International Clearinghouse for MPA Effectiveness Measures: A Conceptual Design

Craig Syms and Mark H. Carr
Institute of Marine Sciences and Department of Ecology and Evolutionary Biology,
University of California, 100 Shaffer Rd, Santa Cruz CA95060, USA
email: syms@biology.ucsc.edu; carr@biology.ucsc.edu

Table of Contents:

1. Abstract

Marine Protected Areas (MPA's) are receiving increased attention as a tool to manage, conserve, and augment marine resources. There is a need for managers to be informed about the effectiveness of existing MPA's, and for a framework to be developed in which new or ongoing monitoring programs can be integrated into a common database to enable the potential benefits of MPA's to be evaluated relative to other management actions. A potential means by which this objective can be achieved is by developing a web-based clearinghouse of information, both past and present, that can be used to centralize the results from studies and synthesize effectiveness statements across a range of different localities and research programs. However, past and existing monitoring programs have used non-standard methodologies of variable quality. Additionally, MPA's have traditionally been expected to me a range of different objectives. These factors present a considerable barrier to be overcome. We suggest a web-based clearinghouse be developed to integrate information from ongoing MPA monitoring programs, published studies, grey literature, and other web-based data management systems. Initially, this database should serve as a metadata 'pointer' to data sources and studies. A broad-based data interface 'form' should be developed to enable integration of different studies and queries of data quality to be made. Finally, an interactive meta-analytical series of data analyses and queries should be developed to generate MPA effectiveness measures that can be applied across study localities, methods, and spatial and temporal scales.

2. Introduction

Marine Protected Areas (MPA's) are designated areas within which human activities that can result in the removal or alteration of biotic and abiotic components of an ecosystem are prohibited or greatly restricted (NRC 2001). They are receiving increased attention as a tool to manage, conserve, and augment marine resources (Dugan and Davis 1993, Creese and Cole 1995, Agardy 1997, Allison et al. 1998, Lauck et al. 1998, Murray et al. 1999). However, the recent climate of accountability and performance-oriented conservation goals has resulted in the need for resource management agencies to provide a strong rationale for the designation of MPA's. There is a strong need for the development of a centralized source of information on the performance of MPA's both nationally, and worldwide.

Marine protected area programs worldwide are moving rapidly to devise and implement systems to measure the effectiveness of individual sites towards meeting their specific conservation objectives. U.S. and international programs currently considering ways to measure MPA effectiveness include the US National Marine Sanctuary System, the IUCN's World Congress on Protected Areas (WCPA), and the trinational Commission on Environmental Cooperation's North American MPA Network. To date, much of this effort has focused on designing practical measures of effectiveness for particular types of MPA's, and on the crucial step of incorporating these measures into MPA planning processes and into long-term monitoring of established sites.

In spite of this growing trend to evaluate individual sites, relatively little effort has so far been focused on how the resulting information will be used beyond assessing and improving the effectiveness of local MPA sites. Specifically, the opportunity exists right now, while these program-specific measures are being designed around the world, to craft a comprehensive, web-based information management system that would compile these site-level effectiveness results to illustrate important trends, and valuable lessons-learned about MPA's across broader geographic scales, including networks entire bioregions. This opportunity is crucial for enabling managers and policy makers to draw from information in a range of systems to:

- Develop strategies to adaptively manage MPA's, and networks of MPA's in a rapidly changing world where major trends may not be apparent at the scale of individual sites (e.g. invasive species, fisheries impacts, climate change).
- Identify resources at particular risk across multiple sites.
- Illustrate to the public, stakeholders and policy/decision makers the value of this promising but often controversial, coastal conservation tool.

There are several reasons why management agencies need to evaluate how well a MPA achieves its objectives, and why there is a sense of urgency to develop evaluation procedures in the very near future. Management agencies are being held more accountable for policy decisions and are compelled to provide both clear statements of MPA objectives and the means by which effectiveness will be measured. Many recently designated MPA programs have legally binding "sunset clauses" that require assessment of effectiveness for the continued implementation of a MPA. This increased accountability stems from two concerns. First is the limited financial and human resources available to any resource agency to develop and implement management strategies. When limited, resources allocated to one management plan preclude their allocation to another. This becomes problematic if resources are allocated to the less effective of the alternative approaches. Thus any management approach comes with a potential cost if either it does not succeed to achieve its objective or does so less efficiently than an alternative approach. Second, management actions may incur costs on stakeholders, and hence the management agency is accountable for perceived, potential, or realized impacts that regulations have on stakeholders.

It is also important to measure MPA effectiveness to avoid a false sense of security by assuming a MPA is achieving its objectives, when in fact it is not. This problem may be exacerbated if other regulations are relaxed because of the presumed precautionary role MPA's are intended to achieve. Failure of any management approach, due either to poor design or evaluation, can potentially endanger the resources it was designed to protect. Moreover, poor evaluation can jeopardize the future of a management approach if it fails to identify the real value of a management approach or leads to an incorrect interpretation that the approach has failed. The sooner the benefit (or cost) of a management approach is evaluated and recognized, the more quickly that approach can be targeted for (or discounted for) allocation of resources. MPA design is unlikely to evolve, through adaptive management, to become more effective if the relative effectiveness of different designs are not determined and compared. As such, the design of realistic and achievable conservation targets, and the measurement of their effectiveness, will be crucial to the successful establishment of new MPA sites and to their long-term success through adaptive management (Carr and Raimondi 1999, Murray et al. 1999).
This document reviews some key concepts for evaluating whether MPA's are effective in achieving their intended objectives. We begin by considering the range of measures that

could, and have, been used by researchers in previous studies. We then consider the relative strengths of different sampling approaches. Our emphasis here is to illustrate that there is no single way to measure effectiveness, and few existing programs could be held up as examples of the best way to evaluate effectiveness. In many cases, this is due to the *ad hoc* development of monitoring programs, which should, in an ideal world, be established well before protection is legislated. The second reason for taking this synthetic approach, rather than drawing on existing monitoring programs, is that existing programs are usually tailored for specific ecosystems and questions. Consequently, they can neither serve as 'blueprints' for a general way to monitor effectiveness, or provide a unified means to compare different monitoring programs. Concurrent research by the NOAA MPA center is in the process of establishing a database of existing MPA monitoring programs (Lani Watson and Lisa Marx, NOAA National Ocean Service, International Programs Office, Silver Spring, MD).

We then propose a structure for a web-based clearinghouse of information on effectiveness of existing marine protected areas which aims to assimilate information from published studies, grey literature, and web-based information sources into a relational database. Data will be coded and weighted to generate a synthetic and comparative effectiveness measure, which will enable cross-site and system comparisons. These data will allow three levels of query.

- First, a listing of metadata and data sources can be generated from a query of the primary key table of the database. This will enable interested parties to identify and obtain the sources of original data, broken down by locality, year etc.
- Second, a data quality query will enable a more detailed breakdown of data on the basis of effectiveness parameters, temporal and spatial scale, and sampling approach.
- Third, an effectiveness query will make use of a series of data filters and weighting factors to generate a cross-system measure of relative MPA effectiveness, analogous to a meta-analytical framework.

3. Measuring MPA effectiveness

3.1 General approaches to evaluating MPA effectiveness

Understanding the various approaches to evaluating MPA effectiveness and their relative costs and benefits is critical both to interpreting the value (and shortcomings) of past and existing studies, and the design of web-based evaluation programs. Evaluating the effectiveness of a marine protected area requires clearly identified goals and objectives, some knowledge of the many sources of uncertainty—process, model, causal, and measurement—both in the ability of a MPA to achieve its objectives and in our ability to accurately evaluate them, and a well-designed evaluation program (Syms and Carr 2001). The design and scope of an evaluation program requires objective-based effectiveness parameters (i.e. response variables: population abundance or size distribution, species composition or diversity, habitat condition), targets (e.g., specified levels or directions of each of these parameters or response variables), limits (acceptable deviations from specific targets), as well as a spatial (over what area a target is to be realized) and temporal (how soon and for how long a target is to be met) context (Syms and Carr 2001).

MPA goals and objectives come from conceptual and theoretical inferences as well as empirically based inferences drawn from results detected in existing programs. The effectiveness targets defined by these objectives may be of three forms. They may be absolute values to be attained over some defined spatial area and temporal period. For example, there may be some reason to target a particular density or abundance of a species within a MPA. Alternatively, a target may be a relative value, such as some percent increase in abundance or density within a MPA relative to non-MPA populations. Or, a target may be a rate of change in the difference between MPA and non-MPA effectiveness parameters over time (i.e. a pre-defined trajectory of the difference between MPA and non-MPA populations). There are strong arguments for any of these three forms of effectiveness parameters depending on the MPA objective and the particular effectiveness parameter.

Two critical components of an effectiveness parameter are the spatial and temporal scale of the parameter. For example, some parameters may be restricted to within the boundary of MPA (e.g., increased larval production) and others may be manifested over a far greater spatial expanse (e.g., larval dispersal to and replenishment of fished populations outside a MPA). Similarly, some parameters may be expected to response rather rapidly after MPA establishment (e.g., change in population size structure of a fast growing species within a MPA) while others may take many years to fruition (e.g., the increased recruitment of a slow growing species into a catchable stock outside a MPA). For realistic spatial and temporal expectations and effectiveness targets, as well as appropriately designed sampling programs, some estimate of the spatial and temporal scales of an effectiveness parameter must be made.

3.2 MPA effects vs MPA effectiveness, and the development of effectiveness parameters

There is a growing body of research that demonstrates that MPA's have an effect on resident assemblages of organisms (e.g., Edgar and Barrett 1997, 1999, Babcock et al. 1999, Garcia Charton et al. 2000, Planes et al. 2000, Jamieson and Levings 2001). However fewer authors have ventured appraisals of how these effects enable MPA's to achieve their intended objectives (but see Rowley 1994, Freitas et al. 1998). There are two widely cited objectives of MPA's – for conservation (of habitats, species, ecosystems etc.) and fisheries management.

Conservation objectives are often loosely defined and thus present a problem in assigning objectives and developing effectiveness parameters. Biodiversity objectives can be defined at a range of organizational levels from species (including genetic diversity), through community to landscape levels (Franklin 1993), and hence may be scale-dependent. However, the underlying objective is to conserve the ecological and evolutionary processes that generate and maintain diversity. This broad objective is frequently re-specified as a focused set of specific objectives that are assumed to act as proxies for these processes – focal species objectives, and community/landscape objectives. As a consequence, a wide range of parameters and derived measures have been used to measure how MPA's 'perform' in fulfilling conservation objectives (Table 1). These parameters range from measures at the individual species level, either for conservation of particular species, or as a measure of community 'health', through

Table 1. Effectiveness parameters for individual and networked conservation MPA's.

I. Species population parameters
Abundance
Density
Size structure
Age structure
Size specific fecundity
Larval production (product of density and size specific fecundity)
Spawning biomass
Population stability
Population resilience
Population resistance
Genetic diversity (within and between populations throughout network)
Demographic rates (reproduction, mortality, immigration and emigration)
Mean individual growth rates
Local population viability estimates
Larval dispersal (to assess extent to which MPA populations are self-replenishing)
Connectivity of larval dispersal with other MPA's
Species-specific habitat quality and abundance
II. Community parameters
Focal species (e.g., rare, endangered, keystone, indicator, umbrella and flagship species)
All or subset of species population parameters identified above with emphasis on interaction strengths and effects of keystone and exploited predator species
Community-wide
Species composition
Species richness
Relative densities of species
Species diversity
Trophic richness
Trophic diversity
Trophic structure
Guild structure and dynamics
Species redundancy
Species interactions and strengths (e.g., competition, predation, parasitism, mutualism)
Community stability and dynamics (e.g., resistance, resilience, constancy and persistence)
Spatial relationships of populations
Community function (e.g., primary and secondary productivity)
Breadth of resource use (e.g., dietary breadth of predators)
Complementarity
Genetic diversity and structure
Threshold effects—potential alternative stable states
III. Ecosystem
Habitat structure (size, shape, spatial arrangement of habitats)
Habitat richness
Habitat diversity
Habitat representativeness
Physical (structural) complexity (of abiotic and biotic substrata)
Interactions between biogenic physical structures and species that alter them.
Productivity (C gm fixed / area / time; total and by trophic level)
Nutrient and matter cycling and fluxes (e.g., rates of change, rates of cycling, fluxes, nutrient ratios, nitrogen fixation)
Detrital production and export.

community and ecosystem levels in which the functioning and linkages between organisms in the community is of greater importance (see Syms & Carr 2001 for a more detailed treatment).

Marine protected areas have also been suggested as alternate and auxiliary means of conserving, maintaining or augmenting fisheries (Beverton and Holt 1957, Roberts and Polunin 1991, 1993, Bohnsack 1993, 1998, 2000, Guénette et al. 1998, Sladek Nowlis and Roberts 1997, 1999, Murray et al. 1999). It has been hypothesized that fisheries MPA's fulfill this broad objective by providing spatial refuges from fishing that safeguard a fishery against over-exploitation (Botsford et al. 1997) and increase resilience to overfishing (e.g., Quinn et al. 1993, Man et al. 1995, Lauck et al. 1998, Sladek Nowlis and Roberts 1997, 1999). A second, and more contentious, objective of fisheries MPA's is to contribute to and augment the fishery by spillover of larvae and/or adults (Polacheck 1990, Carr and Reed 1993, Quinn et al. 1993, Man et al. 1995, Russ and Alcala 1996a,b, Sladek Nowlis and Roberts 1997, 1999, Mangel 1998, 2000a, Zeller and Russ 1998, Hastings and Botsford 1999, Kramer and Chapman 1999, Cole et al. 2000). Quantifying the performance of these types of MPA's requires an additional set of effectiveness parameters (Table 2).

Clearly, there is a wide range of variables that can be quantified to provide a measure of MPA effectiveness. While many studies overlap in their methodologies to some degree, there is no standard way of setting up and maintaining monitoring programs. This can make it difficult to directly compare MPA's or studies that address their effectiveness.

Table 2. Effectiveness parameters for individual and networked fishery MPAs

I. Population parameters
Local (within MPA)
Abundance
Density
Size structure
Age structure
Size specific fecundity
Larval production (product of density and size specific fecundity)
Spawning biomass
Mean individual growth rates
Demographic rates (reproduction, mortality, immigration and emigration)
Population stability and dynamics (e.g., resistance, resilience, constancy and persistence)
Genetic diversity (within and between populations throughout network)
Local population viability estimates
Larval dispersal (to assess extent to which MPA populations are self-replenishing)
Density, dynamics, and stability of by-catch species
Regional (outside MPA)
Larval production and export rate (from inside to outside MPA)
Larval dispersal and recruitment patterns (outside MPAs)
Emigration (i.e. "spillover") and immigration of benthic stages inside and outside of MPAs
Stock stability and dynamics (e.g., resistance, resilience, constancy and persistence)
Fishery yield
II. Community
Local (within MPA)
By-catch assemblage composition, structure, dynamics, and stability
Density, dynamics, and stability of resource requirements for exploited species
Regional (outside MPA)
Community stability, to extent that MPAs contribute to regional stock abundance and stability, and exploited species influence community structure
III. Ecosystem
Local (within MPA)
Abundance and quality of spawning, recruitment and other habitat requirements
Abundance and quality of other ecosystem-based resource requirements
Regional (outside MPA)
Ecosystem stability, to extent that MPAs contribute to regional stock abundance and stability, and exploited species influence ecosystem structure
Ecosystem stability, to extent that MPAs contribute to production and export of ecosystem components (e.g., larval export and replenishment of biogenic habitat)

3.3 Sampling designs that might be used to measure effectiveness

The design and scope of an evaluation program depends on the timing and duration of the sampling or monitoring program relative to the establishment of a MPA. A range of approaches, of varying quality, has been used (Table 3). The worst-case scenario represents the vast majority of evaluation studies and occurs when only one MPA has been established long before an evaluation program is initiated. In the most extreme case, sampling may have been carried out only in the MPA, and not in non-protected areas. In most cases however, the MPA is usually compared to some 'non-MPA' site or sites. In this case, differences between the MPA and non-MPAs are confounded by other pre-existing site differences and cannot be unequivocally attributed to protection afforded by the MPA. It will never be clear whether observed differences (MPA vs. non-MPA) were caused by the MPA or if these differences already existed before the MPA was established.

If instead, one or more MPAs is to be evaluated and sampling can be initiated at the proposed MPA site(s) and non-MPA “control” site(s) prior to MPA establishment, then inferences about MPA effects become much stronger – particularly if non-MPA and MPA areas are sampled. Two general philosophies are commonly used when ‘Before’ and ‘After’ data are available. The Impact vs Reference Site (IVRS) approach treats MPAs and controls as formal randomized experimental replicates, and hence makes inferences about ‘MPA’ effects in general. IVRS requires that sites are truly independent and that they are assigned randomly to either MPAs or control treatments (Stewart-Oaten and Bence 2001). In practice, often these conditions do not hold and so the alternative Before-After-Control-Impact (BACI) sampling design is used. BACI requires that reference sites be as similar to MPAs as possible, and is based on the model that temporal differences in sites are attributable to MPA effects. Consequently, BACI approaches make site-specific statements of MPA effectiveness.

BACI designs have been used more frequently in the literature, in particular to test for single coastal environmental impacts, and a rich literature on this design and analysis exists (Stewart-Oaten and Murdoch 1986, Stewart-Oaten and Bence 2001, and references therein). Non-MPA control sites at varying distances from the MPA (spatial gradient approach) may be incorporated into this design to examine the spatial extent of MPA effects. Alternatively, the effectiveness of a MPA at protecting a species targeted for exploitation can be determined by employing a BACI approach before and after exploitation begins as long as monitoring of that species in and out of the MPA has been conducted over that period. An excellent example of this approach is provided by Schroeter et. al. (2001) in which the status of an exploited invertebrate was monitored in MPAs and fishing grounds before and after initiation of the fishery. This example demonstrates not only how a MPA can protect a population of a targeted species, despite strong declines on fishing grounds, but also the role of MPAs for assessment of stocks and the impact of fishing. If instead evaluation sampling cannot be initiated prior to, but near, the time of MPA establishment, trends in the difference between MPA and non-MPA sites can be compared to determine if the sites are changing in predicted ways (i.e. increasing differences over time in density and mean size of individuals within MPAs relative to non-MPAs).

Table 3. Sampling designs that have been used to measure effectiveness

Design	Frequency of application	Comments
Impact Only: Samples taken only in MPA, after MPA establishment	Uncommon	Very poor inferential ability
Control-Impact: Samples taken both in MPA and control areas, after MPA establishment	Very common	Poor inferential ability, confounds spatial patterns with MPA effects
Before-After: Samples taken before and after MPA establishment, only in MPA	Uncommon	Poor inferential ability, confounds temporal patterns with MPA effects
Before-After Control-Impact: Samples taken before and after MPA establishment, in MPA and control site(s).	Uncommon	If temporally replicated, strong design to make statements of effects of particular MPA's. Weaker ability to make global statements of effectiveness. Conditional on MPA and non-MPA sites having correlated dynamics.
Impact vs Reference Sites: Samples taken before and after MPA establishment, in MPA and control site(s)	Uncommon	If replicated, strong design to make global statements of effectiveness. Weak design to evaluate particular MPAs. Conditional on MPA and non-MPA sites having uncorrelated dynamics, and MPA 'treatment' being allocated randomly to sites

3.4 Additional considerations

The design, scope and inferences drawn from an evaluation program will also be strongly influenced by the design of the MPAs to be evaluated (e.g., the number, size, distribution and environmental conditions). If only one MPA is to be evaluated, any inferences regarding the effectiveness of that MPA are largely constrained to only that MPA and cannot be generalized to MPAs (more importantly, potential MPAs) in general given the great environmental and biotic heterogeneity of the coastal marine environment. Any environmental characteristics (species composition, geologic or oceanographic conditions) unique to that MPA preclude generalizing how MPAs in other areas would respond to protection. This is particularly true with respect to effectiveness targets that are relative differences between MPA and non-MPA sites because the relative differences (or trajectories) will depend on the magnitude of human impacts (e.g., fishing catch) outside the MPA. If multiple MPAs and non-MPAs can be sampled simultaneously, broader inferences regarding MPA effectiveness can be made (general MPA effects rather than the effect of a specific MPA). Moreover, environmental, design and management differences among MPAs can be evaluated relative to one another. Such an approach is critical to the adaptive management of MPAs. Thus, the design, implementation, analysis, inferences, and success of studies conducted to evaluate effectiveness of a marine MPA will be influenced greatly by, and therefore must consider, all of the criteria identified above. It is important to measure the context (i.e., potential covarying factors) within which MPA effectiveness studies have been carried out (Table 4).

Table 4. Covariates required to assess MPA effectiveness

Habitat variables	MPA characteristics	Exploitation variables
1. Physiographic habitat structure 2. Oceanographic environment 3. Biotic habitat structure 4. Connectivity with other biotic and abiotic habitats 5. Climatic variation 6. Proximity of essential habitats (e.g., nursery grounds) 7. Potential for other threats (e.g., pollution) 8. Natural disturbance regime	1. Size 2. Shape 3. Age 4. Enforcement effectiveness 5. MPA network configuration 6. Edge permeability	1. Total fishing effort 2. Spatial location of fishing effort 3. Targeted species 4. Effect of other effort control regulations in managing fishery 5. Gear type and effects on habitat 6. Bycatch composition and abundance 7. Temporal distribution of fishing effort 8. Amount of area fishable by different gear types

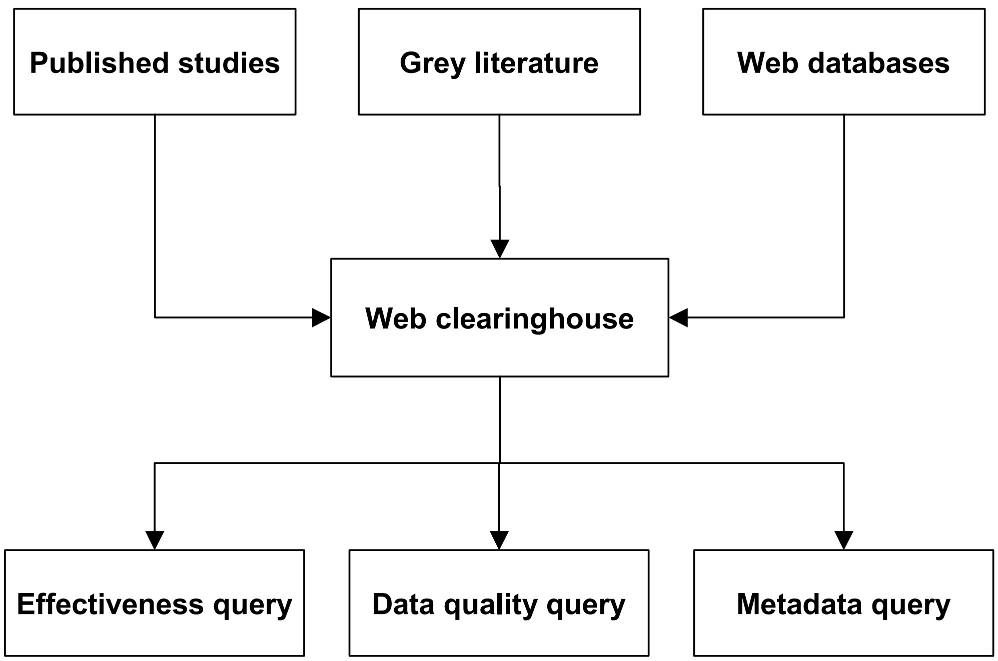
4. Developing a web-based clearinghouse of MPA effectiveness information

At present no standard methodology has been adopted for measuring effectiveness of MPA's. Consequently different studies have used different procedures, measured different variables standardized to different units, cover different spatial and temporal scales, and employ sample designs of variable quality and robustness. Additionally, MPA's exist at different sites, each subject to different environmental and anthropogenic regimes. Finally, many MPAs – even within a single administrative system – have differing goals and conservation objectives. Combined, this variability makes cross-site comparisons difficult and hence the need for a synthetic means to make meaningful general evaluations.

The pressing need for management decisions on MPA dictates that relevant information must be acquired, centralized, filtered and interpreted to provide a means by which managers, policy makers and stakeholders can make informed decisions about the effectiveness of MPA's as a management and conservation tool. We outline a conceptual plan for a web-based clearinghouse of information on effectiveness of existing marine protected areas, which aims to assimilate information from ongoing monitoring programs, published studies, grey literature, and other web-based information sources into a relational database. Data will be coded and weighted to generate a synthetic and comparative effectiveness measure, which will enable cross-site and system comparisons. These data will allow three levels of query.

- First, a listing of metadata and data sources can be generated from a query of the primary key table of the database. This will enable interested parties to identify and obtain the sources of original data, broken down by locality, year etc.
- Second, a data quality query will enable a more detailed breakdown of data on the basis of effectiveness parameters, temporal and spatial scale, and sampling approach.
- Third, an effectiveness query will make use of a series of data filters and weighting factors to generate a cross-system measure of relative MPA effectiveness, analogous to a meta-analytical framework (Fig. 1).

Figure 1. Schematic design of a web based clearinghouse. Web databases from other programs, grey literature such as reports, and published studies are assimilated into a central web database. From this database three levels of queries can be made: Metadata (what studies have been done, what did they measure, and where are the data stored); Data quality (how were studies done, how robust was the sampling design), and Effectiveness (how well did the MPA(s) achieve management objectives and what levels of error or uncertainty are associated with this conclusion).



4.1 Data acquisition and sources

4.1.1 Sources

The MPA effectiveness clearinghouse database will draw upon three primary sources of information. First, the peer-reviewed ecological literature contains many reports of studies that measure MPA effects. Second, many studies are presented in unpublished reports (grey literature). These reports come from a wide range of governmental, non- and quasi-governmental, and academic (e.g., unpublished theses) sources. Third, many other monitoring efforts are either web-accessible or in the process of becoming web accessible. These efforts are expected to expand over time as MPA programs develop and implement permanent monitoring programs intended to measure important effectiveness variables.

4.1.2. Input methods and priorities
At present we suggest a manual form-based input be used to key data from published and grey literature sources. The first entry priority is the metadata – a description of the study, including locality, sample method, variables measured, sample units, spatio-temporal scale over which the study was carried out, and location of the data source. These metadata form the inventory from which all further analyses can be conducted. Designating individuals to develop and maintain a strict data entry format and protocol will regulate quality control. For example, the National Center for Ecological Analysis and Synthesis website (http://www.nceas.ucsb.edu) has several links to metadata models and software (such as the Ceres project http://www.ceres.ca.gov/help.desk/metadata.html).

The second priority is the input of detailed information on different effectiveness parameters, sample designs, and covariates (listed in Tables 1 through 4). This form will necessarily be complex due to the flexibility required to incorporate many different data types, but if implemented correctly will enable the second level of data query – the data quality query.

Over time, the number of MPA sites and programs conducting routine, scientifically designed monitoring programs will expand significantly. Many are or will publish their results in various forms on the web. Web based information can be incorporated in one of two ways. First, data from sources that are simply published to the web (e.g., the Australian Institute of Marine Sciences Great Barrier Reef Monitoring program at http://www.aims.gov.au/pages/research/reef-monitoring/reef-monitoring-index.html) can be manually input via a form-based interface. However we see the potential for automated data entry and updates via direct database communication, especially for ongoing and continually updated programs. This model would require a high degree of cooperation and coordination between data managers. Efforts to design this reporting system, including standard data-sharing agreements among programs should begin in parallel with the design and development of the more static analytical capabilities focusing on published studies.

4.2 Analyzing and reporting trends at multiple sites
There is a strong need to integrate the lessons learned from MPA establishment worldwide. For example, managers, policy makers and stakeholders need to be able to assess effectiveness among MPAs across a large range of ecosystems, sharing similar species, facing similar threats, or having similar management regimes. However, integrating results from different studies and systems is a considerable challenge.

4.2.1. Data entry, filtering, and weighting
At present no standard methodology has been adopted for measuring effectiveness of MPA's. Consequently there is no well defined way in which studies that use different procedures, measure different variables, cover different spatial and temporal scales, and employ sample designs of variable quality, can be directly compared. However, in spite of these challenges, a meta-analytical approach (Englund et al. 1999, Gurevitch and

Hedges 1999, Osenberg et al. 1999) might be developed that enables global statements of MPA effectiveness to be made.

The key elements to be resolved in any development of a meta-analysis are (Table 5):
1. Formulating metrics that correspond to 'effectiveness parameters', yet can be derived from different variables. For example, if 'diversity' is deemed to be an effectiveness parameter, it might be possible to derive a common absolute or relative (to control) diversity 'effect size' that can be based on species richness, diversity metrics, community evenness metrics, raw data, or a combination thereof.
2. Identifying sources of variability that can be used to 'weight' the reliability of individual results. For example, studies with poor replication and poorly estimated effect sizes might be 'down-weighted' in a statement of overall effectiveness. Similarly, short-term studies might not be considered as 'important' as long-term studies.
3. Individual studies might be weighted by their sample design. For example, studies conducted only after MPA status might not be held as 'important' as a more rigorous BACI design.

Table 5. Considerations for developing cross-site measures of MPA effectiveness

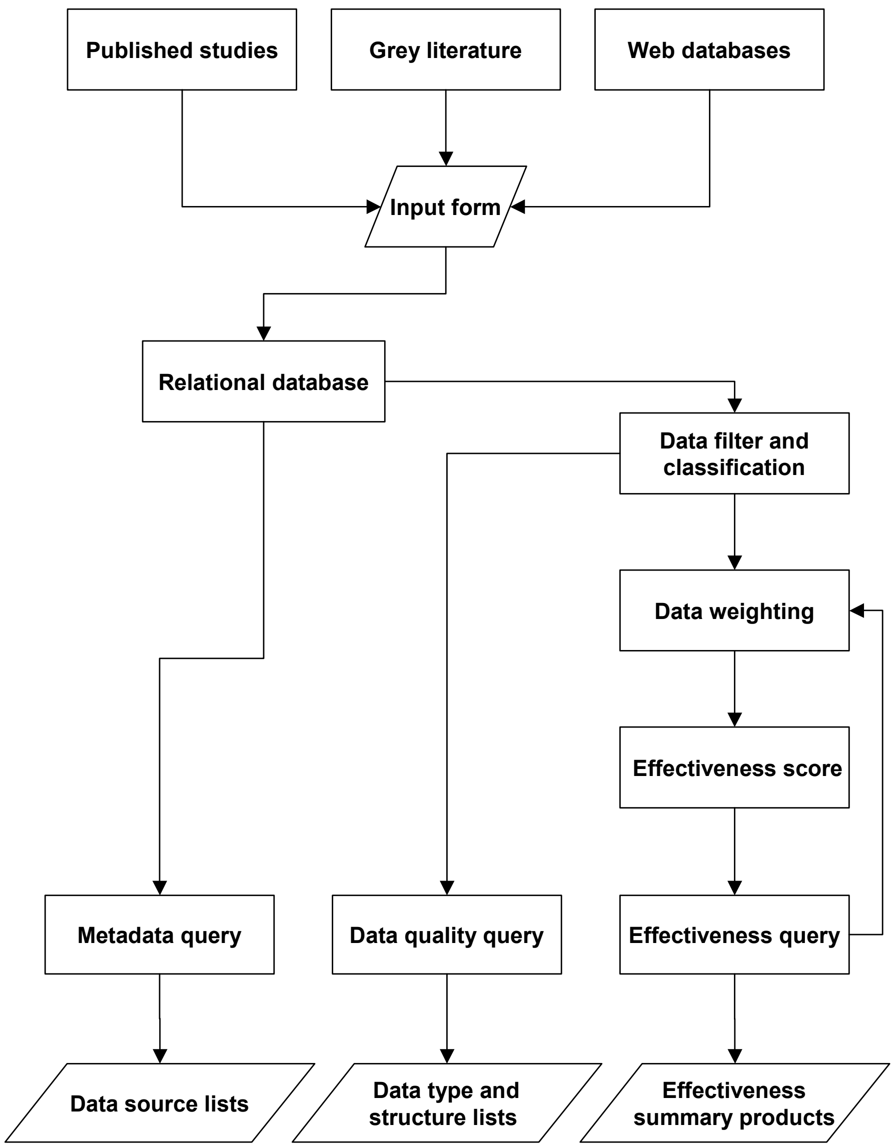
Meta-analytical component	Considerations
1. Effect size	Comparability of different measures Sample unit standardization (e.g., density vs timed counts) Absolute vs relative effect size
2. Sources of variability	Within-study variance Between-study variance Variance-mean scaling Spatial scale Temporal scale Anthropogenic and natural context of MPA study
3. Weighting of studies	Study selection Relative importance of 'snapshot' studies vs Before-after, BACI, IVRS approaches

4.2.2. Analyzing cross-site patterns of effectiveness
A meta-analytical approach to measuring effectiveness is necessarily an interactive procedure, which requires a series of assumptions to be made by the person querying the database. The way in which this procedure is carried out will require concentrated effort to develop a broadly-applicable methodology. In some cases, if studies were carried out using similar sampling protocols, over the same spatial and temporal scales, some parameter estimates, for example, species diversity and abundance, will be directly comparable. However, it is likely that in most cases these conditions will not hold, and comparing different MPA's will be a function of comparing relative performance of MPA's to control areas. For example, reporting rates of change of abundance of key species inside vs outside the MPA. Developing a procedure to do this in a useful fashion remains a challenge.

5. Summary

Despite the disparate objectives, localities, anthropogenic and natural covariates of different MPA's, and the range of methodological approaches used to measure their effectiveness, we believe it is possible to integrate these factors into a single framework that can then provide resource managers with the necessary information to evaluate the potential and realized outcomes of a decision to institute MPA's. We see this as a progressive development of web-based metadata, quantitative interpretation and coding of monitoring results into a general framework, combined with an eventual series of procedures that can generate statements of effectiveness that are comparable across different systems and methodological approaches (Fig. 2).

Figure 2. A web-based clearinghouse 'blueprint'. Metadata and data quality queries should form the first priorities, with progressive development of data filtering and weighting routines to enable an interactive meta-analysis of MPA effectiveness.



We suggest the following sequence and prioritization of tasks to achieve the objective of developing a web-based clearinghouse.

1. Identify data sources and compile them into a database.
2. Begin compilation of published and grey literature results into a database, in a form that can be incorporated into *post hoc* meta-analysis.
3. Seek academic input into developing a strategy to develop a relative 'importance' weighting of different types of variables and sample programs to enable the 'effectiveness query' program to be developed.
4. Work with data and monitoring program managers to enable the integration of ongoing monitoring efforts into a central web-based data/metadata repository.
5. Work with managers, policy makers, and stakeholders to identify the range of output products and level of detail that would be required.
6. Provide guidelines for future monitoring programs to enable their integration into the clearinghouse.

6. Literature cited

Agardy, T. 1997. Marine protected areas and ocean conservation. Academic Press: San Diego, CA.

Allison, G. W., J. Lubchenco, and M. H. Carr. 1998. Marine reserves are necessary but not sufficient for marine conservation. Ecological Applications **8**:S79-S92.

Babcock, R. C., S. Kelly, N. T. Shears, J. W. Walker, and T. J. Willis. 1999. Changes in community structure in temperate marine reserves. Marine Ecology Progress Series **189**:125-134.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Chapman and Hall, London.

Bohnsack, J. A. 1993. Marine reserves: they enhance fisheries, reduce conflicts, and protect resources. Oceanus **36**:63-71.

Bohnsack, J. A. 1998. Application of marine reserves to reef fisheries management. Australian Journal of Ecology **23**:298-304.

Bohnsack, J. A. 2000. A comparison of the short-term impacts of no-take marine reserves and minimum size limits. Bulletin of Marine Science **66**:635-650.

Botsford, L. W., J. C. Castilla, and C. H. Peterson. 1997. The management of fisheries and marine ecosystems. Science **277**:509-515.

Carr, M.H. and D.C. Reed. 1993. Conceptual issues relevant to marine harvest refuges: examples from temperate reef fishes. Canadian Journal of Aquatic Sciences and Fisheries 50:2019-2028.

Carr, M. H., and P. T. Raimondi. 1999. Marine protected areas as a precautionary approach to management. CalCOFI Report **40**:71-76.

Cole, R. G., E. Villouta, and R. J. Davidson. 2000. Direct evidence of limited dispersal of the reef fish *Parapercis colias* (Pinguipedidae) within a marine reserve and adjacent fished areas. Aquatic Conservation: Marine and Freshwater Ecosystems **10**:421-436.

Creese, R. G., and R. G. Cole. 1995. Marine conservation in New Zealand. Pacific Conservation Biology **2**:55-63.

Dugan, J. E., and G. E. Davis. 1993. Applications of marine refugia to coastal fisheries management. Canadian Journal of Fisheries and Aquatic Sciences **50**:2029-2042.

Edgar, G. J., and N. S. Barrett. 1997. Short term monitoring of biotic changes in Tasmanian marine reserves. Journal of Experimental Marine Biology and Ecology **213**:261-279.

Edgar, G. J., and N. S. Barrett. 1999. Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. Journal of Experimental Marine Biology and Ecology **242**:107-144.

Englund, G., O. Sarnelle, and S. D. Cooper. 1999. The importance of data-selection criteria: Meta-analyses of stream predation experiments. Ecology **80**:1132-1141.

Franklin, J. F. 1993. Preserving biodiversity: species, ecosystems, or landscapes? Ecological Applications **3**:202-205.

Freitas, J., R. M. Fujita, and V. Willingham. 1998. A review of the performance of some U.S. west coast marine reserves. Environmental Defense Fund, Oakland, CA.

Garcia Charton, J. A., I. D. Williams, A. P. Ruzafa, M. Milazzo, R. Chemello, C. Marcos, M. S. Kitsos, A. Koukouras, and S. Riggio. 2000. Evaluating the ecological effects of Mediterranean marine protected areas: habitat, scale and the natural variability of ecosystems. Environmental Conservation **27**:159-178.

Guenette, S., T. Lauck, C. Clark. 1998. Marine reserves: from Beverton and Holt to the present. Reviews in fish biology and fisheries **8:** 257-272

Gurevitch, J., and L. V. Hedges. 1999. Statistical issues in ecological meta-analysis. Ecology **80**:1142-1149.

Hastings, A. and L.W. Botsford. 1999. Equivalence in yield from marine reserves and traditional fisheries management. Science **284**: 1537-1538

Jamieson, G. S., and C. O. Levings. 2001. Marine protected areas in Canada - implications for both conservation and fisheries management. Canadian Journal of Fisheries and Aquatic Sciences **58**:138-156.

Kramer, D. L., and M. R. Chapman. 1999. Implications of fish home range size and relocation for marine reserve function. Environmental Biology of Fishes **55**:65-79.

Lauck, T., C. W. Clark, M. Mangel, and G. R. Munro. 1998. Implementing the precautionary principle in fisheries management through marine reserves. Ecological Applications **8**:S72-S78

Man, A., R. Law, and N. V. C. Polunin. 1995. Role of marine reserves in recruitment to reef fisheries: a metapopulation model. Biological Conservation **71**:197-204.

Mangel, M. 1998. No-take areas for sustainability of harvested species and a conservation invariant for marine reserves. Ecology Letters **1**:87-90.

Mangel, M. 2000a. On the fraction of habitat allocated to marine reserves. Ecology Letters **3**:15-22.

Murray, S. N., R. F. Ambrose, J. A. Bohnsack, L. W. Botsford, M. H. Carr, G. E. Davis, P. K. Dayton, D. Gotshall, D. R. Gunderson, M. A. Hixon, J. Lubchenco, M. Mangel, A. MacCall, D. A. McArdle, J. C. Ogden, J. Roughgarden, R. M. Starr, M. J. Tegner, and M. M. Yoklavich. 1999. No-take reserve networks: sustaining fishery populations and marine ecosystems. Fisheries **24**:11-25.

National Research Council. 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystems. National Academy Press: Washington, D.C.

Osenberg, C. W., O. Sarnelle, S. D. Cooper, and R. D. Holt. 1999. Resolving ecological questions through meta-analysis: goals, metrics, and models. Ecology **80**:1105-1117.

Planes, S., R. Galzin, A. Garcia Rubies, R. Goñi, J. G. Harmelin, L. Le Diréach, P. Lenfant, and A. Quetglas. 2000. Effects of marine protected areas on recruitment processes with special reference to Mediterranean littoral ecosystems. Environmental Conservation **27**:126-143.

Polacheck, T. 1990. Year round closed areas as a management tool. Natural Resource Modeling **4:** 327-354

Quinn, J., S. R. Wing, and L. W. Botsford. 1993. Harvest refugia in marine invertebrate fisheries: Models and applications to the red sea urchin, Strongylocentrotus franciscanus. American Zoologist **33**: 537-550.

Roberts, C. M., and N. V. C. Polunin. 1991. Are marine reserves effective in management of reef fisheries? Reviews in Fish Biology and Fisheries **1**:65-91.

Roberts, C. M. and N. V. C. Polunin. 1993. Marine reserves: simple solutions to managing complex fisheries? Ambio **22**:363-368.

Rowley, R. J. 1994. Marine reserves in fisheries management. Aquatic Conservation: Marine and Freshwater Ecosystems **4**:233-254.

Russ, G. R., and A. C. Alcala. 1996a. Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. Marine Ecology Progress Series **132**:1-9.

Russ, G. R., and A. C. Alcala. 1996b. Marine reserves: rates and patterns of recovery and decline of large predatory fish. Ecological Applications **6**:947-961.

Schroeter, S. C., D. C. Reed, D. J. Kushner, J. A. Estes, D. S. Ono. 2001**.** The use of marine reserves in evaluating the dive fishery for the warty sea cucumber (*Parastichopus parvimensis*) in California. Canadian Journal of Fisheries and Aquatic Science **58**: 1773-1781.

Sladek Nowlis, J., and C. M. Roberts. 1997. You can have your fish and eat it, too: theoretical approaches to marine reserve design. Proceedings of the Eighth International Coral Reef Symposium **2**:1907-1910.

Sladek Nowlis, J., and C. M. Roberts. 1999. Fisheries benefits and optimal design of marine reserves. Fishery Bulletin **97**:604-616.

Stewart-Oaten, A., and J. R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs 71: 305-339.

Stewart-Oaten, A., and W. W. Murdoch. 1986. Environmental impact assessment: "Pseudoreplication" in time. Ecology 67: 929-940.

Syms, C. and M. H. Carr. 2001. Marine Protected Areas: Evaluating MPA effectiveness in an uncertain world. Scoping paper presented at the Guidelines for Measuring Management Effectiveness in Marine Protected Areas Workshop, Monterey, California, May 1-3, 2001, sponsored by the North American Commission for Environmental Cooperation. http://www.biology.ucsc.edu/people/carr/Syms/syms_download_page.htm

Zeller, D. C., and G. R. Russ. 1998. Marine reserves: patterns of adult movement of the coral trout (*Plectropomus leopardus* (Serranidae)). Canadian Journal of Fisheries and Aquatic Science 55:917-924.