brought Giuseppe to a fateful encounter with many of the other champions who would become so instrumental in fostering Pelagos. Key was his membership in and subsequent coordination role in the marine mammal working group of CIESM (the International Council on the Exploration of the Mediterranean Sea). Also critically important was his founding of *Tethys Research Institute*, the NGO specializing in the study of Mediterranean cetaceans that spearheaded the establishment of the Pelagos Sanctuary. In 1996, the Environment Minister of Italy nominated Giuseppe for the presidency of ICRAM (the Central Institute for Applied Marine Research), and his term there brought him into the realm of diplomacy and politics – providing him invaluable insight and tools for continuing his push for establishment of the Sanctuary.

Prince Rainier III of Monaco was another key champion in the 15 years of developments that ultimately led to the Pelagos Sanctuary. The Monegasque royal family had had a longstanding relationship with the sea and marine science, beginning with the reign of Prince Albert I (1848-1922), who set out to follow the "career of a navigator" (the title he put on his memoirs). Prince Albert I directed 3,698 operations at sea, founded the Oceanographic Institute with its centers in Paris and Monaco in 1906, and founded CIESM in 1919. Prince Rainier III followed his ancestor's footprints, becoming appointed President of CIESM in 1956, at a time when the institution had grown to 17 member states and much influence. Fifteen years later, he created the *Albert I of Monaco Prize for Oceanography* to recognize other champions of marine science and conservation. Prince Rainier's concern for the marine environment and marine pollution continued to grow. In 1970 he took the initiative for launching a Franco-Italo-Monagasque project for cooperation between the administrative, technical, and scientific authorities of the three countries. This set the stage for the RAMOGE Convention (named after its geographic spread from St Raphael in France through Monaco, and to Genoa), which created a legal framework for cooperation between the three countries in the region of the greater Ligurian Sea – the very same region that would become the territorial sea portion of the Pelagos Sanctuary. So it was that in 1991 when *Tethys* and its NGO partners presented the proposal for Pelagos in Monaco, the idea found a ready, willing, and eminently capable champion in Prince Rainier III. It is reassuring to learn that his son, Prince Albert II, is intending to carry on his legacy.

The Role of Individuals in Establishing MPAs (Continued)

The Pelagos Sanctuary might never have happened without the personal support of Carlo Ripa di Meana and Segolène Royal, who in 1991 were Ministers of the environment, respectively, of Italy and France. Ripa di Meana and Royal had an informal breakfast conversation in Scotland during an European environment summit, in the presence of Ambassador Giuseppe Cassini, then diplomatic counselor to Ripa di Meana. They agreed that Italy would support the creation of a transboundary French-Italian marine park in the Strait of Bonifacio, between the islands of Sardinia (Italy) and Corsica (France). This was a matter close to the French heart, and France was grateful. In turn, the Italian diplomats lobbied their French colleague to support the promotion of the Pelagos concept. Soon after the meeting in Scotland, Ambassador Cassini organized and chaired in Genoa and Nice a series of French-Italian-Monegasque intergovernmental meetings to move forward with the Sanctuary, which led to the signing of the 1993 Brussels declaration. It was since the Genoa meeting that substantial support for the construction of the legal framework of the Sanctuary Agreement was secured from Tullio Scovazzi, professor of international law at the University of Milan. In 1995, Prof. Scovazzi contributed substantially to the drafting of the revised SPA Protocol to the Barcelona Convention. His recent involvement with the Pelagos Sanctuary strongly contributed to the inclusion in that Protocol of a provision for the creation in the Mediterranean of high-seas MPAs.

The idea of a whale sanctuary was rapidly endorsed by a number of NGOs, most notably the World Wildlife Fund (WWF). At the 1994 World Conservation Union (IUCN) General Assembly in Buenos Aires, NGOs put forward Resolution 19.92 concerning the "Establishment of a Marine Sanctuary for Large and Small Cetaceans in the Ligurian Sea, Western Mediterranean," which was successfully adopted.

Soon the environment ministers of Italy and France decided to join Monaco in the effort to establish a cetacean sanctuary in the high seas. Although a joint declaration of intention "concerning the institution of a Mediterranean sanctuary for marine mammals," had been signed in Brussels in March 1993 by officials of the three countries, a five-year lull followed. However, thanks to vigorous lobbying by the NGO community, and in particular by WWF Italy, the issue reappeared in 1998 when it was taken up by the Italian Parliament. At this time, public opinion was very much in favor of a sanctuary, even among Italian fishermen, whose interests in using driftnets in that area had diminished as their attention went to other areas and gears.

A final document known as the "Agreement on the Creation of a Mediterranean Sanctuary for Marine Mammals" was produced in the second round of intergovernmental meetings. This was signed in Rome on 25 November 1999 and deposited with the Principality of Monaco (Table 1). A declaration appended to the agreement stated that parties would

Table 1. Timeline

Year	Event
1980s	Widespread concern in Italy and France for the impact of pelagic driftnets and other human activities on cetacean populations in the area.
1990	The Tethys Research Institute formulates "Project Pelagos" for a Reserve of the Biosphere in the Ligurian-Corsican-Provençal Basin to protect cetaceans. The study is sponsored by the European Association Rotary for the Environment (AERA).
1991	Tethys and AERA present "Project Pelagos" in Monaco, at the presence of Prince Rainier III, who embraces the idea.
1992	The governments of Italy and France join Monaco in an international effort to establish a marine mammal sanctuary in the area.
1993	France, Italy and Monaco sign in Bruxelles a Declaration of intent for the establishment of a marine mammal sanctuary in the area.
1999	France, Italy and Monaco sign in Rome the Agreement on the creation of an international sanctuary for marine mammals in the Mediterranean.
2001	The Parties to the Barcelona Convention inscribe the Sanctuary in the List of Specially Protected Areas of Mediterranean Importance (SPAMIs).
2002	The Agreement on the Sanctuary comes into force.
2004	The Sanctuary management plan is developed and adopted.

voluntarily abide by the intent of the agreement even before it came into force. In November 2001, the Parties to the Barcelona Convention adopted the decision of inscribing the Sanctuary in the List of the Specially Protected Areas of Mediterranean Importance (SPAMIs). The Sanctuary entered into force on the 21st of February 2002, after having been ratified by Monaco (2000), France (2001), and Italy (2002).

The Pelagos Sanctuary

The Pelagos Sanctuary for Mediterranean Marine Mammals is a large protected area covering more than 87,000 km2 of sea surface in the north-western Mediterranean Sea, between south-eastern France, the Principality of Monaco, north-western Italy and northern Sardinia (Figure 1). The waters of the Sanctuary contain the internal maritime and territorial waters of France, Monaco and Italy, as well as the adjacent high seas. In contrast to most of the offshore Mediterranean waters, this marine area is characterized by very high levels of primary productivity in what is known as a frontal system, caused by an interaction among oceanographic, climatic and geomorphologic factors. These interactions cause high levels of local primary production, with *chlorophyll a* concentrations exceeding 10 mg m-3 (Jacques, 1989), which supports an important zooplanktonic biomass, in large part euphausiids (Figure 3; Sardou et al., 1996). Zooplankton, in turn, attracts to the area a variety of marine predators, cetaceans included. These species, however, must coexist in the Sanctuary with very high levels of human pressure (Anonymous, 1999).

The oceanographic dynamics of this permanent frontal system and the physical – biological links that sustain this productive ecosystem are subject to several short-term and long-term perturbations, including climatic changes in weather (e.g., precipitation, wind patterns, storminess), river run-off (e.g., fresh-water and nutrient inputs), and thermohaline (temperature and salinity-driven dynamics of seawater) circulation in the Mediterranean Sea. These oceanographic shifts can influence the magnitude and the timing of primary productivity, the phytoplankton and zooplankton community structure, and the population dynamics and concentration of euphausiids (Box 4).

The large densities of euphausiids (Figure 3) attract resident and transient populations of marine mammals to the area. Fin whales number in the several thousands, and appear to be permanent residents (Box 5). In addition to the fin whale concentrations, the Pelagos Sanctuary provides suitable feeding and breeding habitats for the entire community of cetaceans inhabiting the Mediterranean Sea. Seven odontocete species toothed whales (sperm whales *Physeter macrocephalus*, Cuvier's beaked whales *Ziphius cavirostris*, long-finned pilot whales *Globicephala melas*, Risso's dolphins *Grampus griseus*, common bottlenose dolphins *Tursiops truncatus*, striped dolphins *Stenella coeruleoalba*, and short-beaked common dolphins *Delphinus delphis*) regularly occur within Sanctuary waters (Figure 2; Notarbartolo di Sciara, 1994; Beaubrun, 1995). Because these species are also susceptible to entanglement in fishing gear and ship strikes (Figure 4), they will also benefit from the protection afforded by the Pelagos Sanctuary. Additionally, the highly endangered Mediterranean monk seal *Monachus monachus*, which was extirpated from this area in the mid 20th century, could theoretically re-colonize the Sanctuary waters if its popula-

Figure 2. Selected cetacean species of the Ligurian Sea (Source: Massimo Derma)

tion increased (Notarbartolo di Sciara, 1990; Notarbartolo di Sciara and Demma, 1997).

Current Status

In spite of the difficulties posed by the formidable task of granting protection to cetacean populations in such a large area, and within such a heavily exploited environment, the Pelagos Sanctuary has already resulted in a number of positive outcomes. These include: raising public awareness; taking what for the region is the rare but necessary step of creating and implementing a management plan; catalyzing voluntary measures by the three governments to minimize environmental impacts on the area; and providing a demonstration model for large scale, ecosystem-based management, high seas MPAs, the utility of regional seas agreements, the use of species as "umbrellas" to protect whole ecological communities, and the role of individuals in carrying forward a conservation vision. These positive developments are discussed in more detail below.

Raising public awareness is a crucial aspect of conservation, especially in regard to the marine environment where the negative anthropogenic impacts on the environment mostly go unseen. Before the creation of the Sanctuary, very few people among the general public in France, Italy, Monaco, and even within the scientific community, were aware of the presence of resident whale populations in these waters. At least eight ecologically distinct cetacean species are regular residents of these waters (Notarbartolo di Sciara, 1994), and new genetic evidence indicates that many of these are likely distinct from their North Atlantic counterparts (Reeves and

Box 4. From Phytoplankton to Fin Whales
by David Hyrenbach

The dominant circulation pattern in the Ligurian Sea, a cyclonic (anti-clockwise) current, flowing north along Corsica and Tuscany and hugging the coast of Liguria and mainland France in a westerly direction (Margalef, 1985), creates a permanent hydrographic *frontal system* which separates coastal and offshore waters (Millot and Taupier-Letage, 2004). The dynamics of the *water masses* associated with the front generate intense biological activity along this boundary, leading to enhanced levels of primary production, concentrations of *zooplankton* (including the *euphausiids Meganyctiphanes norvegica*, Figure 3) and dense concentrations of top marine predators (including krill-eating Fin Whales *Balaenoptera physalus*, fish-eating Striped Dolphins *Stenella coeruleoalba*, and squid-eating Sperm Whales *Physeter macrocephalus*; Forcada et al., 1995, 1996; Goffart et al., 1995; Sardou et al., 1996; Gordon et al., 2000).

The marine productivity of this region is influenced by several intermittent oceanographic processes, including vertical mixing due to storms and wind events, coastal upwelling of nutrient-rich water at canyons and shelf-breaks, and the input of terrigenous nutrients from rivers – most notably the nutrients and organic substances contributed by the Rhone (Arnau et al., 2004). These processes are influenced by the dynamics of the mistral, the prevailing north-westerly wind in this region, which mixes the water column bringing nutrients up into the *euphotic zone*, fuelling high localized ocean productivity (Gonella et al., 1977). The resulting high levels of primary production support high standing stocks of *chlorophyll a* concentration. This is a metric of the abundance of the phytoplankton primary producers and the amount of the productivity at the base of the *pelagic* food web - over 10 g m-3 (Jacques, 1989). These enriched localized values are equivalent of those found in well-known productive eastern boundary currents, like the California Current system (*chlorophyll a* concentration > 1 mg m –3; Kahru and Mitchell, 2000). This enhanced productivity supports high zooplankton biomass, including swarming euphausiid crustaceans (krill), and attracts aggregations of upper-trophic marine predators, including fin whales (Sardou et al., 1996).

From Phytoplankton to Fin Whales (Continued)

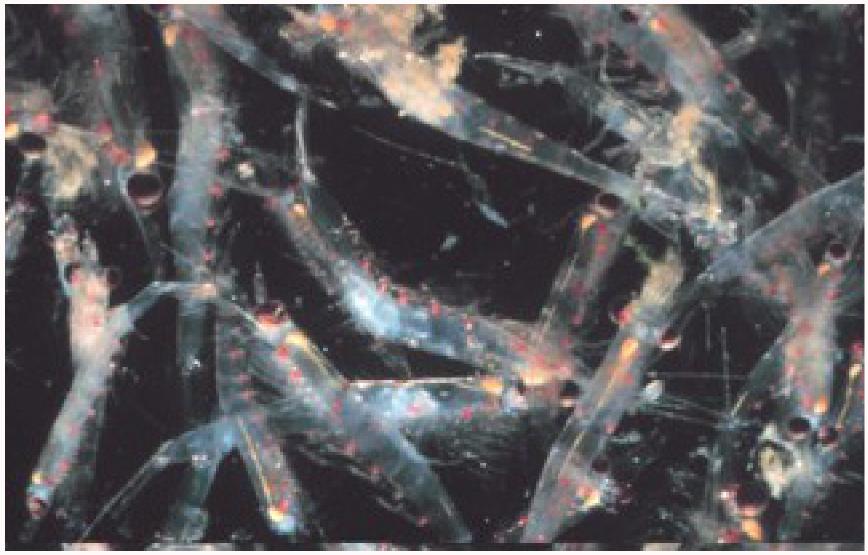

Figure 3. Euphausid Zooplankton (Source: Jamie Hall/NOAA)

It has been estimated that baleen whales consume between 3 – 4 % of their body weight every day during the feeding season (Klumov, 1963; Sergeant, 1969). Fin whales consume large amounts of euphausiids every day, with the estimates ranging from 1000 – 2800 kg (Tynan, 2004). Even though the diet and stomach contents of fin whales vary geographically and with the type of prey ingested, several published reports have documented that fin whales can consume large quantities of euphausiids (560 kg consumed in 8 hours off Nova Scotia, Brodie et al., 1978; 700 kg consumed four times a day in the Antarctic, Zenkovich, 1970). Overall, it has been estimated that an adult fin whale requires 2,000 – 2,500 kg of euphausiids to meet the daily metabolic requirements (Lockyer, 1981). Thus, over a three month summer residency period, a fin whale would consume 180 – 225 metric tons of euphausiids. These calculations underscore the critical ecosystem processes, linking primary producers, zooplankton and fin whales, which make the Ligurian Sea such a unique and especial habitat in the Mediterranean Sea.

Notarbartolo di Sciara, 2006). The Sanctuary helped to educate the public about the diverse cetacean fauna in this region.

The Sanctuary was unusual in adopting a detailed management plan soon after the Agreement entered into force. This is relevant since few of the dozens of MPAs throughout the Mediterranean Basin have any management plan at all. In addition to thinking through the management process, the Sanctuary effort has considered financial feasibility for conservation. The allocation of sizeable funds to promote the Agreement's goals through the ratification laws of some of the participating countries (notably, Italy allocated about half a million euros / year) is making financial resources available for marine conservation. The Sanctuary also provides an arena for effective regulation of the emerging whale watching industry, to avoid the risk of unwanted detrimental impacts of the increasing numbers of human / cetacean interactions.

As soon as the treaty for the establishment of the Sanctuary was signed, several institutions started offering acts of goodwill attuned to the spirit of the Agreement, even though the law may not have required these acts. Examples include the decision by the Italian Navy to refrain from conducting naval exercises (involving the use of ordnance or sonar) in the Sanctuary area, and the decision of the Italian Ministry of the Environment to discontinue the discharge in Sanctuary waters of the toxic mud dredged from the area's harbors. Some provisions of the Agreement (e.g., the prohibition of offshore high-speed motor races; the adoption of rules and codes of conduct to regulate whale watching) have introduced immediate further improvements in the animals' environment.

The Pelagos Sanctuary provides an unprecedented demon-

Box 5. Fin Whale Natural History in the Mediterranean
by David Hyrenbach

Fin whales, the second largest animal that ever existed on Earth, are very large cetaceans – reaching up to 25 meters in length and 60 tons in weight (Figure 2). Humans have been aware of the existence and the aggregation of these large marine predators in the Ligurian Sea for centuries, with the Romans already recognizing this area as the "coast of the whales". However, in spite of their large size and charismatic nature, such memories have been lost in subsequent centuries. Currently, these cetaceans are impacted by human activities, at a time when we are only starting to understand their ecology and life history in the Mediterranean.

An estimated 3,500 fin whales occur in the western Mediterranean, most of which concentrate in the Corsican-Ligurian-Provençal Basin (Figure 1) to feed on krill during summer, although this species can be observed there year-round (Forcada et al., 1996; Notarbartolo di Sciara et al., 2003). These cetacean densities are in fact similar to those encountered within other high density areas, illustrating the truly remarkable nature of these whale concentrations. The ecological significance of the Ligurian Sea for Fin Whales, both in the Mediterranean and on a global context, is underscored by the predictable and dense concentration of this protected species within a fairly restricted geographic area. Researchers have documented both the return of individual whales to the Pelagos Sanctuary year after year, and their residence during the summer. Part of the population is now known to reside in the area also during winter, as demonstrated by acoustic monitoring (for instance, see Clark et al., 2002). Fin whales show significant site fidelity, as evidenced by the numerous re-sightings of recognizable individuals made during a 9-year study (1990–98). For instance, single individuals have been encountered up to four instances in different years, and up to three times within the same season. These re-sightings of the same individuals have been recorded at intervals spanning 1 to 90 days (Notarbartolo di Sciara et al., 2003).

Novel satellite tracking technology has also allowed researchers to study the movements of individual fin whales in the Ligurian Sea, and throughout the Western Mediterranean. These recent data have revealed that a large sample of tagged whales remained within the Sanctuary throughout the year. One whale ventured outside of the Mediterranean, and eventually returned to the Sanctuary (C. Guinet, pers. comm.).

The Ligurian Sea is a critical habitat for Mediterranean fin whales, as illustrated by their dense aggregations, the predictability of their presence in the area, and their special natural history. Fin whales forage and breed in the Ligurian Sea, where they occur in all seasons. On a population level, the realization that fin whales in the Mediterranean and Atlantic are genetically distinct further underscores the conservation significance of the Ligurian Sea (Berubé et al., 1998).

stration of many important tenets of large scale marine conservation. Having been designed to include the Ligurian permanent frontal system and its surrounding biological effects, the Sanctuary has a scale that was defined by natural, as opposed to political, considerations, and provides a sound basis for ecosystem-based management (Hyrenbach et al., 2000; Gerber et al., 2005). Originally envisioned for the protection of whales and dolphins, through the provisions of the Agreement the Sanctuary in fact provides protection to a wealth of other species that are associated to whales and dolphins by sharing the same ecosystem (e.g., the Mediterranean devil ray *Mobula mobular*, the basking shark Cetorhinus maximus, and many species of large pelagic fishes). Thus the Sanctuary is a prime example demonstrating the validity of the "umbrella species" argument, and shows how a creative implementation approach can reconcile MPA designs with the dynamic nature of ocean systems.

Similarly, the inscription of the Pelagos Sanctuary in the list of SPAMIs (Specially Protected Areas of Mediterranean Importance) of the SPA Protocol to the Barcelona Convention, thereby binding all Countries that are party to the Protocol to the provision of the Agreement, has demonstrated an important practical application of a Regional Sea Convention.

Finally, the unconventional series of events that led to the creation of the Sanctuary is a testimony to the empowerment and role of champions, both individuals and NGOs [see Box 3.

Special Challenges

Management

There are still considerable shortcomings to the current approach to management of the Pelagos Sanctuary. There was a lot of innovation and creativity in the process of establishment of the Pelagos Sanctuary, and now such innovative spirit and approach is needed in management as well. This might be a difficult feat since the actors are confronted with the more mundane demands of political and administrative matters.

The development and implementation of MPAs is a long and laborious process, often spanning several decades (see NCEP module: *Marine Protected Areas and MPA Networks*). Historically, MPAs have followed a diverse array of implementation venues, ranging from top-down (e.g., implementation via a decree of the central government), to bottom-up (e.g., implementation spurred by efforts of grass-root marine conservation organizations or individuals) approaches. While the broad array of political and working structures devised to implement and design MPAs is well beyond the scope of this case study, students should be aware that these diverse roads to implementation exist. The Pelagos Sanctuary illustrates the important roles that pioneering champions and non-governmental organizations can play in initiating and steering the MPA design and implementation process.

The implementation of the Pelagos Sanctuary has been a very dynamic process, with the identity and the roles of the different actors involved changing over time. Some of the most critical achievements of this implementation process may appear rather fortuitous, and merely the result of being at the right time and in the right place. However, they have been the result of tenacious and unrelenting work of committed and visionary marine conservationists. In other words, the ability and opportunity to take advantage of propitious conditions (e.g., political climate, public opinion and awareness, developing international collaborations and agreements) whenever they presented themselves, often precipitated rapid advances in the implementation process. These critical developments punctuated long periods of inaction, caused by changes in the political climate and transient declines in the public awareness of the plight of Ligurian Sea cetaceans.

After about 15 years, the Pelagos Sanctuary implementation process is transitioning from an initial "visionary" phase, stimulated by conservation-minded individuals and organizations, to an "administrative – institutional" phase, whereby the management mechanisms and governance institutions will be established (Table 1). However, the Sanctuary is still struggling to get up to speed with a recently established, undermanned management body, in the new headquarters at the Ducal Palace in Genoa, Italy. Most of the management functions are still undertaken by the Meeting of the Parties and by national and tri-national steering committees. These temporary solutions are clearly inadequate to face the demanding tasks posed by such a large and complex protected area.

As the identity and the roles of the actors change during this phase transition, the implementation process is at the risk of falling into a period of inaction caused by a mis-match in the incentives and expectations driving these two implementation phases. Namely, disparities in the vision, commitment, and socio-economic drivers influencing the actions of government administrators, NGOs, scientists, and the public at large, will continue to shape the implementation process. Yet, this paralysis could derail the implementation process, by rendering the Sanctuary management plan ineffective. A failure to account for dynamic socio-economic and ecological conditions (e.g., changing fishery threats and cetacean distributions over time, global change), and the inability to implement the management plan (e.g., lacking enforcement) could easily condemn this visionary pelagic Sanctuary to remain a "paper park" devoid of real protective measures for cetaceans. Several political and scientific steps are required to ensure that the implementation process progresses unhindered and leads to an effective Sanctuary capable of achieving its conservation goals over the long-term. The continued engagement of NGOs will be critical at this stage, both in an oversight role and as a catalyst for public awareness and participation in the implementation process (Box 2).

Scientific Monitoring

A critical aspect of MPA management entails the continued monitoring of the changing ecological and anthropogenic conditions, including the status of the protected resources, the patterns of human use in time and space, and the status and trends in existing and anticipated threats. This need for adaptive management is perhaps most critical in the Pelagos Sanctuary, given the dynamic nature of this productive frontal habitat and the highly migratory habits of cetaceans.

An estimated at least one thousand fin whales aggregate within the Pelagos Sanctuary in summer (Forcada et al., 1995), each being capable of consuming up to several hundred kilograms of euphausiids daily. These predators have large energetic requirements, which are supported by the productive food web of the Ligurian Sea. While dense prey concentrations are likely critical for fin whales, very little is known about the mechanisms responsible for the observed patterns of *chlorophyll a* distribution and euphausiids concentration. Thus, it is critical to gain an understanding of the physical processes that sustain high localized ocean productivity, and the trophic links supporting the food webs exploited by cetacean aggregations in this area.

Figure 4. Cetacean entangled in fisheries equipment (Source: Alberto Romeo)

Therefore, an understanding of the dynamics and the scales of the processes responsible for the formation of these important physical (e.g., hydrographic front) and biological (e.g., euphausiid concentrations) aspects will be critical to assess the degree to which the Pelagos Sanctuary will encompass the fin whale foraging grounds in the future. Furthermore, an improved understanding of the ecological significance of the Pelagos Sanctuary for marine mammals over the long-term requires an assessment of their local trophic requirements and of the abundance and dynamics of their fish and squid prey (Hooker and Gerber, 2004). In particular, the extent that the location and extent of these features vary in time and space will influence the criteria and the success of any zonation process. The Parties to the Pelagos Sanctuary Agreement are still insisting that no zoning measures be introduced in the management plan. Zoning is the spatial definition of activities permitted within delimited areas of a PA, and can range from heavier restrictions on human use within "core" areas, to regulated activities such as limited fishing or recreation allowed in "buffer" areas. Conflicting activities, such as extraction and recreation, may be spatially separated using zoning (see NCEP module "*Protected Areas and Biodiversity Conservation I: Reserve Planning and Design*"). Yet, the reasons for such insistence against zoning at Pelagos are not easy to understand. The zoning component is essential to proper management and conflict resolution, and could at least be tried out to deal with the least conflicting activities, such as whale watching.

Protecting cetaceans represents an extraordinary challenge, because these highly-mobile vertebrates range over 100s – 1000s of kilometers and may engage in seasonal migrations. Therefore, any cetacean population and species will remain susceptible to unmitigated threats and impacts outside of any sanctuary which is smaller than the annual range. In principle, MPAs may be used to protect the feeding and foraging grounds and the migration corridors where these species concentrate. Nevertheless, due to the large ranges of these species, no sanctuary will ever provide a "silver bullet" capable of mitigating all anthropogenic impacts. Thus, MPAs often prove most effective when used in conjunction with other more diffuse conservation measures (e.g., bycatch mitigation measures) enacted within the broader range of the species (Gerber et al., 2005). Ultimately, the degree of aggregation and the habitat associations of the Ligurian Sea cetaceans will influence their susceptibility to different anthropogenic threats, and the ability of the Pelagos Sanctuary to mitigate those impacts.

Because the cetaceans of the Ligurian Sea are susceptible to different threats and impacts inside and outside MPA waters, the Pelagos Sanctuary management plan should consider the threats and protections that exist both within and outside its jurisdiction. Moreover, it is critical to anticipate how MPA implementation will change the magnitude and the spatial distribution of these threats, given the known impacts of displaced fishing effort (Sanchirico, 2000; Sanchirico et al., 2002). The pervasive problems of displaced effort and enforcement that complicate MPAs throughout the world may also be a factor in the Pelagos Sanctuary. For example, shifting gillnet fisheries into less productive areas may actually increase the overall fishing effort. Thus, any spatial restriction may merely intensify bycatch impacts outside of the MPA, by shifting the fishing pressure into adjacent areas. MPA managers should anticipate the likely ecosystem-level consequences of Sanctuary implementation. In particular, narrowly-focused single-species conservation actions may merely reduce the bycatch of one threatened or popular species at the expense of other taxa. Thus, it is imperative to coordinate management and monitoring actions within and outside the sanctuary boundaries.

The information base developed by broad-based research and monitoring programs will be critical to integrate the Sanctuary management plan with other cetacean and ecosystem protections outside of its waters. In particular, the long-term protection of the Ligurian Sea cetaceans will benefit from the following actions: (i) coordination with the objectives of other conservation and management initiatives (most notably, ACCOBAMS, the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area), (ii) integration of other existing fisheries and coastal zone management concepts within sanctuary management objectives, and (iii) adherence to the principles of adaptive management and the precautionary principle (Mangel et al., 1996; Dayton, 1998). The precautionary principle or approach to management of resources recommends taking action against a specific practice that may cause damage to the environment even if there is no proof of a causal link. Essentially, in the presence of scientific uncertainty or absence of data, precautionary action should be taken to conserve the species or address the environmental problem (see NCEP module: "*International Treaties for Marine Conservation and Management*").

Looking to the Future

The Pelagos Sanctuary for Mediterranean Marine Mammals, admittedly a work in progress, has already achieved significant results, despite the challenges posed by protection of highly mobile animals in the large scale, dynamic marine environment. To realize its full potential, the Sanctuary should articulate clear objectives, initiate a monitoring regime that feeds information into adaptive management, and devise tangible ways to assess effectiveness.

The Pelagos Sanctuary management plan clearly formulates the purpose of this MPA: (i) manage human activities within Sanctuary waters to minimize impacts, (ii) increase scientific knowledge of cetaceans and their habitats within the Sanctuary, and (iii) promote awareness among professionals, practitioners, and the wider public.

These broad overarching goals provide a tangible target for the management of this MPA, which will help steer the implementation plan and the design of a monitoring plan to assess Sanctuary effectiveness. In addition to the systematic ecological and socio-economic research program envisioned by the management plan, effective stewardship will require developing measurable and tangible objectives that are much more specific than the general Sanctuary goals listed above. These may include measures of biotic integrity (e.g. standing stocks, productivity), and environmental variability (e.g. oceanography, disturbance regimes), along with appropriate indicators of physical and biological variability at short (interannual) and long (climate change) temporal scales (Zacharias et al., 2006).

By linking the broader management goals with the field monitoring program, these quantitative and measurable objectives will help identify those habitats, processes, and threats 'critical' to achieve the management objectives. In doing so, these metrics of success will catalyze research, outreach, and education within the Sanctuary and in the broader Mediterranean Sea.

Recommendations

On the basis of the Sanctuary management plan, we can advocate two general recommendations for a monitoring program and associated quantitative metrics of success:

1. Develop a broad biogeographic and ecosystem-level analysis of cetacean ecology, including their distributions, abundance, habitats, and community structure. This approach should quantify changing conditions within and outside Sanctuary waters, and consider genetic, stock, species, community, and ecosystem levels. Potential metrics could include changes in ocean productivity over time, studies of the density and distribution of cetaceans, research on the population structure (e.g., age classes) and reproductive rates on cetaceans, and investigations of the abundance and composition of their zooplankton / fish / squid prey.

2. Establish a program to map the spatial and temporal distributions of the threats to cetaceans and the oceanographic processes supporting ocean productivity and prey availability within and outside of the Sanctuary. Potential metrics could include changes in bycatch rates and ship strikes, surveys of floating marine debris and derelict fishing gear, studies of pollutants in the food web and in cetacean tissues, studies of anthropogenic noise levels in the area, as well as monitoring of human activities (whale watching, oil tanker and cargo vessel traffic, fishery distributions) within and outside the Sanctuary.

Conclusions

In summary, the development of a coordinated Sanctuary management plan and a quantitative monitoring program will be critical to ensure the effective implementation of the Pelagos Sanctuary and the long-term conservation of Ligurian Sea cetaceans. This dual approach will provide the information foundation required for long-term management of the Sanctuary, as well as clear guidelines to assess the Sanctuary's effectiveness. The lack of clear metrics of success is a dangerous pitfall of MPA implementation, because the inability to gauge the success of these management actions can result in disillusionment, loss of credibility, and community / industry backlash against established and future parks and marine zoning initiatives (Agardy et al., 2003).

Discussion Questions

1. What were the major contributing factors in the development of the Pelagos Sanctuary? Which would you consider the most important?
2. Describe the two-edged sword that the existing international legal framework presented (hint: discuss whether the lack of EEZ helped or hurt the process)
3. What seems to be more important in this case: institutions or individuals?
4. What accounts for how surprised the scientific community and the public was when the discovery of this important area occurred?
5. What is the role of civil society in MPA establishment?
6. If you were a stakeholder in this process (fisher, coastal resident, tourist, whale watching operator, cetacean researcher, naval officer, ferry captain) what would you do?

Additional Reading

If you would like to learn more about the Pelagos Marine Sanctuary, please see:

Notarbartolo di Sciara G, T. Agardy, D. Hyrenbach, T. Scovazzi, and P. Van Klaveren. 2007. The Pelagos Sanctuary for Mediterranean marine mammals. Aquatic Conservation: Marine and Freshwater Ecosystems. In press.

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Thirsty Metropolis: A Case Study of New York City's Drinking Water

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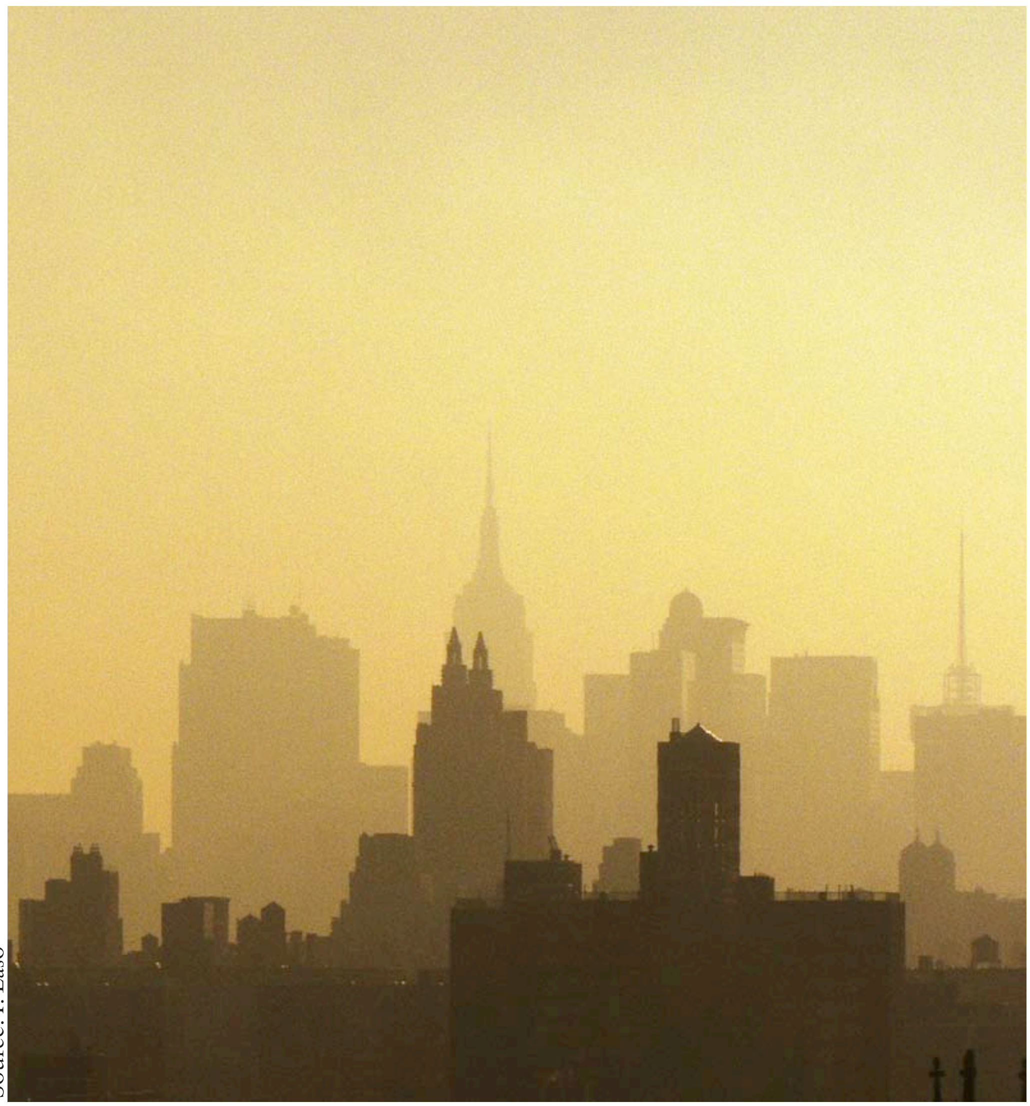

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Thirsty Metropolis: A Case Study of New York City's Drinking Water

Erin.C.Vintinner

Case Study Subject and Goals

This case study is divided into two parts to explore many aspects of the development of the drinking water supply for New York City. In Part I, a brief history on the evolution of the water supply system is presented within the social and political context of the system's history. The case study lesson divides students into groups to examine various perspectives on a pivotal moment in the development of the water supply. This exercise allows students to consider the practical challenges in such a scenario and work through a real life case study in search of a solution. In Part II, an epilogue section allows students to compare their proposed solutions to the actual actions that occurred. Up-to-date information on the status of the water supply system is provided to provoke discussion among students on recent pressing issues for *stakeholders*.

Through a decision based format, this case study aims to provide undergraduate level students with a solid understanding of the biophysical, social, and economic dimensions of *watershed* management while fostering critical thinking and problem-solving skills. The goals of the case are to promote development of analytical and decision-making proficiency in a group setting, as well as encourage evaluation, reflection, and deeper research into conservation and development challenges.

Part I

It is 1995, New York State: Following the passage of a Congressional Act targeting the safety of the nation's water supply systems, attention is now focused on the current state of New York City's water supply. Tension is building between numerous stakeholders in the future of New York City's water supply. Pressures from all sides, along with the prospect of extensive litigation and political maneuvering, are threatening to destabilize years of progress on the safety of the water from *upstate* watersheds. How to balance the drinking water needs of millions of people with the needs of watershed communities? The controversy over the New York City water supply is about to enter a new phase…

New York City's Water Supply

The first settlers on the island of Manhattan in the early 17th century drew their drinking water from private wells. For the next three centuries, the City's water supply system grew from a series of simple local reservoirs to complex aqueducts systems that carried water to the City from several kilometers away. At the turn of the 20th century, faced with growing demands for reliable water, the city's Board of Water Supply decided to look to watersheds in upstate New York to supplement existing water supplies. Construction on an increasing number of reservoirs and aqueducts continued until the 1960's. Gradually, the upstate system of reservoirs and aqueducts became the primary source of drinking water for one of the largest cities in the world (New York City Department of Environmental Protection [NYCDEP], 2006).

Today, the New York City water supply system is derived from *surface water* north of the metropolitan area (some parts of Queens rely on a *groundwater* supply). The surface water network consists of three watersheds: the Catskill and Delaware watersheds about 160 kilometers north of the city in the Catskill Mountains and the Croton watershed about 80 kilometers north of the city and east of the Hudson River. The system encompasses over 5000 square kilometers across eight counties: Westchester, Putnam and Dutchess on the east side of the Hudson River and Delaware, Greene, Schoharie, Sullivan and Ulster in the Catskill Mountains, west of the Hudson (Figure 1). The system stretches *downstate* to NYC via a complex of aqueducts and tunnels to supply 5.3 billion liters of safe drinking water per day to millions of customers including residents, businesses, commuters, and tourists (Foran et al., 2000; Solecki and Rosenzweig, 2001). In fact, the system supplies water to nearly half of the population of New York State. In addition, excess water from upstate reservoirs not used for drinking water is released to the Delaware River to sustain adequate flow in the lower Delaware for New Jersey and other downstream users. The reliable function and safety of this water supply was and is absolutely essential to the existence of NYC (Foran et al., 2000; Solecki and Rosenzweig, 2001, 2004; NYCDEP, 2005b, 2005c).

As New York City and upstate communities have grown, pressures from two different sides have impacted the water supply. Increasing human population and development in watershed communities exerts pressure on natural water flows that supply the water supply system. In addition, expanding populations in New York City exert pressure on the system in order to supply a growing downstate need. The human presence at both ends of the water supply system creates tensions that affect the decisions that must be made to satisfy needs of all stakeholders.

Decision time: Controversy Regarding New York City's Water Supply

Prior to the 1980s, drinking water from the Catskill/Delaware watersheds and the Croton water supply system was unfiltered. Due to appropriate management of watershed lands, water quality had been consistently good and there was no perceived need for a *filtration* facility. However, in the late 1980s, public health concerns regarding outbreaks of waterborne illnesses across the country raised awareness of water quality and health issues (Crotty, 2002). In response, Congress passed the Safe Drinking Water Act Amendments of 1986. In 1989, pursuant this Act, the **United States Environmental Protection Agency (EPA)** promulgated the **Surface Water Treatment Rule (SWTR)** to protect drinking water sources against *microbial* contamination. The SWTR required that any public water supply system using unfiltered surface water either filter the *source water* or demonstrate that it met

Box 1. Landscape Changes to NYC Waterways

The familiar land-forms on today's atlases are drastically different from the coastline that greeted Henry Hudson as he sailed into the river that now bears his name. The Mannahatta project, sponsored by the Wildlife Conservation Society, provides an interesting perspective on the native habitat and ecology found on Manhattan Island, then home of the Lenni Lenape people, in the 17th century (Wildlife Conservation Society, 2006). Since that time, vast portions of shoreline have been modified, channels dredged and wooded coasts and *wetlands* disrupted as European settlers poured into the New World. These changes were considered necessary to accommodate increases in trade and growing human population by creating more usable land and disposing of waste (Montalto and Steenhuis, 2004).

According to the recent Health of the Harbor Report sponsored by the NY/NJ Harbor Estuary Program, 80% of the area's original tidal wetlands and underwater lands have been lost due to human activities such as dredging or filling (Steinburg et al., 2004). Well-known locations such as LaGuardia, Newark, and Kennedy Airports, Shea Stadium, and the now closed Fresh Kills Landfill were all built on top of former marshlands (Montalto and Steenhuis, 2004). In this respect, the evolution and development of New York City followed patterns typical of large urban cities. Some hallmarks of this development include the progressive concentration of population and infrastructure, along with changes in the biological and physical components of the original existing environment (Paul and Meyer, 2001; Alfsen-Norodom et al., 2004; Kleppel et al., 2004).

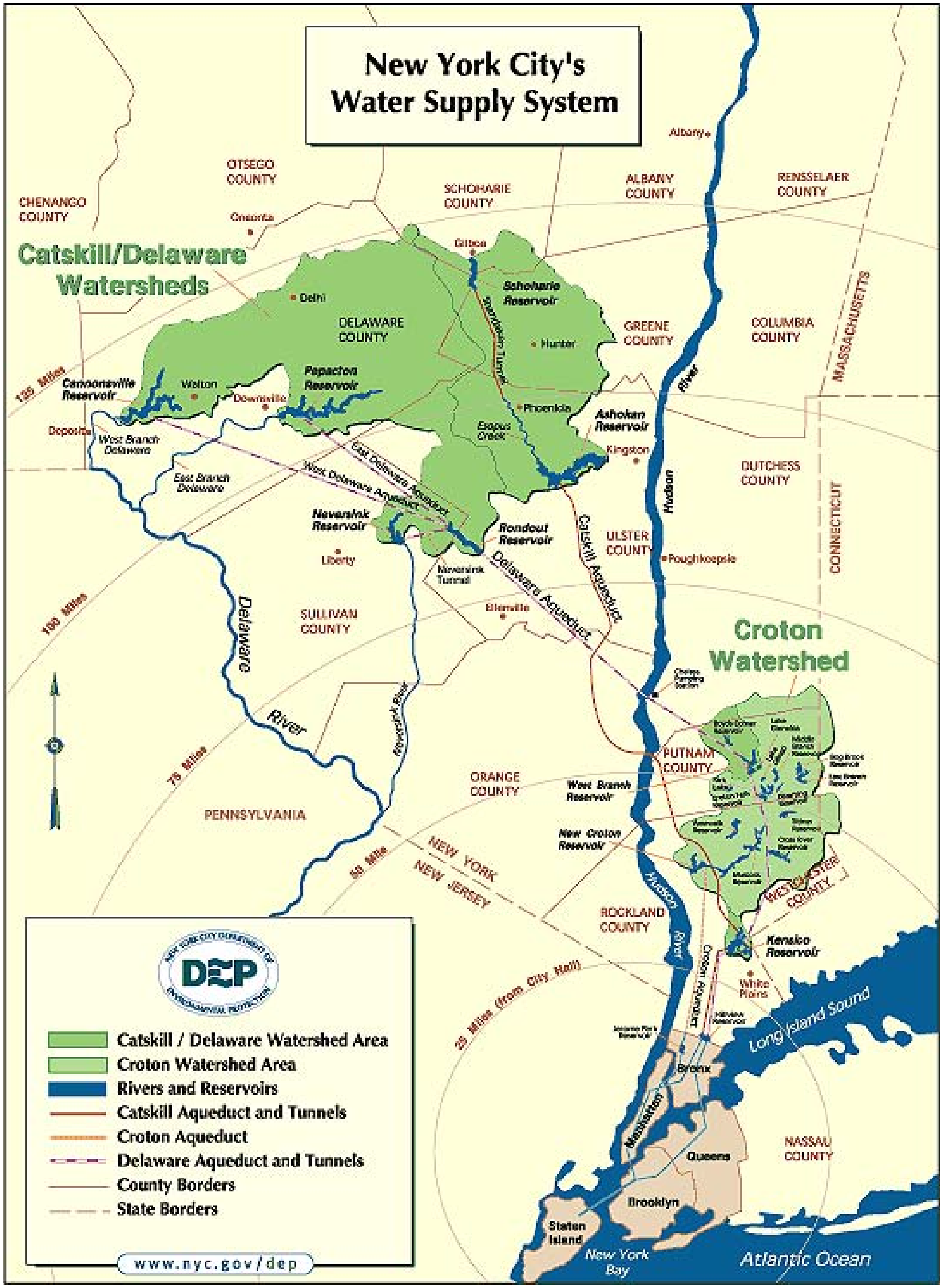

Figure 1. NYC Water Supply System (Source: New York City Department of Environmental Protection)

a series of objective water quality, operational, and watershed control criteria. NYC was faced with a choice between two options: filter the water or satisfy the provisions of the SWTR for unfiltered water.

After a series of initiatives by the City in the early 1990's to comply with the SWTR, the EPA issued a conditional ***Filtration Avoidance Determination (FAD)*** in 1993. The main conditions in the FAD centered on an improved watershed protection plan and a land acquisition program which would regulate activities on water sensitive lands through restrictions and *buffer zones*. EPA also required that the City proceed with preliminary design of a filtration facility for the Catskill/Delaware supply, to minimize any delays if the EPA decided that filtration was necessary in the future. These programs directly affected upstate residents and businesses and created potential for conflict between parties concerning property rights and land use regulations. The history of conflict between NYC and upstate communities dates back to the 1950's, when the City claimed *eminent domain* to build its reservoirs and flooded whole villages and displaced numerous residents in the process (Catskill Watershed Corporation, 2005; Ellison, 2006).

Uncertainty regarding the City's follow-up actions to the FAD and possible use of eminent domain for land acquisition caused relations between the City and upstate communities to deteriorate. Upstate stakeholders, lead by the Coalition of Watershed Towns, filed lawsuits against NYC (Specter, 1992; Pfeffer et al., 2002). These lawsuits caused an impasse in efforts by all stakeholders to reach a compromise about a watershed protection program (Rosenburg, 1995; Ashendorff et al., 1997; National Resource Council Commission on Geosciences, Environment and Resources, 1999; Burnett, 2004).

Since the conditional FAD impacted many disparate stakeholders in New York, EPA and other interested parties recommended that the Governor of New York State, George E. Pataki, convene a meeting of stakeholders to mediate the controversy (National Resource Council Commission on Geosciences, Environment and Resources, 1999). Subsequent negotiations involved the following four primary stakeholder groups: government entities (City of New York, New York State, EPA, NYS Department of Health-DOH, NYS Department of Environmental Conservation-DEC, NYCDEP), upstate stakeholders (Coalition of Watershed Towns, representatives of eight upstate counties), downstate stakeholders (representatives from NYC, Putnam County, Westchester County), and environmental groups (Hudson Riverkeeper, Catskill Center for Conservation and Development, Trust for Public Land, Open Space Institute, and New York Public Interest Group) (New York State Environmental Facilities Corporation, 1997; Wolosoff and Endreny, 2003).

As of 1995, the alternative to meeting the stringent criteria mandated by the EPA is the construction of a filtration facility for all of the water coming from the Catskill and Delaware watersheds. It has been estimated that the cost of such an endeavor would be upwards of $6-8 billion dollars, with annual operating costs of $500 million (Chichilnisky and Heal, 1998; Ellison, 2006).

The Scenario

The FAD is scheduled for re-evaluation within one year of this roundtable meeting. In order to facilitate a compromise between many varied stakeholders that is compatible with legal obligations and economic and environmental concerns, New York State Governor Pataki has assembled representatives from each perspective to present their viewpoint. Each group is charged with producing a position statement that also contains recommendations for compromise with other stakeholders. One additional group will be given the task of facilitating the discussion as each stakeholder presents their position and works towards a compromise. Possible compromises may consist of a land acquisition agreement, watershed rules and regulations, partnerships, or a determination to explore filtration options.

1. Your task is to adopt the concerns of the stakeholder group you have been assigned to represent. The four perspectives are: upstate stakeholders, federal and state level government agencies, downstate stakeholders, and environmental groups. Strive to understand and accept the

Box 2. American Museum of Natural History's Survey

In 2005, the American Museum of Natural History completed a nationwide survey to gauge American's knowledge of and attitude towards water and water-related issues. Remarkably, most respondents did not recognize that some of the main sources of water quality degradation are flushing toilets (through the effluent of wastewater treatment plants), *runoff* from treated lawns, and stormwater *runoff* from roads. As further development occurs in upstate watersheds, each of these threats to water quality may lead to lower drinking water quality for New York City. Both upstate and downstate residents are tightly linked.

The survey also found that of the 78% of respondents on a municipal water system such as New York City's system, only one-third gets their drinking water from an unfiltered tap. The rest of the respondents either filter their tap water or drink only bottled water. All respondents were asked to rate the quality of their tap water. Over 65% responded with positive reviews, while 1/3 of the sample gave fair or poor responses.

validity of your assigned position. You should familiarize yourself with the details of your position so that you can present your particular viewpoints clearly and comprehensively in a discussion.

2. During the roundtable discussion, be open to creative solutions and collaborative approaches. In Part II of the case, you will be able to compare your recommended course of action with the realities of the case. You will further consider how the real outcomes have affected various stakeholders in the years since the decision and the current status of the NYC water supply system.

Information statements on each of the stakeholder groups are provided below. Your assignment is to review the background of your assigned stakeholder group and create a 5 minute position statement on your view of the situation. Discuss your goals for the stakeholder meeting, and prepare suggestions for solutions that can incorporate these goals into plans for the future of the New York City water supply.

Upstate Stakeholders

Upstate stakeholders who live and work in the rural watersheds of the Catskill and Delaware systems are intimately involved with decisions regarding New York City's water supply. NYC owns less than 10 percent of the watershed, which covers roughly 5,000 square kilometers (Figure 1). The watershed has a year-round population of around 78,000, as well as a significant number of summer residents (Ashendorff et al., 1997). The main economic sectors of the upstate communities focus on tourism, recreation (such as skiing) and the arts, agriculture (mainly dairy farms), small businesses and manufacturing, and natural resource based industries such as agriculture, forestry and mining products. Citizens and businesses in these watersheds have varying degrees of concern regarding the impact that a land acquisition program might have on the character and economic viability of their communities (Hamilton et al., 1998). A majority of residents of Westchester County support the prospect of land acquisition in their county, for example. Notably, these residents depend on the NYC water supply system for their drinking water. However, residents of many towns west of the Hudson River have opposed any land acquisition plans that might devalue private property and have expressed concerns regarding property rights. For example, in 1993, the **NYC Department of Environmental Protection (NYCDEP)** released a draft impact statement for revised watershed rules and regulations according to the FAD. New regulations called for buffer zones around waterbodies and restrictions on the construction of sewerage and service connections. Residents are concerned that these regulations could reduce property values by making land unavailable for development.

Uncertainty over NYC's intent to use eminent domain to gain control of the watershed lands and the perception that NYC is shifting the costs of watershed protection to upstate communities has resulted in the deterioration of relations between NYC and upstate communities. Watershed residents claim that efforts to protect surface water quality will impose unreasonable costs on property owners directly and indirectly on all watershed residents by reducing economic growth and associated economic opportunities. In responding to the NYCDEP's statement, the **Coalition of Watershed Towns (CWT)** (a group that has emerged to represent the interests of upstate stakeholders) has concluded:

"*The City has hidden from discussion …land acquisition programs which it is already beginning to implement. The total program would involve the acquisition of approximately half of the developable land. The net result is that the watershed will suffer unmitigated impacts of both the regulatory program and a land acquisition program.*"

The tensions peaked when the CWT, representing about thirty watershed communities, filed suit to prevent NYC from implementing its filtration avoidance plans. The CWT cited economic burdens on watershed residents resulting from restrictions placed on the use of privately owned land. The group claimed that NYC would benefit almost exclusively from environmental measures in the countryside to protect drinking water supplies at their source (Pfeffer et al., 2002).

Government Agencies

A diverse array of government agencies has a stake in the outcome of decisions regarding the New York City water supply. The USEPA, New York City Department of Environmental Protection (NYCDEP), NYS Department of Health, and NYS Department of Environmental Conservation are all concerned with compliance with the SWTR and the safety and regulation of an enduring water supply for NYC. In particular, the DEP holds primary responsibility for the water supply system, with a mandate to ensure the public's continued access to safe drinking water. In New York State, EPA Region II has primary enforcement responsibility for the SWTR regarding the unfiltered Catskill/Delaware systems, and therefore it has ultimate enforcement authority over the state and local agencies.

According to the STWR, filtration avoidance criteria are comprised of three main areas that must be enforced for the water supply system to remain unfiltered.

- Objective Water Quality Criteria – the water supply must meet certain levels for specified constituents including *coliforms*, *turbidity,* and *disinfection by-products*.
- Operational Criteria – a system must demonstrate compliance with certain disinfection requirements for inactivation of *Giardia* and viruses; maintain a minimum chlorine residual entering and throughout the distribution system; provide uninterrupted disinfection; and undergo an annual on-site inspection by the primacy agency to review the condition of disinfection equipment.
- Watershed Control Criteria – a system must establish and maintain an effective watershed control program to minimize the potential for contamination of source waters by *Giardia* and viruses.

Representatives of government agencies are committed to the safety of the New York City water supply system. Notably, all the surface water and groundwater entering the City's water system is treated with chlorine for disinfection, fluoride to prevent tooth decay, orthophosphate to reduce the release of metals from household plumbing, and in some cases sodium hydroxide to adjust pH.

The objectives of the government agencies vary. If the system does not meet the criteria for the FAD, the EPA may decline to renew the FAD and trigger the utilization of a filtration plant. Therefore, the EPA is solely concerned with maintenance of water quality either by ensuring quality of unfiltered water, or filtering the water if quality drops. In contrast, the local agencies such as the NYCDEP are in favor of the most cost-effective solution for the continued safety of the water supply system. For this reason, the NYCDEP is most likely to favor the creation of a compromise that allows water to flow unfiltered from upstate communities to avoid costly filtration.

Downstate Stakeholders

The New York City metropolitan area is one of the most populous and heavily industrialized coastal areas on earth. According to the last decennial census by the US Census Bureau in 1990, almost 17 million people live in the metropolitan area of New York City, Long Island, Northern New Jersey, and Northeastern Pennsylvania, including the over 7.3 million people living in the five boroughs of NYC. The pressures of a large population, with associated requirements such as clean water and waste disposal, impact the need for a consistent water supply. The City of New York, Putnam County, and Westchester County currently receive the unfiltered water from upstate watersheds. Residents, businesses, commuter and tourists in these areas are concerned with a safe, consistent supply of water.

New York City's drinking water has long been renowned for its safety and quality, and has even been described historically as the "champagne of drinking waters." Some proponents have argued that the drinking water is the secret ingredient in the famous New York City bagel and pizza. As the recipients of this drinking water supply, downstate residents have a considerable stake in maintaining the quality of their supply.

Notably, residents and business would be faced with shouldering the potential costs of a filtration plant if mandated. NYC faces upfront costs of multiple billions of dollars for the construction and maintenance of a filtration plant for its Catskill/Delaware water supply. As the City's annual budget is about $29 billion, this cost could double water rates in the City, adversely affecting residents, especially NYC's large low income population (Perlee et al. 1994; Appleton 2002) Drastic rate increases could also lead to closure of housing units in rent-controlled areas of the City where the landlords cannot pass the additional cost of the water on to their tenants (Mouat, 1993; Burnett, 2004). However, it is also notable that the costs for administering the requirements of any future FADs and associated agreements are also borne by the City.

Environmental Groups

The principal environmental groups involved with the decision regarding NYC's water supply are: Hudson Riverkeeper, Catskill Center for Conservation and Development, Trust for Public Land, Open Space Institute, and New York Public Interest Group. These groups are concerned with advocacy for safe water for all parties. In addition, these stakeholders are concerned with other aspects of the Catskill, Delaware and Croton watersheds, such as preservation of biodiversity and riparian corridors, which may be protected under the umbrella of water purification (Daily et al., 1999). In addition to supplying NYC's drinking water, rural upstate watersheds contain wetlands and waterways that provide numerous *ecosystem services* such as nutrient cycling and mitigation of floods and drought (Baron and Poff, 2004).

The freshwater ecosystems in the Delaware, Catskill, and Croton watersheds also support a large amount of biodiversity (Foran et al., 2000, Edinger et al., 2002, also see the New York State Biodiversity Project at http://cbc.amnh.org/center/cbcnews/state.html). For example, watershed lands serve as a major core area for several regionally rare large mammal species, including black bear (*Ursus americanus*), bobcat (*Lnyx rufus*), and fisher (*Martes pennanti*). The waters that supply the reservoirs support healthy populations of coldwater fish such as brown (*Salmo trutta*), rainbow (*Oncorhynchus mykiss*), and brook trout (*Salvelinus fontinalis*), and the reservoirs themselves are important fisheries for smallmouth bass (*Micropterus dolomieu*), redfin pickerel (*Esox americanus*), yellow perch (*Perca flavescens*) (Dowhan et al., 1997).

The watershed lands support numerous endangered and threatened species. Federally listed threatened species include the northern wild monkshood (*Aconitum noveboracense*) and the bald eagle (*Haliaeetus leucocephalus*). Bald eagle pairs have successfully nested at reservoirs such as Ashokan, Roundout, Schoharie, and Neversink, all of which are part of the NYC water supply system. State-listed endangered species include the shoreline sedge (*Carex hyalinolepis*) and roseroot stonecrop (*Sedum rosea*), and threatened species include the timber rattlesnake (*Crotalus horridus*), red-shouldered hawk

Lake ecosystem created by beaver dam - Catskill watershed
(Source: F. Laso)

(*Buteo lineatus*), fragrant cliff fern (*Dryopteris fragrans*), moschatel (*Adoxa moschatellina*), and Appalachian Jacob's ladder (*Polemonium van-bruntiae*). Other species are state-listed as special concern, including the spotted salamander (*Ambystoma maculatum*), eastern hognose snake (*Heterodon platirhinos*), spotted turtle (*Clemmys guttata*) and eastern bluebird (*Sialia sialis*) (Dowhan et al., 1997). Many environmental groups support environmental protection measures that protect both New York City's water supply and the resilience and diversity of upstate ecosystems.

Part I: Issues for Further Analysis and Discussion

1) What are some of the benefits and weaknesses of using the approach of conserving watershed integrity rather than relying on a water filtration plant?

2) Consider that the upstate watersheds are experiencing increases in population. Downstate residents have also been acquiring second homes in watershed communities, which has resulted in a new wave of development pressure (Commission on Geosciences, Environment and Resources, 2000 and The Nature Conservancy, 2005). What additional threats might this settlement and development pose to the water supply of New York City?

3) How does this model compare to other urban water supply systems throughout the world (see Fitzhugh and Ritcher, 2004)? For example, consider Mexico City's water supply. The city's water is delivered from a groundwater system that is experiencing a reduced water table and pollution problems (see Excurra and Mazari-hiriart, 1996; Tortajada and Castelan, 2003). Comprehensive information in order to make a comparison can be found in Joint Academies Committee on the Mexico City Water Supply et al. 1995. Further comparison can be made to other American cities that depend on surface water systems, such as Los Angeles (Archibold, 2007).

Part II

Epilogue

Following years of negotiations between downstate and upstate stakeholders (including 270 meetings over a period of 2 years), a New York City Watershed Memorandum of Agreement (MOA) was signed on January 21, 1997. This landmark agreement successfully resolved long-standing controversies and set forth responsibilities and benefits for all major parties.

Generally, the MOA represented a consensus of a stakeholder coalition and provided a legal framework for protecting the drinking water supply of New York City while safeguarding the environmental quality and economic prospects of upstate watershed communities. In order to address the deadlock imposed by litigation, all parties agreed to drop outstanding lawsuits and abstain from filing legal challenges to the MOA. Most importantly for government stakeholders, the agreement satisfied provisions of the SWTR that allowed the City to avoid filtering its upstate Catskill/Delaware water supply until at least 2002, thereby avoiding the multi-billion dollar construction costs of a water filtration plant. Notably, the FAD provisions required that the City begin construction of a water filtration plant for the more populated and developed Croton watershed. Currently, a $1.2 billion filtration plant is under construction in the Mosolu Golf course site in the Bronx for the Croton water supply. The MOA also delegated responsibility to various agencies and institutions for the goals of economic growth and environmental protection in upstate watersheds (Ellison, 2006, U.S. EPA Region II, 2006a). Noted environmentalist Robert Kennedy Jr. expressed the difficulty in reaching this landmark agreement by stating "there was blood shed over every word (Ellison, 2006)."

More specifically, the MOA consisted of three major components: a watershed land acquisition program, revised watershed rules and regulations, and watershed protection and partnership programs. Each component was created to address the challenges posed by the SWTR requirements and the political and social contexts of the resource issue.

1) For the watershed land acquisition program, New York State issued a land acquisition permit that allowed the City to purchase or provide conservation easements to vacant water quality-sensitive watershed lands on a 'willing buyer/willing seller' basis (New York State Environmental Facilities Corporation, 1997). At the time of the MOA signing, NYC owned less than 10% of the land in the Catskill/Delaware watersheds (U.S. EPA, 2006).

2) For the revised watershed regulations, the City was tasked with the revision of watershed regulations that addressed both *point* and *non-point source pollution* from sources such as waste-water treatment plants, disposal systems, and stormwater runoff. The goal of these revisions was to protect the public health by averting future contamination to, and degradation of, the water supply and by remediating existing sources of pollution or degradation (NYCDEP, 1997; DOH and DEC, 2002).

3) The innovative watershed protection and partnership programs were designed to foster collaborative understanding between upstate and downstate stakeholders regarding the water supply. The MOA included provisions for substantial funding for economic and environmental partnership programs targeted at upstate communities. The MOA explicitly mandated the creation of two partnership programs: the **Watershed Protection and Partnership Council (WPPC)** and the **Catskill Watershed Corporation (CWC)** (New York State Environmental Facilities Corporation, 1997; U.S. EPA Region II, 2006a). The WPPC was delegated the responsibility of evaluating the many watershed protection and partnership programs specified by the MOA, while the CWC was more specifically tasked with developing and implementing several city-funded programs, including education initiatives, residential septic rehabilitation, stormwater controls and economic development through the city-funded $59.7 million **Catskill Fund for the Future (CFF)** (WPPC, 2004; CWC, 2005).

Each of these three complex components presented considerable challenges for implementation. Furthermore, as an innovative agreement, the MOA had no comparable pre-existing model. Each component of the agreement therefore demanded creative approaches in implementation, maintenance, and assessment.

In the years since the signing of the MOA, the City has finalized its regulations for watershed land uses, acquired sensitive lands to protect key reservoirs and waterways, conducted more extensive water quality testing in the watershed, and supported upstate/downstate partnership programs. These projects have required an estimated investment of $1-$1.5 billion by New York City. New York State adopted the City's watershed regulations and land acquisition permits, and established a new Watershed Inspector General's Office to ensure that the City's regulations are implemented to protect public health. Watershed residents have been able to develop property to the extent the regulations allow, or sell it to the City if they chose. In addition, upstate community representatives have participated in the regional watershed partnership council, which included representatives of the State, City, and downstate consumers (Platt et al., 2000).

Progress on the MOA objectives has been continually evaluated. In 2002, the FAD was reviewed and renewed by the EPA, with the provision that NYC begin construction of an ultraviolet (UV) light disinfection treatment facility in Westchester County for the Catskill/Delaware system. Just four years later, progress on the many requirements of the 2002 FAD (infrastructure, protection and remediation programs, watershed monitoring, etc) was positively reviewed by the EPA. Notably, NYC's water supply system became the largest surface water supply system in the United States for which a FAD has been authorized (in 1997) and re-authorized (in 2002 and 2006) due to continued compliance (Mugdan, 2004; U.S EPA Region II, 2006a).

The NYCDEP has also evaluated progress since the MOA. The 2005 Drinking Water Supply and Quality Report, published by the DEP, noted that progress has been made on several fronts (NYCDEP, 2005d). For example, land acquisition

Box 3. New York City: Unexpected Source of Aquatic Biodiversity

For all its famous terrestrial landmarks, the NYC metropolitan area is actually dominated by water, with approximately 2400 kilometers of coastline (see Figure 1) (Solecki and Rosenzweig, 2001). The city itself has a 930 kilometer coastline and four of its five boroughs are located on islands (Goldstein and Izeman, 1990; Solecki and Rosenzweig, 2001). A complex network of waterways connects the metropolitan area to its heavily urbanized neighbors New Jersey and Connecticut via the New York/New Jersey (NY/NJ) Harbor Estuary and the Long Island Sound. Just outside the NY/NJ Harbor Estuary is the New York Bight, a 39,000 square kilometer sector of the Atlantic Ocean (Friedman et al., 2000). There is a remarkable diversity of ecosystems throughout these waterways. The ocean waters support marine deepwater and subtidal and intertidal ecosystems (Edinger et al., 2002). At the interface between marine and terrestrial environments are the coastal estuarine wetlands. These wetlands provide many important ecological functions such as the dissipation of wave energy and buffering of storm surges, which would otherwise result in accelerated erosion of the coasts. The frequency of tidal inundation and rates of runoff from tidal marshes are important in determining the magnitude of exchange of nutrients, organic matter, toxins, and pollutants between marshes and their surrounding estuaries (Montalto and Steenhuis, 2004).

Biodiversity, or biological diversity, is defined as the variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it. Even in the highly urbanized environment of New York City, there are pockets of high aquatic biodiversity in the many marine, coastal, and freshwater ecosystems. For example, the biodiversity of the coastal wetland communities in the New York City metropolitan area is notable for its wide variety. Located at a critical point along the Atlantic flyway, the wetlands of the NY/NJ Harbor Estuary provide habitat for resident and migratory birds (Edinger et al., 2002; Montalto and Steenhuis, 2004; Steinburg et al., 2004). The marshes of Jamaica Bay (see Figure 2) support over one-fifth of all North American bird species and even the endangered Kemp's Ridley turtle can be found there (Goldstein and Izeman, 1990; Brown et al., 2001; NY/NJ Clean Ocean and Shore Trust, 2004). Many fish species occupy the estuaries of New York City's waters for at least some portion of the year, including migratory species such as sturgeon and resident species such as white perch (Dowhan et al., 1997). These estuaries also contain habitats that support shellfish such as oysters, fauna such as crustaceans and nematodes, and microbiota such as blue-green algae (Dowhan et al., 1997; Edinger et al. 2002). All types of wetlands serve as important links in food webs (Steinburg et al., 2004).

continues and the City has worked to manage these newly owned lands appropriately, while providing opportunities for recreation including fishing and hiking. There has been a 60% increase since 1997 in the number of City owned watershed lands open for recreation. Partnership programs have also been continually progressing. In particular, the CWC continues to work to improve failing septic systems and stormwater control measures.

Most recently, the success of the MOA approach has been reinforced by the USEPA's April 2007 release of a draft FAD for the Catskill/Delaware water systems that will last until 2017. This draft FAD hinges on the City's 2006 Long-Term Watershed Protection Program and plans to continue the land acquisition progress started by the MOA (NYCDEP 2006b, NYCDEP 2007).

The Scenario

Currently, NYC is part of an exclusive group of major American cities including Boston, San Francisco, Seattle, and Portland, Oregon that have unfiltered water supply systems. Numerous considerations are affecting current plans for and perceptions of the water supply system. Listed below are issues that may be used to begin a discussion in the class about the future of the NYC water supply system. Students should apply the knowledge they have acquired about the history of the system to address one or more of these issues.

1) *Epilogue:*
   Part II of this case provides an overview of the sequence of events that occurred after "decision-time" on the NYC water supply system. How does the MOA agreement and epilogue compare with the stakeholder forum suggestions from the class exercise in Part I? To what extent does reality match the recommendations? Do the class groups have an idea of how each of the stakeholders might have responded to the decision?

2) *Stakeholders:*
   Part I of this case study listed four stakeholders in the NYC water supply system (upstate and downstate stakeholders, government agencies, and environmental groups). In the 10 years since the signing of the MOA, are there any additional stakeholders that must now be considered regarding the water supply system? Review the February 2006 article in the *New York Times* "Floodwaters Reveal a Divide Between Upstate and Down (Applebome, 2006)", the March 2006 article in *New York Times* "City Takes Steps to Balance Its Water Needs With Flood Protection Upstate (DePalma, 2006b)" and publications by the Croton Watershed Clean Water Coalition (http://www.newyorkwater.org/) to enhance this discussion.

3) *Current water quality issues:*
   a. Turbidity – A New York Times article from July 2006 describes the increased concentrations of clay particles in the drinking water supply, washed into reservoirs by storms and increased runoff from land development. This increased turbidity can interfere with chlorination to remove contaminants. Currently, turbidity is treated chemically, with aluminum sulfate, to clear out the clay particles by lumping them together so they settle out. What potential implications could this water quality issue hold for the city and the FAD (DePalma, 2006a)?
   b. The DEP's 2005 Drinking Water report notes the delicate balance between treating water with chlorine to disinfect microbial contaminants and the resultant disinfection by-products such as haloacetic acids (chlorine reacts with naturally occurring metals in drinking water) (NYCDEP, 2005d). What potential implications could this water quality issue hold for the city and the FAD?

4) *Implications of climate change:*
   Studies have shown that air temperature in the Catskill Mountain Region of New York has warmed by 1.1° F since the 1950s along with an increase in average precipitation of over 13 centimeters per year. Studies have also indicated that the area can expect a warmer and wetter climate in the next century, but droughts will also occur, especially in the more developed parts of upstate regions (Burns, 2006). How might the following issues, com-

bined with the effects of climate change, affect the water supply system?

a. Increase in variability of stream runoff.
b. Potential for sea-level rise in coastal areas of NYC and potential negative impacts on wetlands and other natural flood-mitigation and water retention systems.
c. Human land use and development increasing vulnerability to climate change through increase in *impervious* surface coverage in the watersheds or further clearing of forested land.
d. Planning for the future needs of upstate and downstate customers.

Part II: Issues for Optional Analysis and Discussion

1) *Source to Sink Pollution Issues*
Most of the water that comes from upstate watersheds ends up in the various waterways that surround New York City (Figure 2). Interestingly, respondents to the American Museum of Natural History's survey mentioned above associated "water pollution" with urban and/or industrial areas such as New York and New Jersey. Indeed, pollutants such as total suspended solids, biological oxygen demand, pH, fecal *coliform* bacteria, oil, and grease can result from human activities. The effects of these pollutants can result in fish kills, oil slicks, and unusual colors or odors associated with the water. Such pollutants are under control throughout most of the NYC area. However, contaminants can be released during 'combined sewer overflows' (CSOs). CSOs constitute one of the most important point-source water pollution problems in New York City (Goldstein and Izeman, 1990, Beard et al., 1996; Solecki and Rosenzweig, 2001; Stoddard et al., 2002; Alfsen-Norodom et al., 2004). As little as 0.1 centimeters of rain in some portions of the NYC metropolitan area can initiate overflow conditions causing up to 10% of the city's raw wastes to enter the city's aquatic ecosystems through more than 540 overflow points (Beard et al., 1996). Increases in non-point sources of pollutants in urban areas have been shown to affect

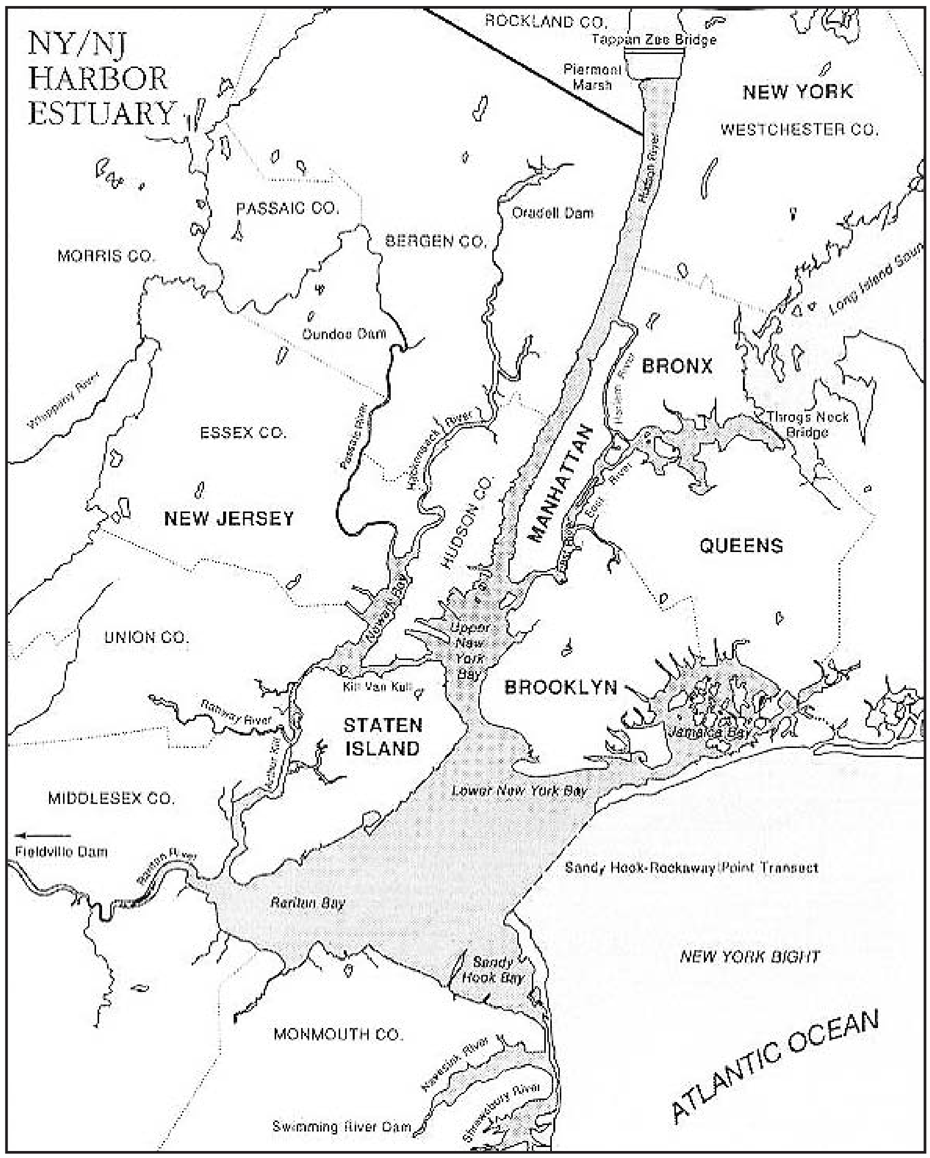

Figure 2. NY/NJ Harbor Estuary – Ultimate Recipient of Upstate Water (Source: USEPA)

water quality and aquatic biodiversity. Most of these effects are compounded greatly by vast stretches of *impervious* surface cover in urban areas that increase the velocity of stormwater and provide a continuous pathway along which many pollutants can be transported (Kennen and Ayers, 2002).

Pollution prevention and appropriate land management planning are some of the most effective methods currently being employed to reduce diffusive environmental contamination in urban areas (Wakeman and Themelis, 2001). New York State's statewide non-point source management program focuses on reducing input from agricultural, urban, and onsite disposal systems (Beard et al., 1996). One example of the application of *non-point source* management to reduce ocean pollution and improve ecosystem health is the Long Island Sound Study. Currently in Phase III, this comprehensive management plan seeks to reduce nitrogen loading into Long Island Sound in order to mitigate *eutrophication* and resultant *hypoxia*. The strategy for meeting nitrogen reduction targets relies on aggressive control of point and non-point sources via land use decisions at the local level. At the scale of the watershed, the plan implements stormwater detention ponds, streetsweeping, and habitat protection and restoration. As a result of such actions, upgrades to sewage treatment plants have decreased nitrogen discharges to the Sound by 25% from peak years in the early 1990s and the severity of hypoxia has decreased (Long Island Sound Study, 1998).

2) *Challenges of Maintaining a Large Metropolitan Water Supply System*
   a. Ongoing construction of NYC water tunnel No. 3 to be completed in 2020 at a cost of almost $6 billion. See resources on progress (NYCDEP, 2006a) and the story of the sandhogs (urban miners) working to dig the tunnel (Levay, 2005).
   b. The importance of water conservation and initiatives to reduce water consumption such as: leak detection, water metering, incentive programs and education programs such as a toilet rebate program to encourage use of water-saving models (NYCDEP, 2005e).

3) *New Techniques to Identify Threats to Watershed and Drinking Water Quality*
   The use of landscape analysis and *Geospatial Information Systems (GIS)* to determine risks to water resources as a result of watershed landscape change in the EPA's "A Landscape Analysis of New York City's Water Supply (1973-1998)" (Mehaffey, 1998).

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Glossary

Buffer Zones: A defined land area adjacent to a water body on which activities that may impact water quality are regulated or restricted.

Coliforms: A group of related bacteria whose presence in drinking water may indicate contamination by disease-causing microorganisms.

Disinfection By-products: Products formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter present in the source water. Different disinfectants produce different types or amounts of disinfection byproducts. Disinfection byproducts include trihalomethanes, haloacetic acids, bromate, and chlorite.

Downstate: A term for the southeasternmost portion of New York State, in contrast to Upstate New York.

Ecosystem Services: Benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services that affect climate and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as nutrient cycling.

Eminent Domain: Power of state entities to take private property for public use with compensating payment to the owner.

Eutrophication: The increase of chemical nutrients, typically compounds containing nitrogen or phosphorus, into a water body, oftentimes resulting in excessive plant growth and decay and subsequent reductions in water quality.

Filtration: Slowly filtering drinking water through clean sand or a simi¬lar filtering medium to eliminate contaminants and make the source water potable.

Filtration Avoidance Determination: An agreement between the EPA and local and state governments that waives the federal requirement to filter drinking water known as the Surface Water Treatment Rule.

Giardia: A protozoan parasite that infects the gastrointestinal tract and causes the disease giardiasis.

GIS (Geographic Information System): A computer system for capturing, storing, querying, analyzing and modeling geospatial data.

Groundwater: Water beneath the Earth's surface, beneath saturated soil and rock, that supplies springs and wells.

Hypoxia (also oxygen depletion): A phenomenon that occurs in aquatic environments as dissolved oxygen is reduced to a point detrimental to aquatic organisms.

Impervious surfaces: Hard surfaces (rooftops, sidewalks, driveways, streets, parking lots, etc.) that do not allow rain water to infiltrate into the ground. Instead, the rain water runs off these surfaces, picking up heat and other water pollutants that can be transferred to streams, rivers, and lakes, creating water quality problems.

Microbial Contamination: Concentrations of microbial *pathogens* such as viruses, bacteria, *Giardia lamblia* and *Cryptosporidium* spp.

Non-Point Source Pollution: Pollutants from many unidentifiable sources such as agricultural runoff. Non point source pollution is from a more diffuse source than point-source pollution.

Pathogen: A disease-causing organism.

Point Source Pollution: Pollutants that are emitted from a specific point of discharge or a concentrated originating point like a pipe from a factory. One example of point source pollution from stormwater runoff is NYC's combined sewer overflows described above in 'Part II: Issues for Optional Analysis and Discussion Topic 1."

Runoff: The flow of water from rain, snowmelt or other sources over the land surface in the form of rivers, lakes and streams to the oceans.

Source Water: Water in its natural state, prior to any treatment for drinking.

Stakeholder: Any entity dependent on the use and management of specific resources. Stakeholders may belong to different socially and politically defined units but all have an interest or 'stake' in the same resource.

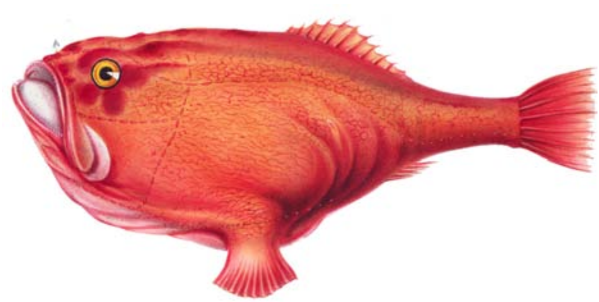
Surface Waters: Water that is on the Earth's surface, in streams, rivers, lakes, and reservoirs.

Turbidity: Cloudy appearance of water caused by the presence of tiny particles. High levels of turbidity may interfere with proper water treatment and monitoring.

Upstate: A term generally referring to the Northernmost region of New York State, outside of the core of the New York Metropolitan area.

Watershed: The region draining into a river, river system, or other body of water.

Wetlands: A general term applied to land areas which are seasonally or permanently waterlogged, including lakes, rivers, estuaries, and freshwater marshes.



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