Presented by Mark Carr, Ecology and Evolutionary Biology Dept., University of Calif., Santa Cruz: **The Role of Science in Defining MPA Goals, Design, and Evaluation**

Science in general, and ecological research in particular, has played an important role in linking the different phases of development of marine protected area (MPA) policy.

Early efforts of scientists began by identifying the needs for, and potential management roles of, MPAs. By doing so, this work not only raised the visibility of MPAs as a potential management tool, but also helped to clarify the specific objectives and goals of MPAs.

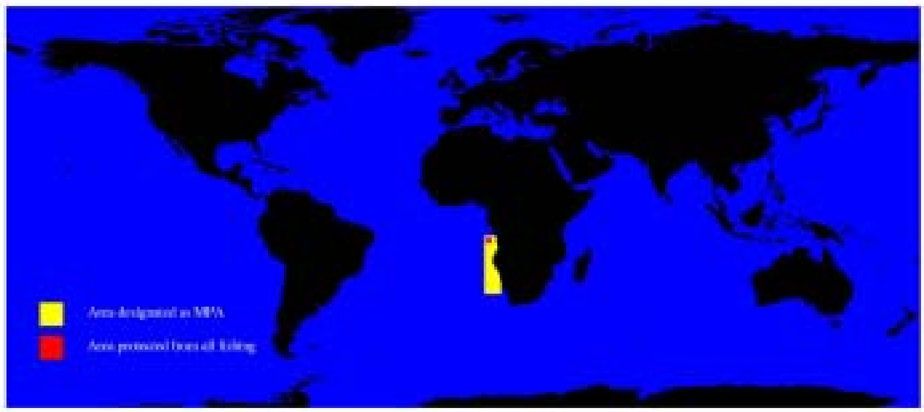
In turn, the goals and objectives identified for an MPA determine criteria for its design as well as approaches for evaluating its effectiveness in achieving specified goals and objectives. Moreover, approaches to evaluate the MPA's effectiveness are largely influenced by its design. And of course evaluation is the underpinning of any hope for adaptive management (i.e. modifying a MPA or network of MPAs in response to the relative effectiveness of different designs).

Thus, need, objectives, design, and evaluation are all inextricably linked and science has illustrated the importance of recognizing these links in consideration of each phase of this process.

Scientists have identified two general goals for MPAs. The primary goal of MPAs (and no-take marine reserves in particular) is to contribute to the conservation of biodiversity. By biodiversity, I'm referring to the diversity of species in the ocean. Like terrestrial reserves, the intent is to set aside areas of the ocean protected from human impacts so as not to disrupt the ecological processes that naturally create and maintain species diversity.

However, unlike terrestrial reserves, very little of the coastal ocean has been afforded this level of protection. For example, along the West Coast of the United States, less than one tenth of one percent has been set aside as no-take reserves.

The State of Ocean Protection



Far less than 1% of ocean in marine reserves
Less than 0.01% of US waters in marine reserves

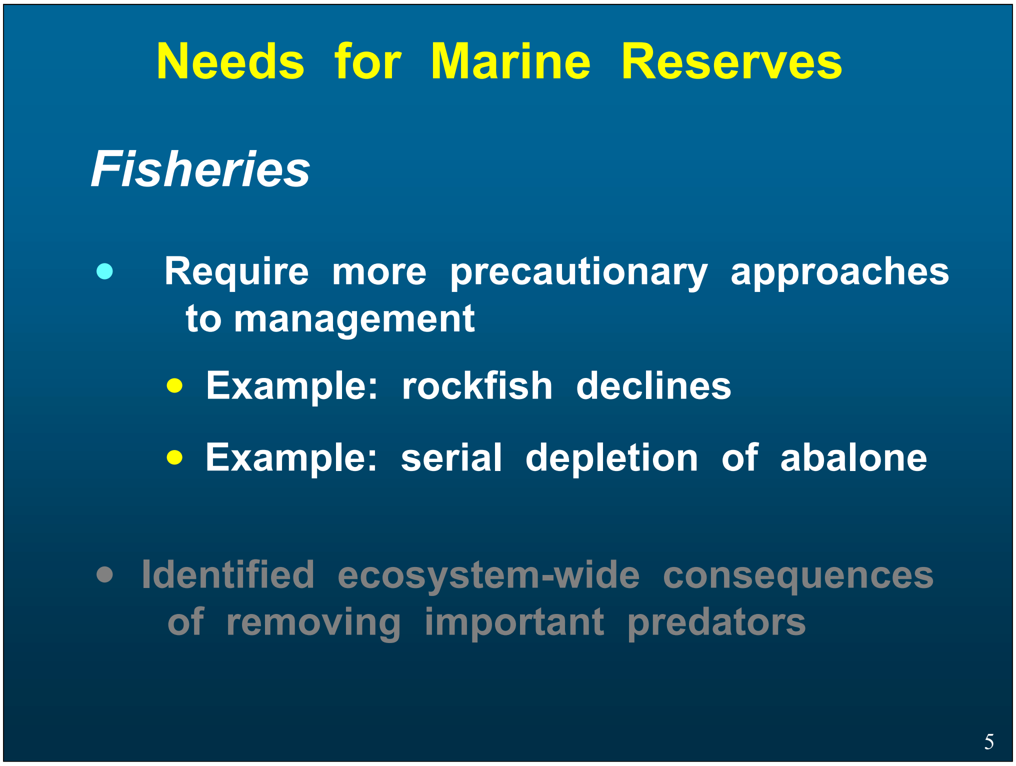
This small amount of area set aside in reserves reflects a general pattern throughout the US and global oceans (0.01 and 1%, respectively).

Needs for Marine Reserves

Conservation

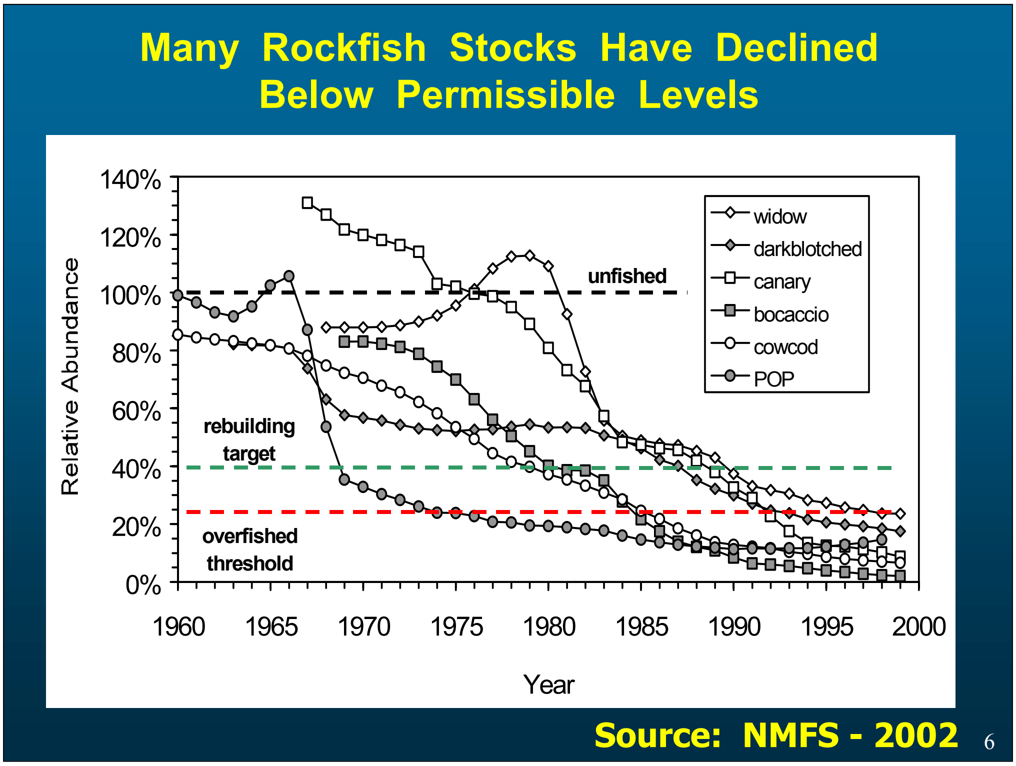
- Miniscule portion of coastal waters set aside as reserves (West Coast < 0.1%)
- Scientists recognize reserves necessary to understand:
  - how natural ecosystems function
  - distinguish natural from human-caused changes

Two reasons for concern for the paucity of reserves, is recognition of the importance in (1) understanding how natural marine ecosystems function in the absence of human alteration, and (2) the importance of distinguishing human-caused changes from natural changes in ecosystems. This is a continuing source of debate in fisheries management, and terribly difficult to resolve without sites protected from human influences that reflect only responses to natural environmental variation (e.g., El Nino, climate regime shifts).

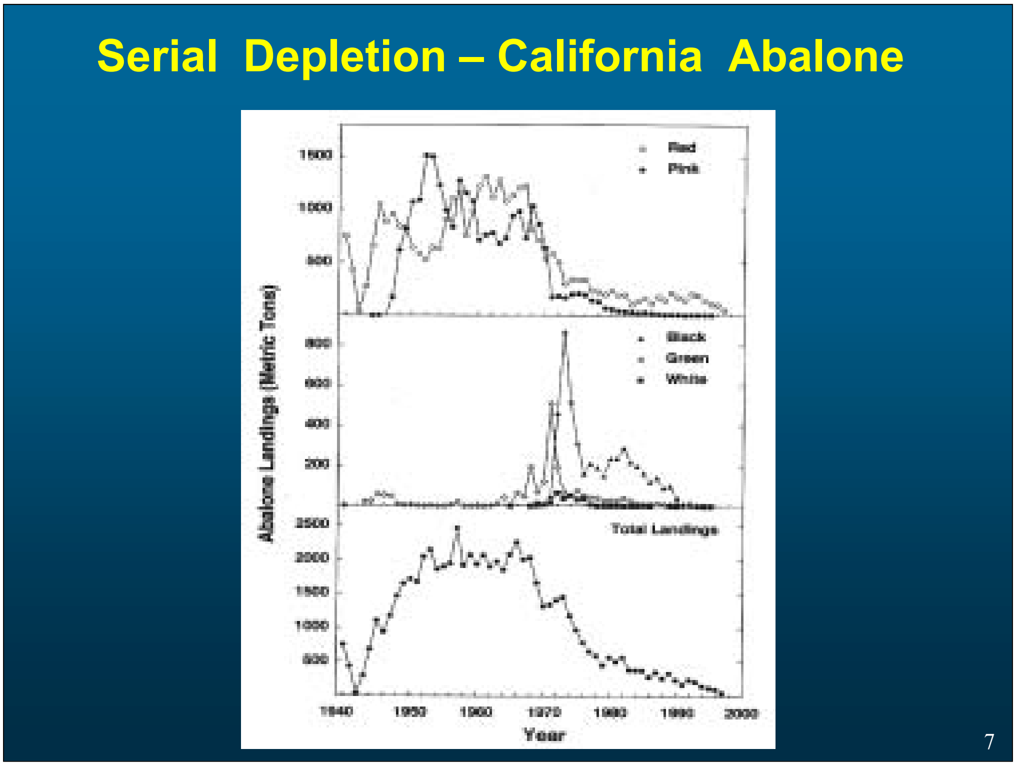


A secondary goal, closely related to the conservation goal, is to protect fished species and their habitat, and contribute to the sustainability and perhaps even augmentation of fisheries.

One reason for this growing concern for fisheries protection is a growing number of closures in historical important fisheries. Two examples from the West Coast include the decline and closure of rockfish fisheries and the serial depletion of abalone stocks prior to the widespread closure of that fishery.

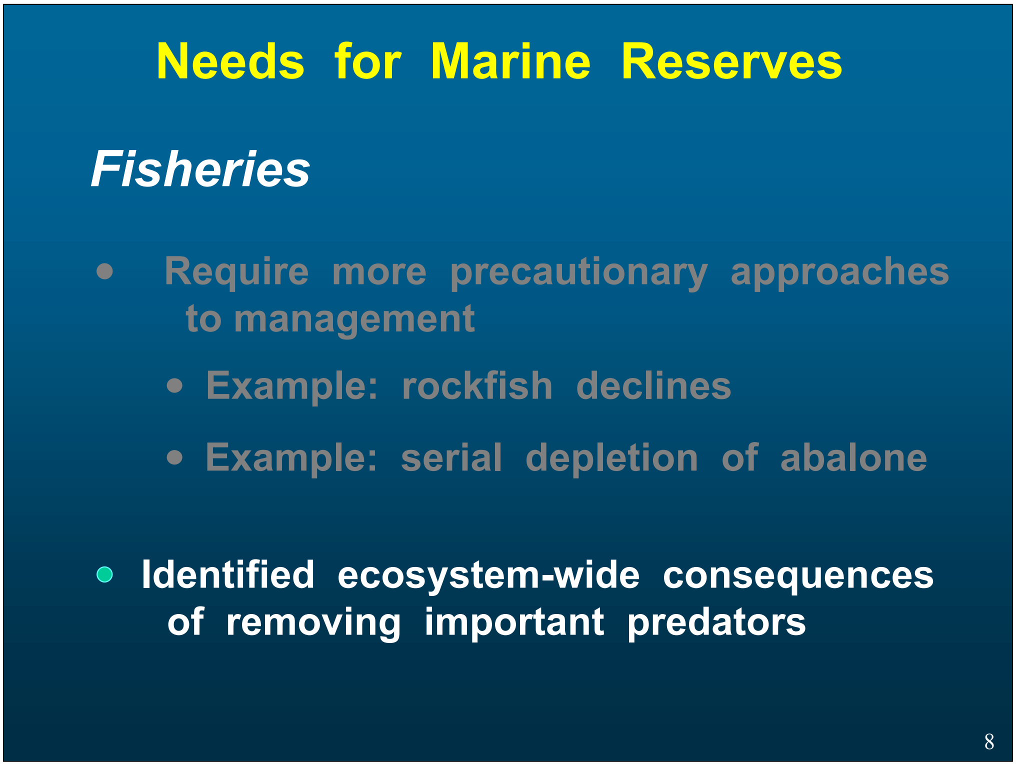


This graph illustrates stock declines of several West Coast rockfish species, based upon recent stock assessments. Having declined below the level indicated by the dashed red line, concern for these stocks prompted closure of the West Coast groundfish fishery along the continental shelf in 2002.

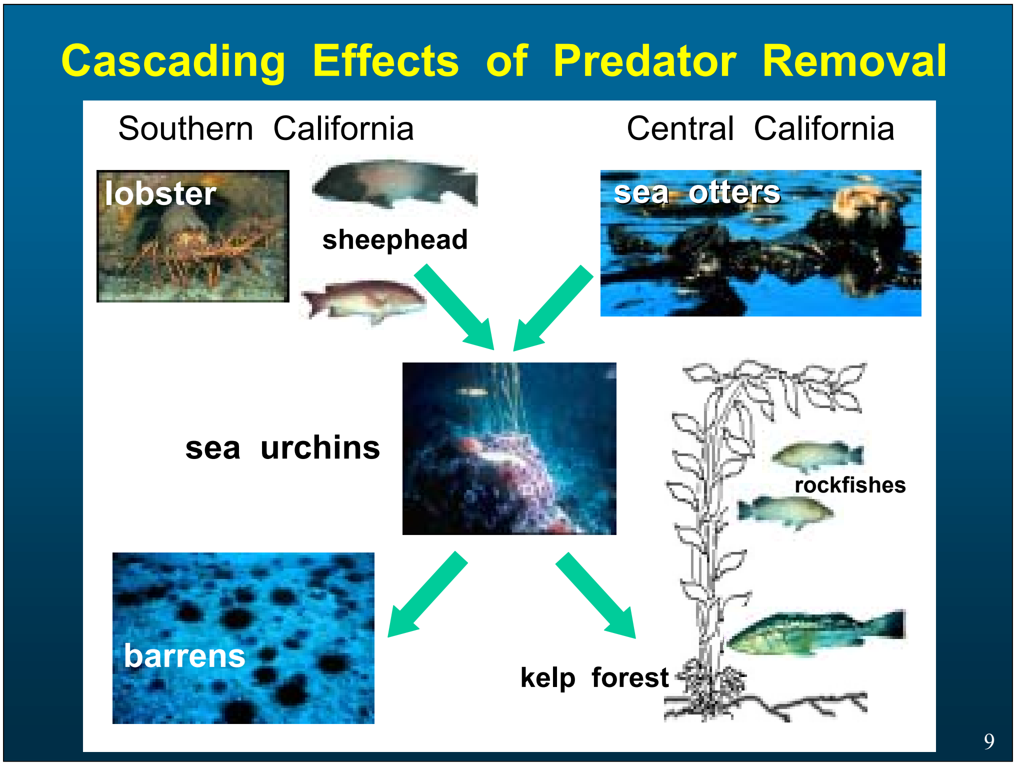


Serial depletion of fishery stocks occurs when a fishery moves from one stock to another as each one declines to levels at which it is no longer economically feasible to fish, or fisheries managers feel it is necessary to close the fishery.

This graph illustrates serial depletion of California abalone stocks (each a different species of abalone) that continued until the entire commercial abalone industry was closed throughout southern and central California.



Science has also played an important role in demonstrating how important species diversity is in maintaining the structure (composition and relative abundance of species) and function (ecological interactions) of an ecosystem. This has highlighted the value of protecting and preserving biodiversity and maintaining the integrity of ecological interactions within a community. For example, when particular species, especially predators high in a food web, are removed, unforeseen effects can cascade throughout the ecosystem.

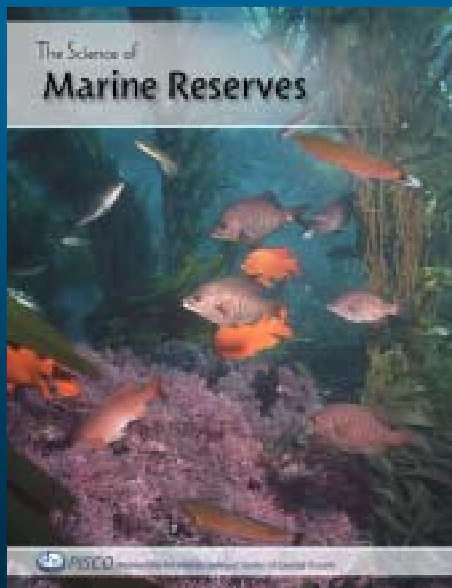


Two examples can be seen along the coast of California. Along the coastline of central California, sea otters graze heavily on sea urchins and limit their numbers. Otherwise, high densities of sea urchins can overgraze kelp forests and create barrens similar to that shown above in the Southern California example. South of Point Conception, throughout southern California, the sea otter is absent but spiny lobster and a large wrasse called the sheephead both feed on and limit the abundance of sea urchins. Both the fish and lobster are heavily fished throughout the coast of southern California. All three of these species play an important role in determining the condition of the reef habitat. In their presence, these shallow reefs tend to be dominated by lush stands of kelp, which harbor large populations of reef fish and enhance recruitment of some species to those reefs.

In addition to the perceived need for the kinds of protection that marine reserves can contribute described above, reserves provide additional benefits to both conservation and fisheries.

These benefits (and some caveats) have been summarized recently in a booklet created by the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO). This booklet is an attempt to make some of these benefits accessible and understandable to audiences outside of the scientific community.

Benefits From Marine Reserves



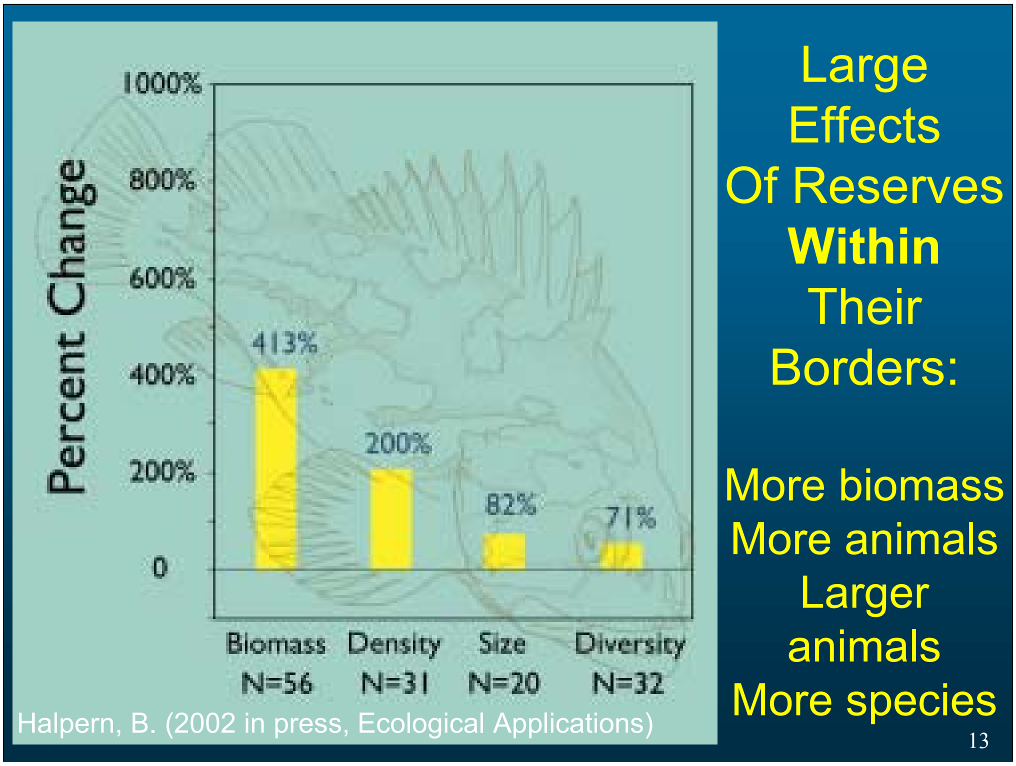
More than 250 scientific publications on marine reserves

One example draws from a global review of marine reserve effects by Ben Halpern. This work is in press in a special issue of the journal Ecological Applications, devoted to the theory and design of marine reserves. This map illustrates the spatial scope of the 80 reserve studies that Ben examined.

80 Marine Reserves with Peer Reviewed Scientific Studies

Range in size from less than 1 square mile to 400 square miles

Across the 80 studies he reviewed, which compared differences in the biomass, density, size, and species diversity of fishes before and after reserve establishment or inside and outside of reserves, he found substantially greater values of all four variables within reserves.



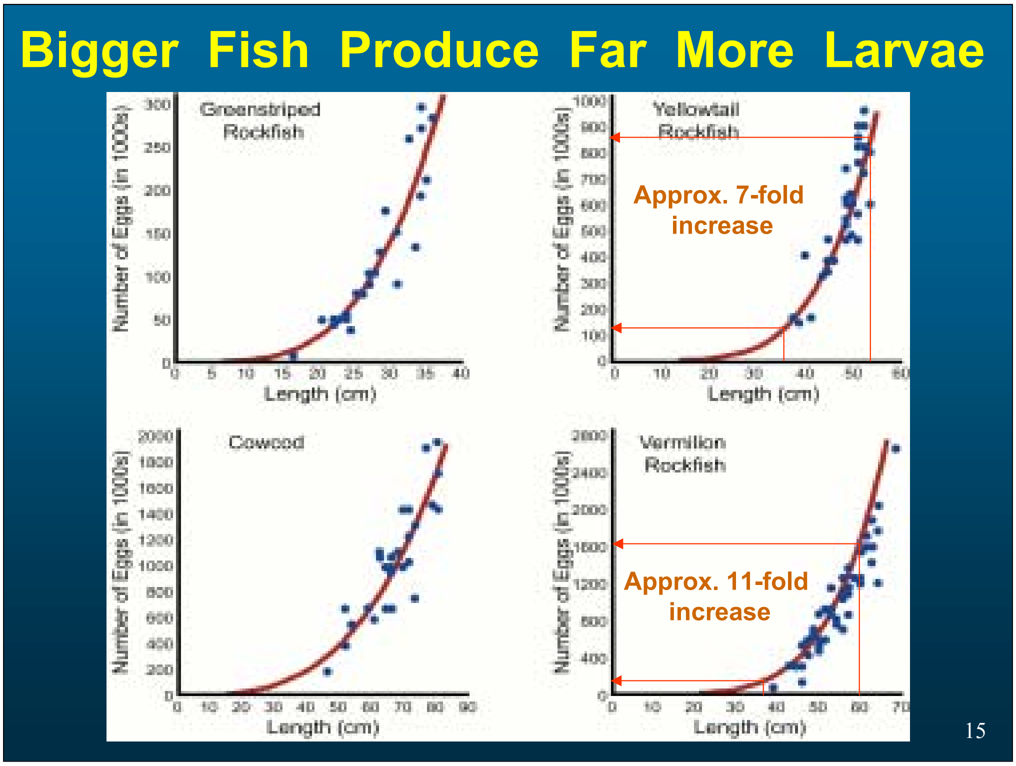
Other benefits of reserves are related to the sustainability of populations. These pertain to the reproductive capacity of individuals and populations and the success of offspring to recruit to populations. Examples from the West Coast include rockfish and sea urchins.

Benefits From Marine Reserves

Other Benefits

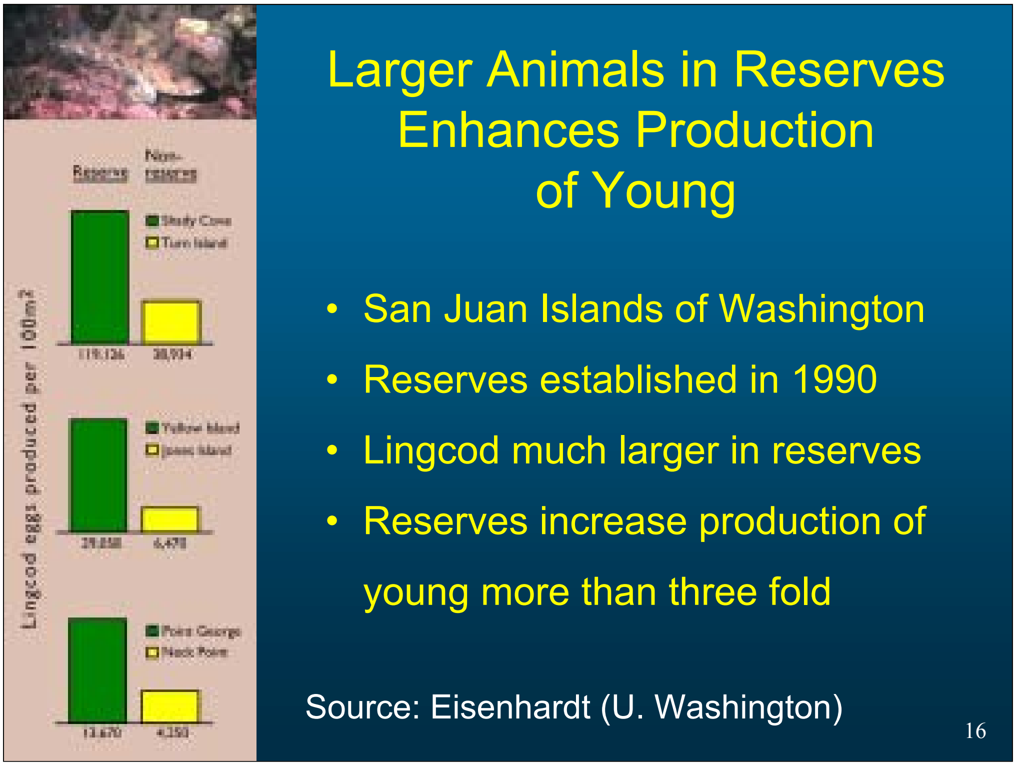
- Increasing sustainability of populations
  - Reproductive capacity (size / fecundity)
  - Recruitment success (abalone recruitment)
- Protecting habitat (oyster reefs)
- Reducing bycatch (trawls, traps, hook + line)
- Assuring functional ecosystems

As individual fish get older, they devote more of their energy to reproduction. If fish are allowed to survive and grow to become older and larger, they contribute disproportionately to offspring production than do younger individuals.

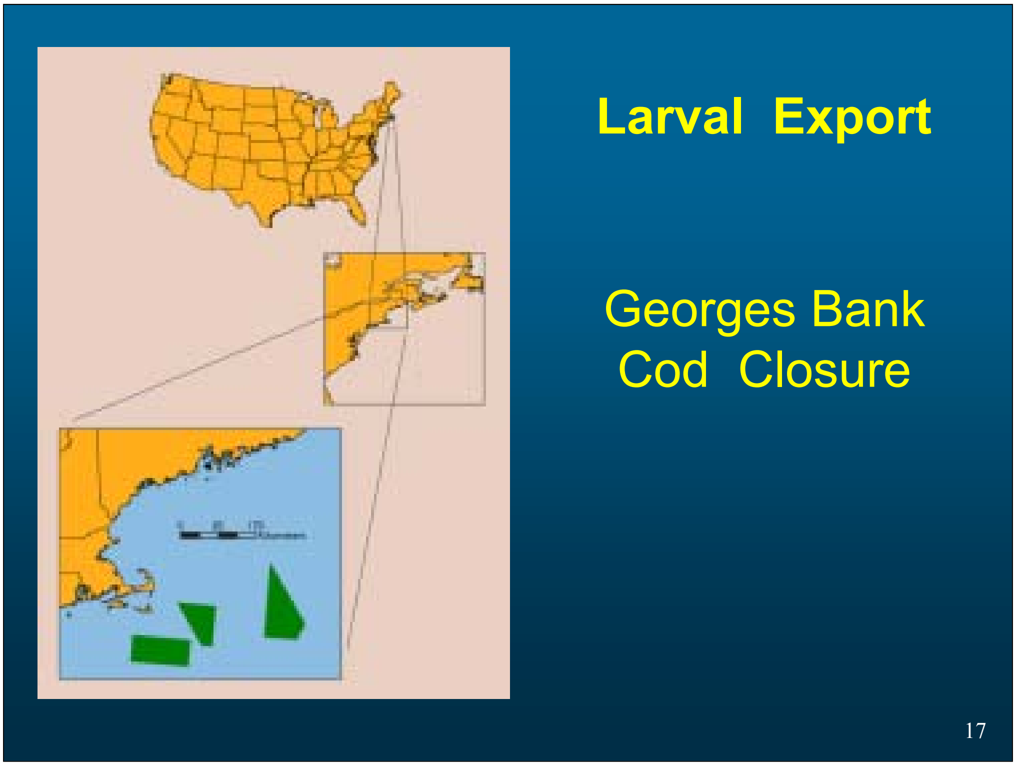


Plotted here, for example, is the relationship between egg production and size for each of four rockfishes. Note, for example, the 7-fold (i.e. 700%) increase in fecundity (egg production) with less than a doubling of length in yellowtail rockfish, and the 11-fold increase with a 50% increase in length of vermillion rockfish.

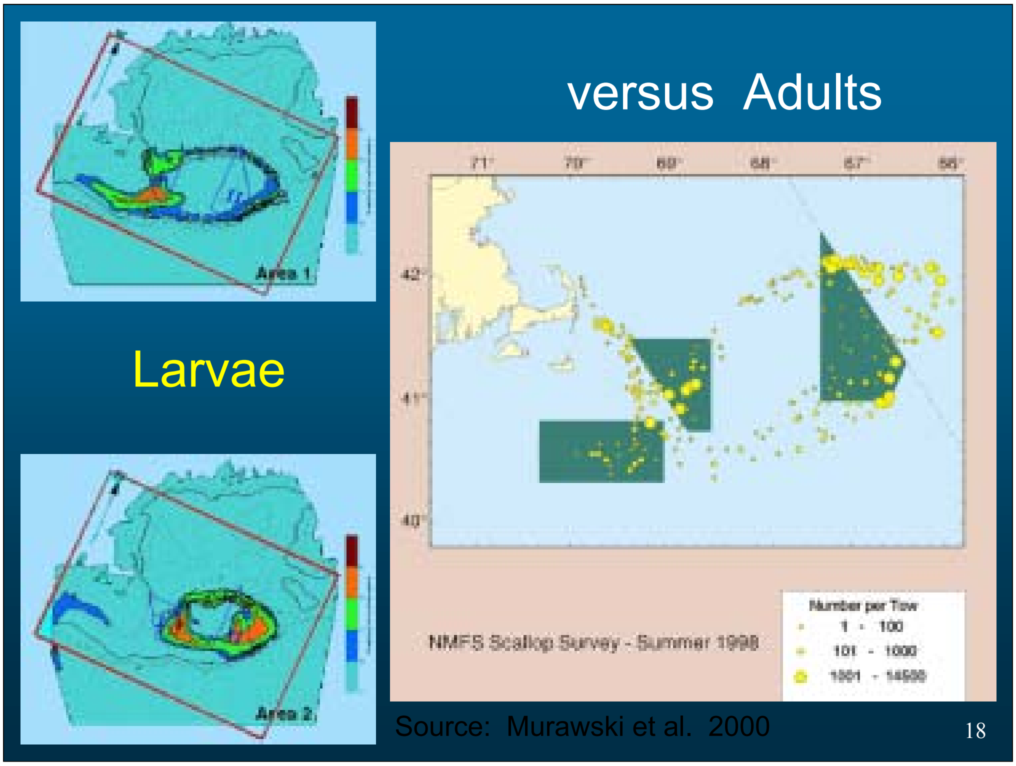
This illustrates the idea that the accumulation of large old fish in reserves may have a disproportionate contribution to reproduction for a given area of habitat.



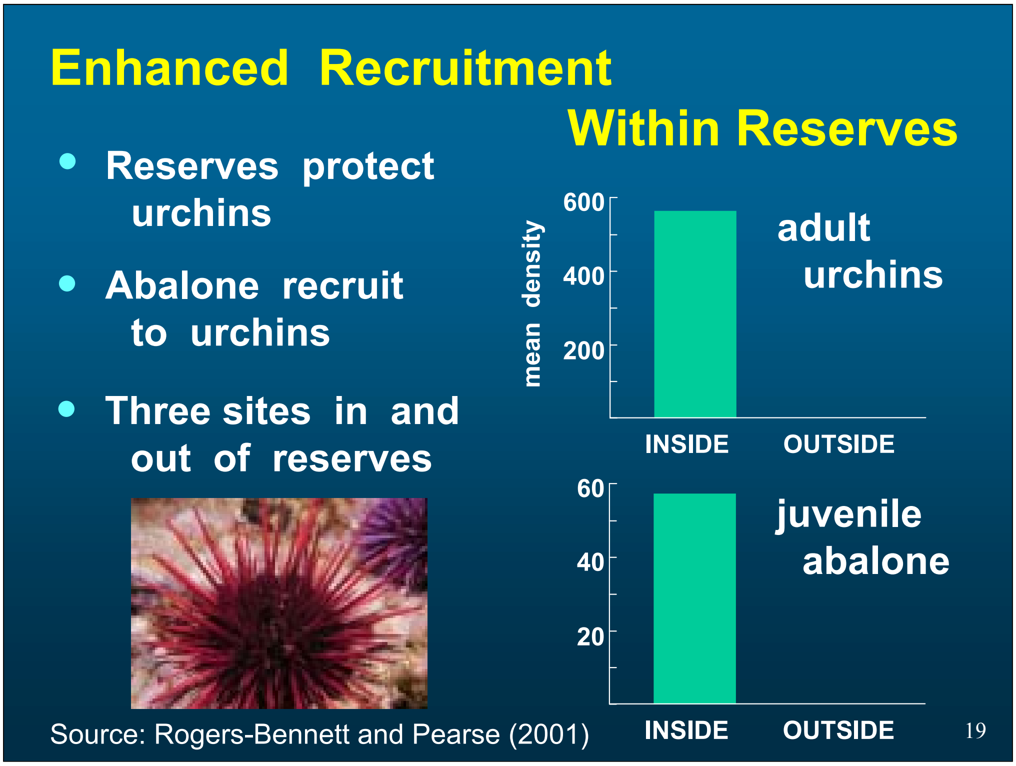
Another example of this is the greater egg production per reef area by larger lingcod within reserves in Puget Sound, Washington compared to similar nearby habitats outside reserves.



Most marine organisms produce young that are dispersed by currents, potentially for great distances. The young produced by adults of these species within a reserve are very likely to be transported outside that reserve. To actually detect such an effect, however, would require substantially large reserves.



One possible example of this is the relationship between the distribution of scallops adjacent to the large reserves created on Georges Bank and the hypothesized patterns of dispersal and recruitment of scallop larvae produced within those reserves. Note the close match between the predicted patterns of scallop recruitment (based on larval duration and current patterns) produced by adults and the distribution of older scallops outside the reserves.



The presence of adults of a species can enhance the recruitment of young into a population. One example is the well-known enhancement of juvenile sea urchin recruitment beneath the canopy of spines of the adults. Surveys of reserves along northern and central California have indicated higher densities of both adult and juvenile sea urchins within reserves compared to similar habitats outside those reserves.

Benefits From Marine Reserves

Other Benefits

- Increasing sustainability of populations
  - Reproductive capacity (size / fecundity)
  - Recruitment success (abalone recruitment)
- Protecting habitat (oyster reefs)
- Reducing bycatch (trawls, traps, hook + line)
- Assuring functional ecosystems

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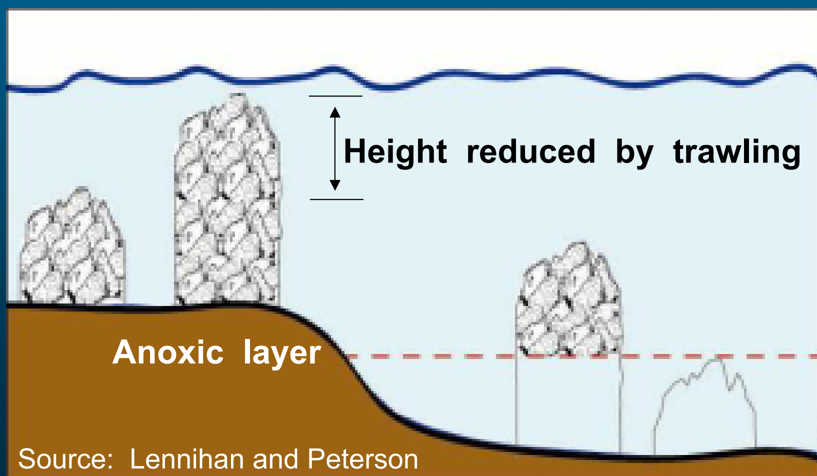
Another important effect of reserves is to protect habitats from destructive human activities.

Fishing Impacts on Habitat

Oyster reefs in Chesapeake Bay



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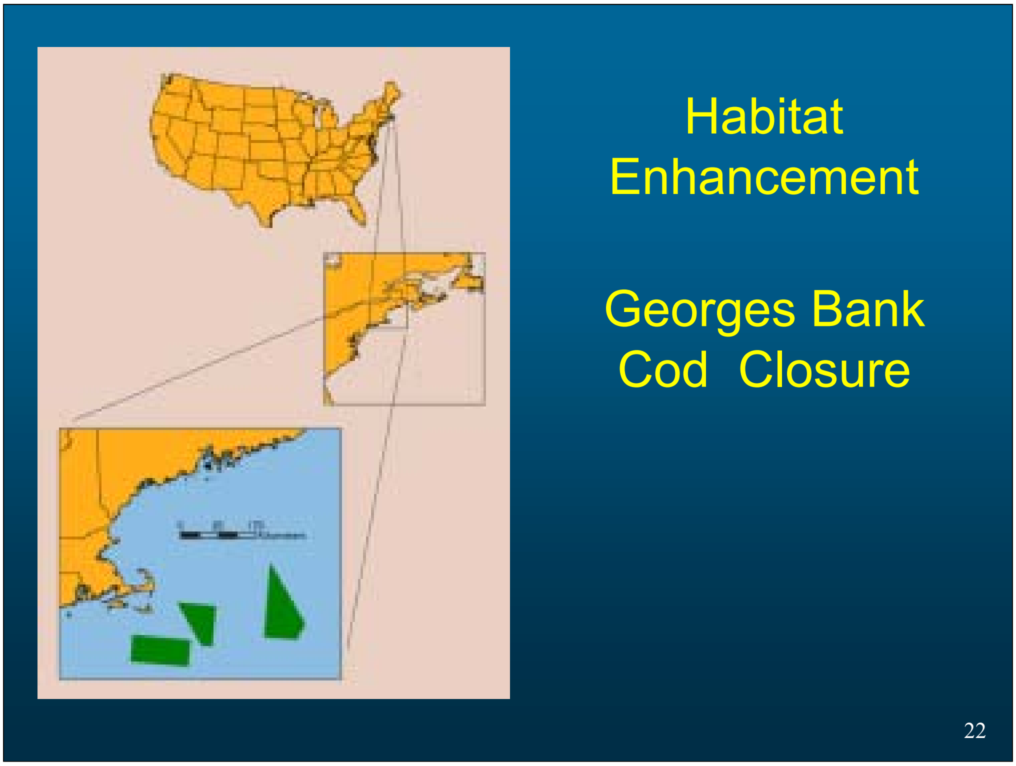
For example, oyster dredging in Chesapeake Bay removes the upper portion of oyster reefs, reducing the vertical height of reefs. In deeper, anoxic portions of the Bay, the height of oyster reefs allows oyster beds to develop and persist (and reproduce to help replenish other portions of the Bay) above this anoxic layer. Where reefs have been toppled and shortened below the anoxic layer, reefs cannot develop.



Another example comes again from the groundfish closures on the Georges Banks. An important source of physical structure, providing young fish and other organisms shelter from predators, are scallop beds.

Increased Density and Size of Scallops Within Reserve

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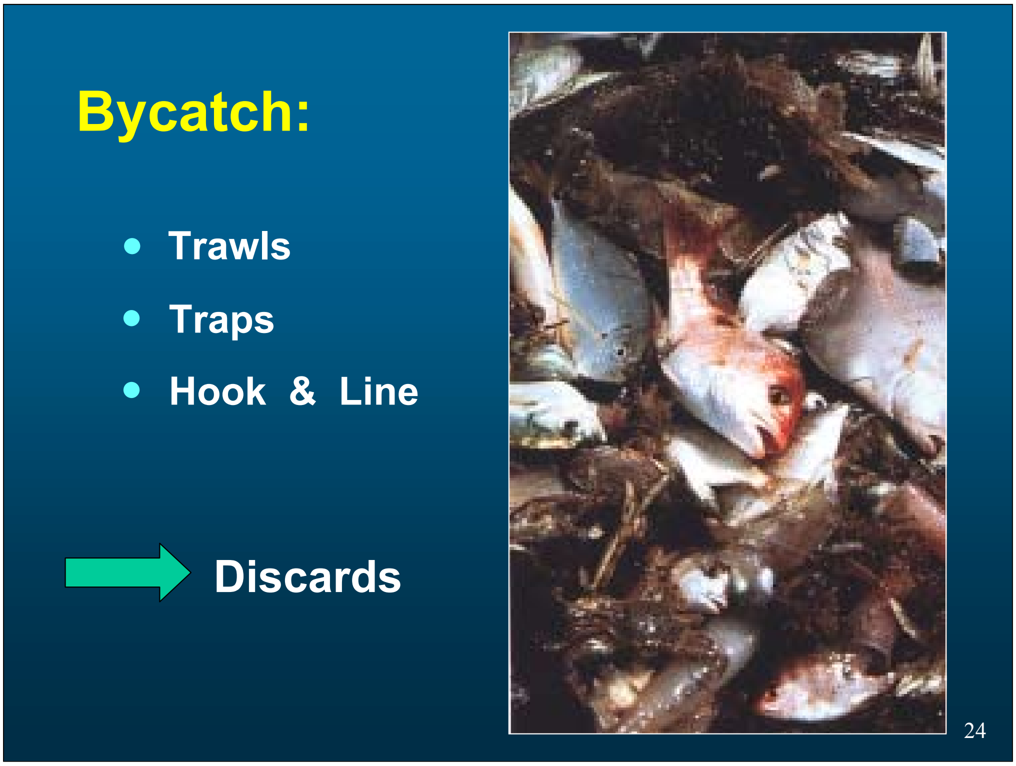
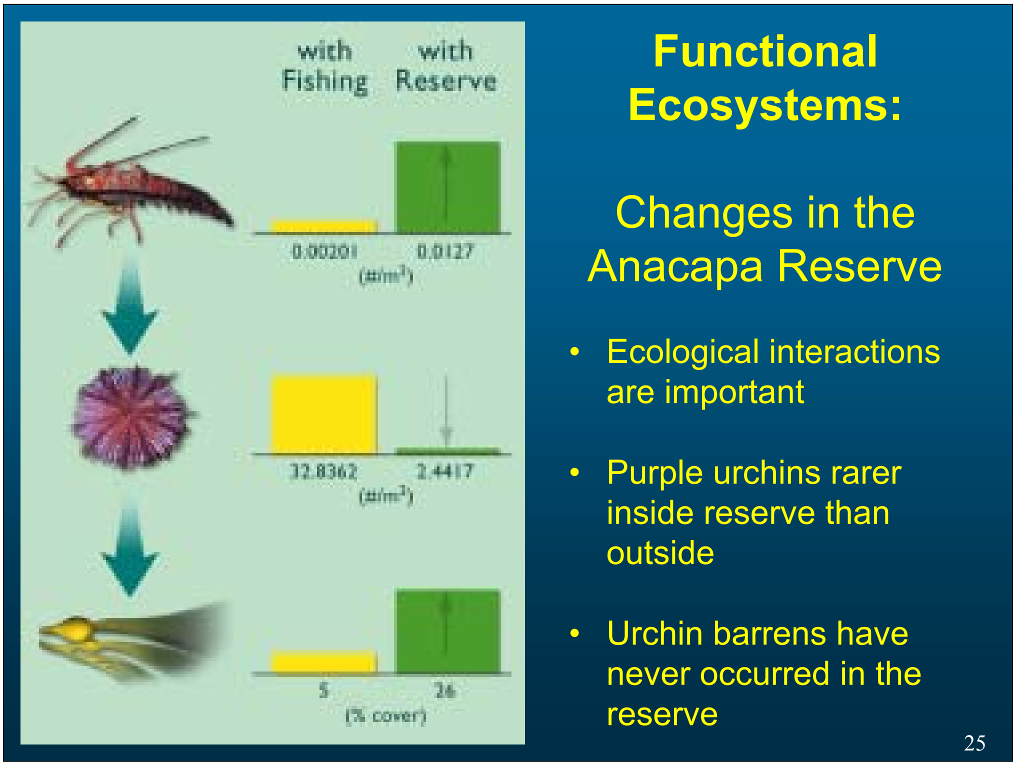
Closure to trawling allowed for great increases in both the density and size of scallops within closures, compared to outside. Differences in scallop size attained inside and outside of reserves is illustrated in this photograph.



Another potential benefit of reserves is elimination of the incidental mortality of unintended catch within reserves. The fate of this unintended catch, referred to as "by-catch" is usually death and return to the ocean, referred to as "discards", contributing neither to future generations or yield to a fishery. This significant source of mortality for such species, it is not regulated in many cases.



Another important management objective identified for reserves is to protect ecological communities from the cascading effects of the removal of key species, often targeted by fisheries.

One West Coast example of this, alluded to earlier, is the important effect of lobster and sheephead, two species targeted by both recreational and commercial fisheries, in controlling grazing sea urchins from deforesting kelp forests. In a small reserve on Anacapa Island, one of the Santa Barbara Channel Islands, lobster densities are greater, sea urchin densities lower and kelp density greater than the corresponding areas outside the reserve.

The needs and benefits identified for marine reserves are important determinants of reserve objectives, which in turn determine how reserves are designed.

Designing Marine Reserves

Number, size, spacing, habitat

- **Open population structure**
- **Necessity of reserve networks**
- **Importance of larval dispersal patterns**
- **Implications for reserve size and spacing**

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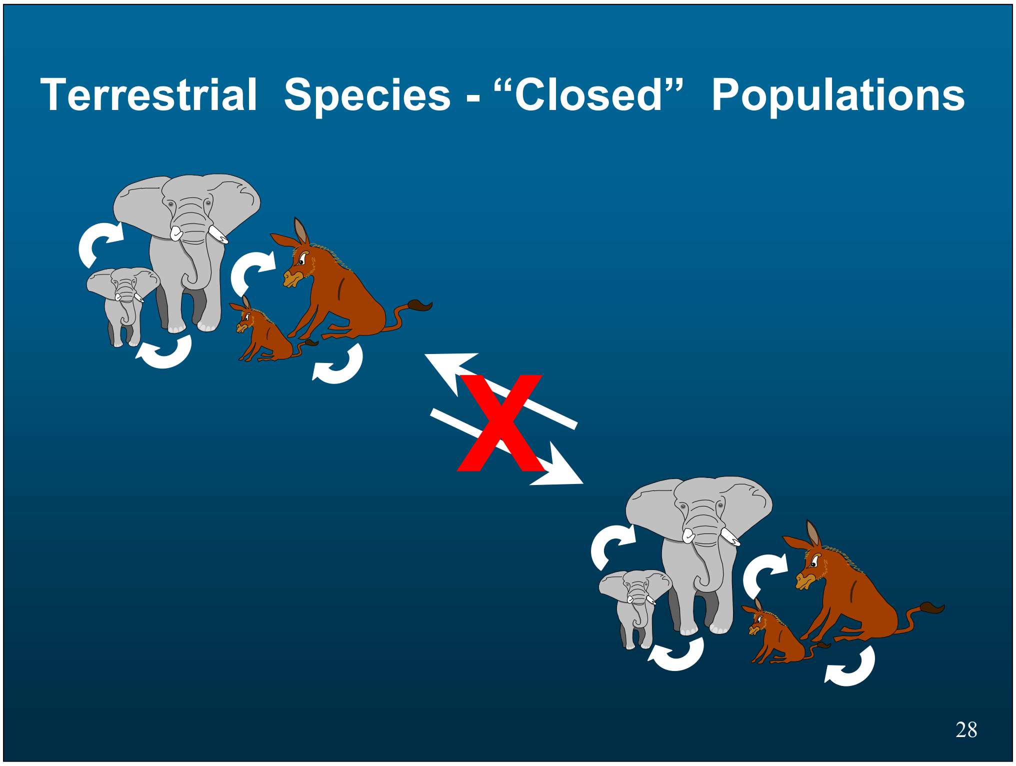
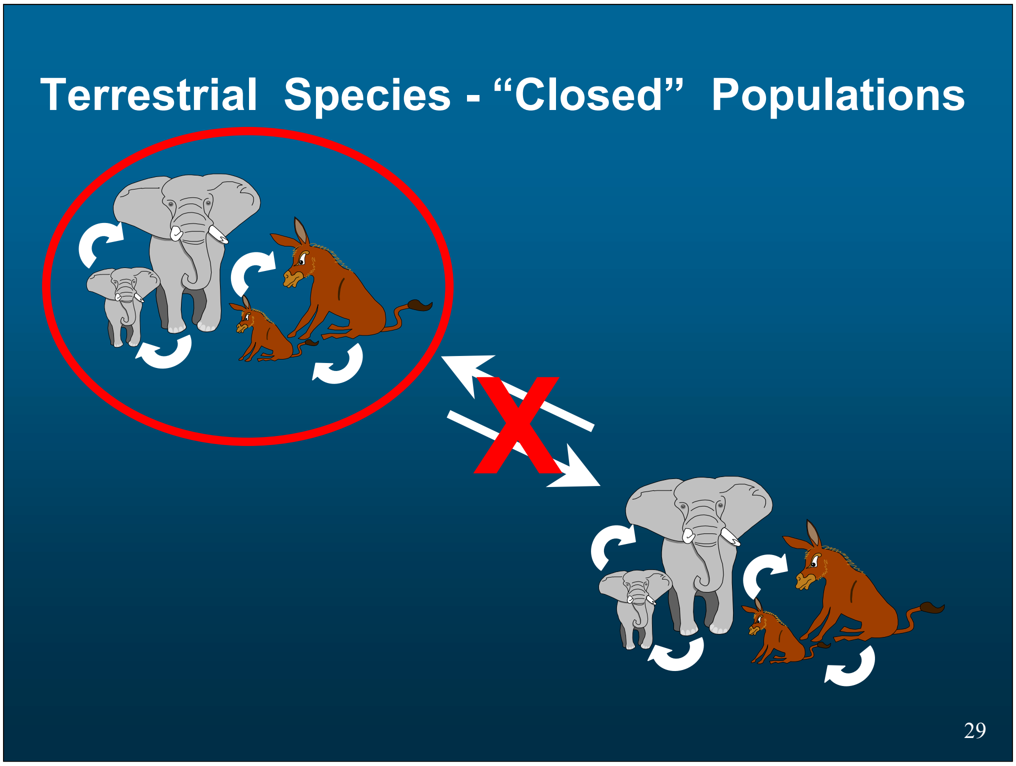
Criteria for reserve design include their number, size, spacing and what kinds of habitats are included within reserves.

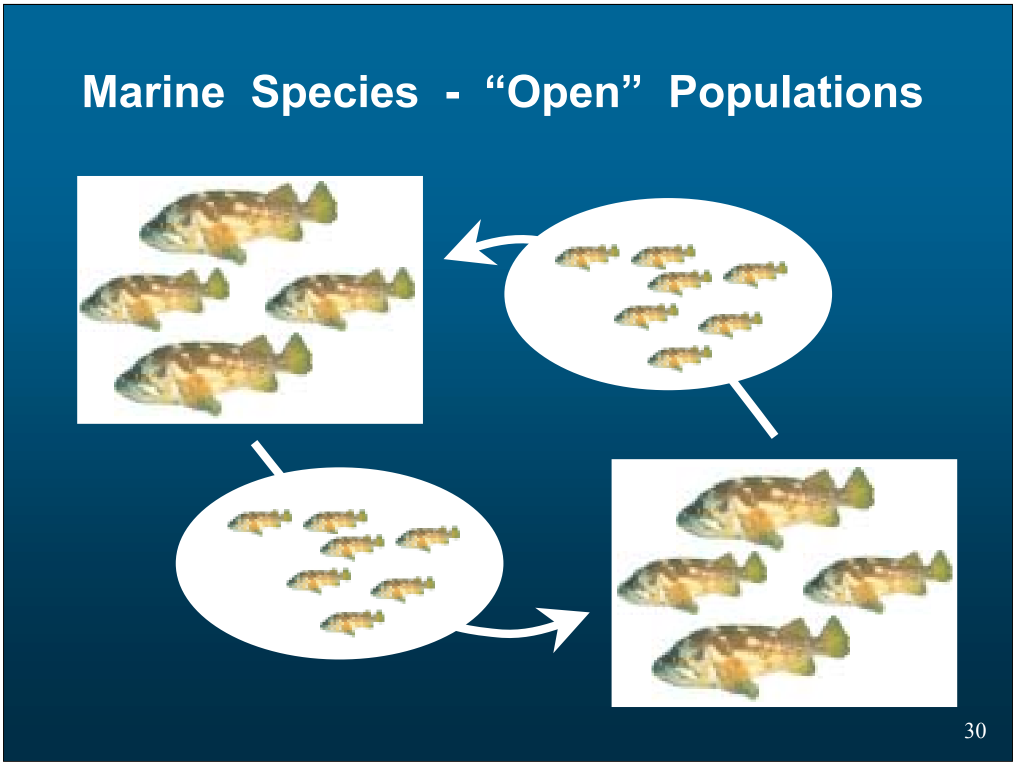
Most marine organisms produce young that can be dispersed great distances by ocean currents. This has fundamental consequences to the replenishment and structure of populations and communities, and enormous implications for the design of marine reserves. Let me explain the “open” nature of marine populations, and its implications for the necessity of networks reserves and the importance of larval dispersal on reserve design.



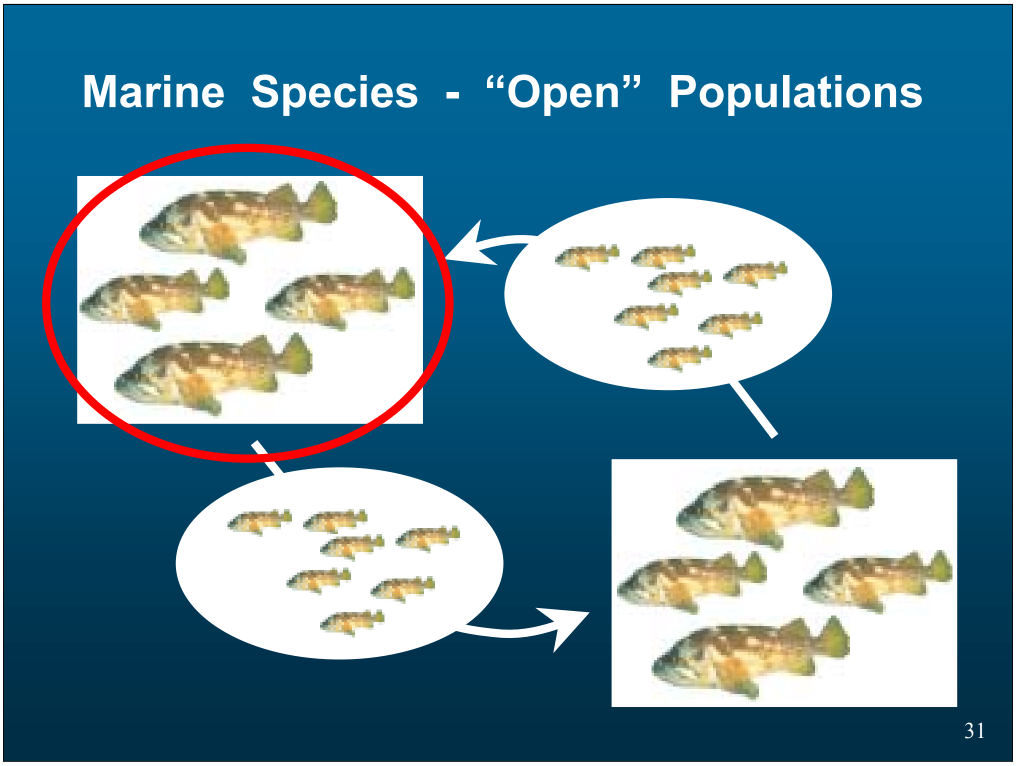
Let's start by considering more familiar species. The young of most terrestrial species do NOT disperse far from their parents. Because of this, there is a direct link between the number of young produced by parents and the number of new individuals in the next generation in that population. Also, this means that young produced by one population contribute very little to the replenishment of other, distant populations.



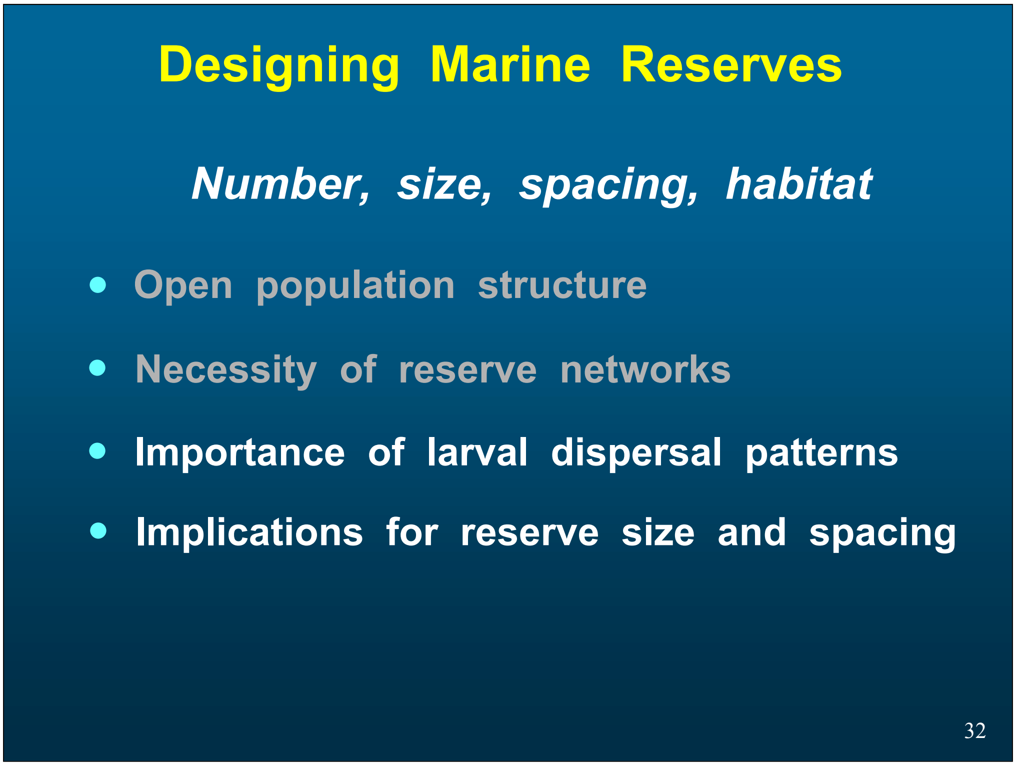
Therefore, a population or community protected within a terrestrial reserve will act to replenish and sustain itself, but contribute little to the replenishment and persistence of populations outside that reserve.



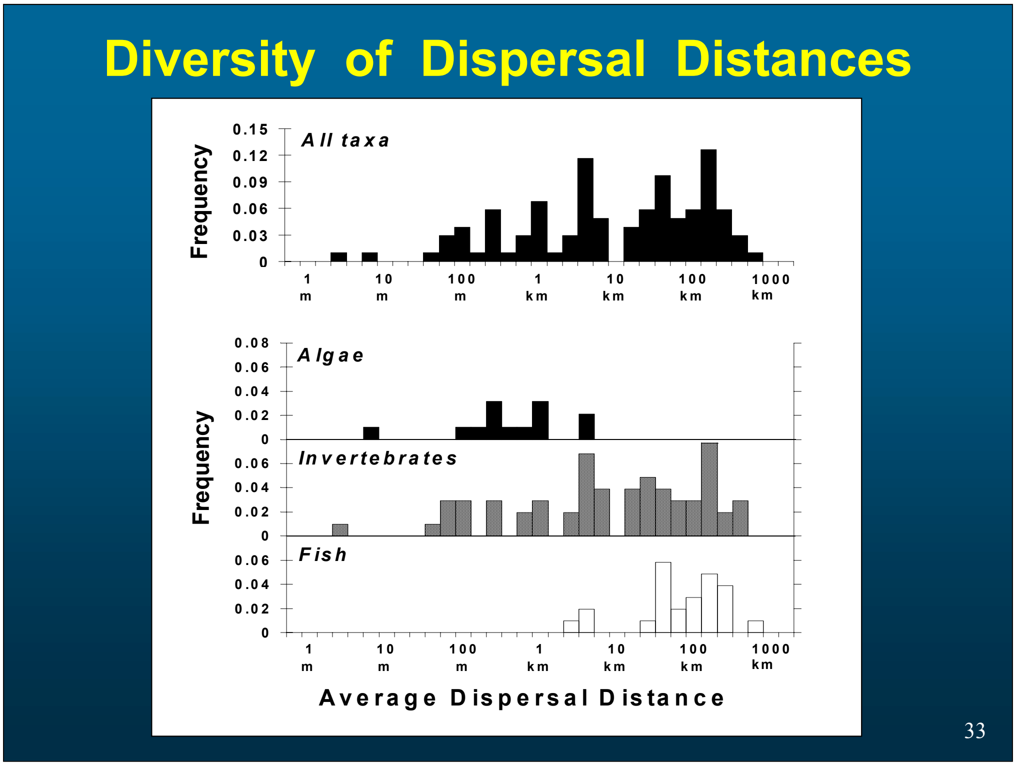
In contrast, because the young of most marine species are transported away from the population that produced them, replenishment of "open" marine populations is often reliant on young that are produced and dispersed from some other population.



This implies that populations within reserves can contribute to the replenishment of populations outside reserves, but it also means that populations in reserves can be reliant on replenishment from unprotected populations unless reserves are spaced at distances to assure that protected populations replenish one another.



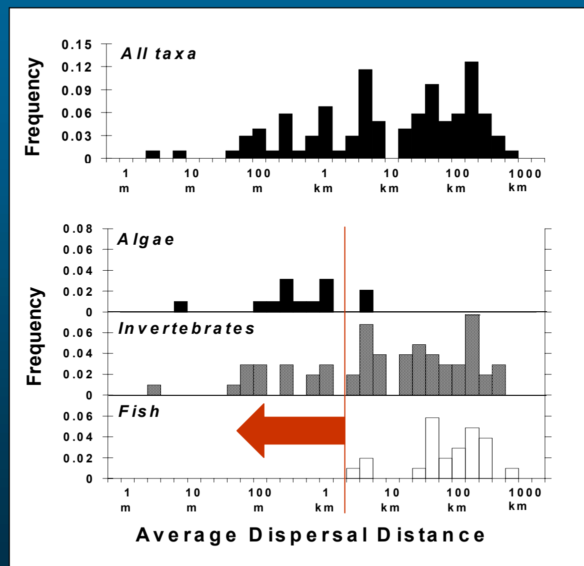
This “spatial structure” of reserves implies that distances of larval dispersal are key to the design of reserve networks. This has lead to a recent plethora of studies of larval dispersal, the result of one are illustrated here.



This graph illustrates the number of algal, invertebrate and fish species whose larvae are estimated to travel the distances indicated along the horizontal axis. These estimates are based on real data on patterns of genetic similarity along a coastline and models that translate distances of genetic similarity into dispersal distances.

One noteworthy pattern, generated by this analysis and others, is that algal dispersal is much shorter than many invertebrates, who vary widely in dispersal distances, and fish dispersal tends to be much greater.

Individual Reserve Size

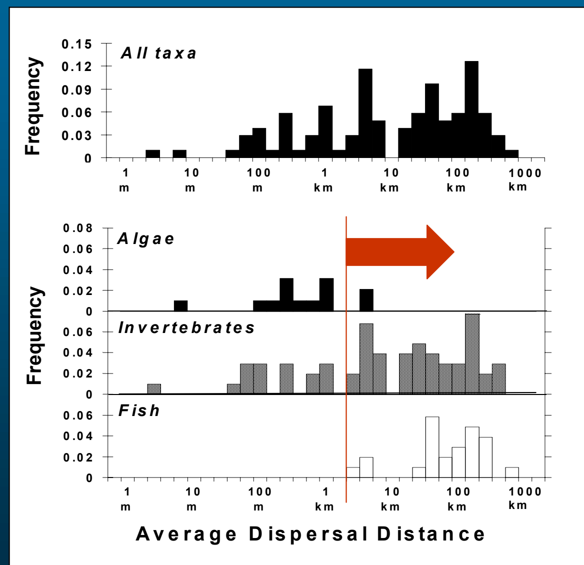


Several km's:

- Short dispersers self-replenishing
- Encompass fish movement

These patterns suggest that reserves on the scale of a few kilometers are sufficiently large such that the short distance dispersing algae and many marine invertebrates species can be self-replenishing within a reserve. This scale is also sufficient to encompass the movement of many reef fishes, thereby protecting them within a reserve over their lifetime.

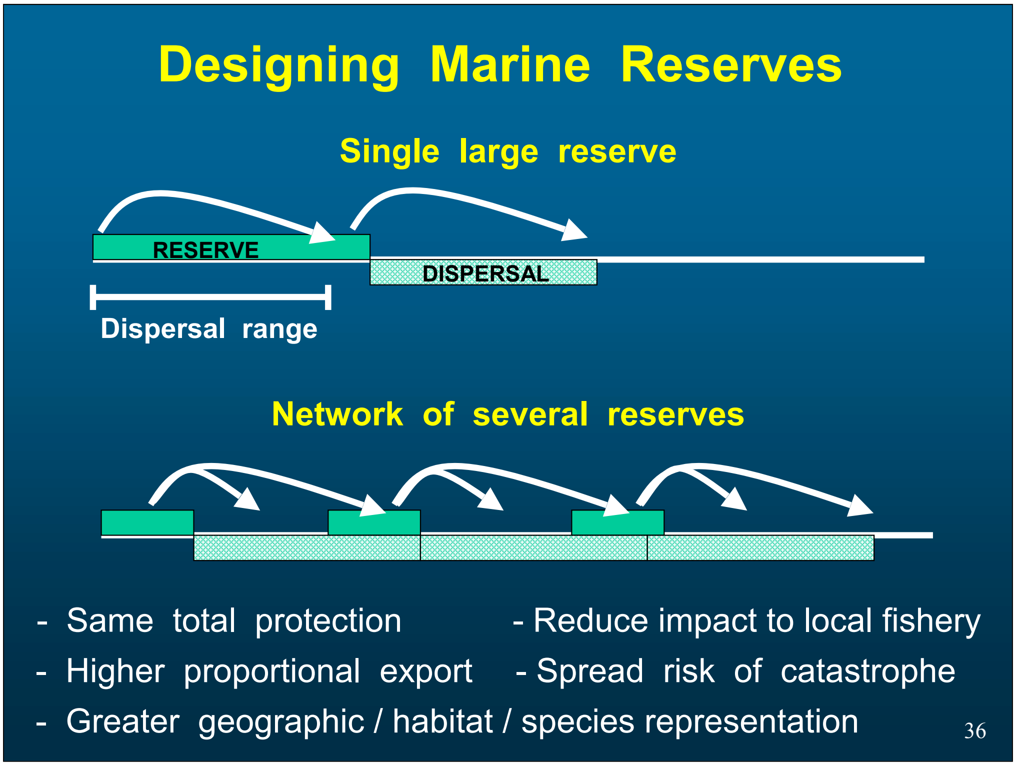
Reserve Spacing



10's of km's:

- Long dispersers self-replenishing
- Replenish unprotected populations

These patterns also suggest that reserves spaced on the order of 10's of km from one another are likely to replenish one another as well as the populations between them.



Networks of many “small” reserves have other benefits over fewer larger reserves. By breaking up and spreading the same reserve area over a larger area (as shown here), the amount of coastline that receives larvae from within reserves becomes much greater. Thus the benefit of enhanced larval production is experienced over a larger portion of the coast and the local impacts to fisheries by excluding fishable area is reduced.

At the same time, spreading reserves widely increases habitat and species representation and reduces the proportion of the entire reserve lost to a local impact (e.g. oil spills, storms).

Science and Marine Reserves

- Need
- Benefits
- Design
- **Evaluation**

The science of reserve design also translates to the science of reserve evaluation.

Evaluating Reserve Effectiveness

I. Monitor protected stock size

II. Contrast protected and non-protected populations

- individual reserve and controls
- network of reserves and controls

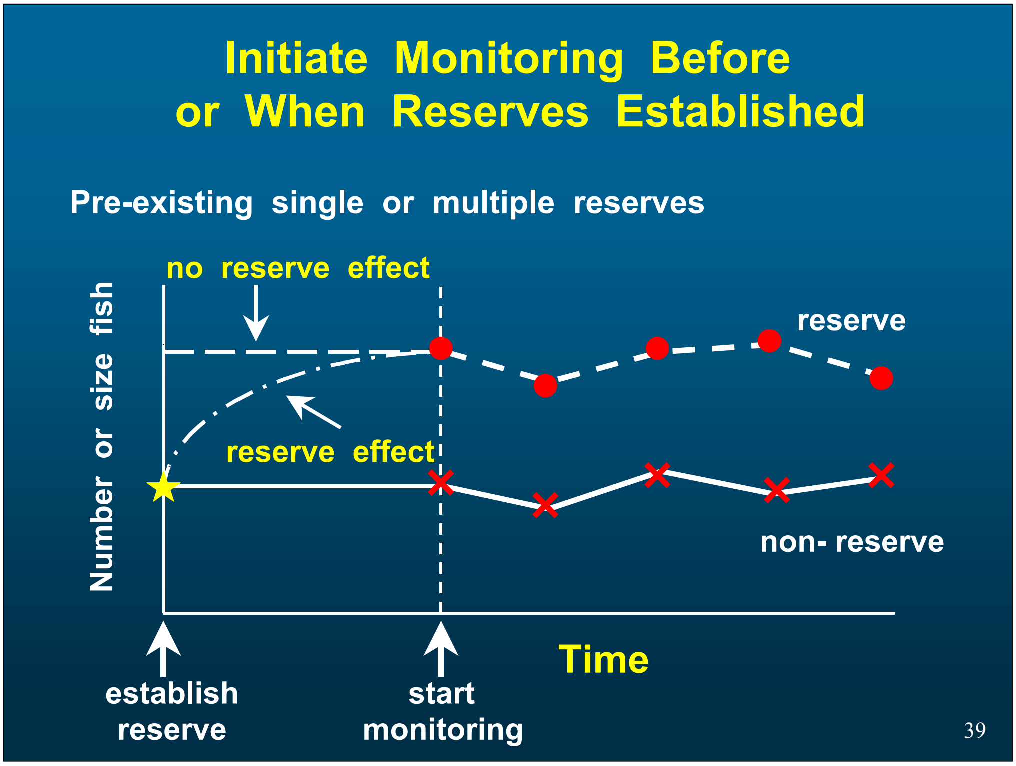
III. Test for evidence of export and replenishment (e.g., larval tags)

Three approaches to reserve evaluation include:

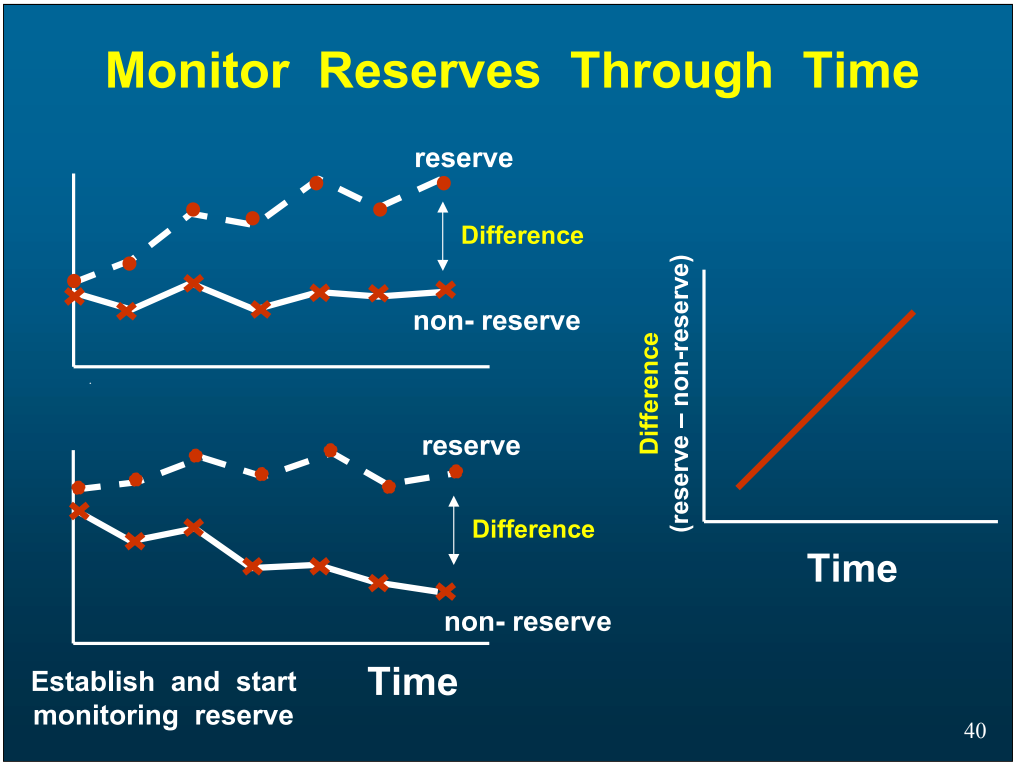
1. If the objective of a reserve is to guarantee protection of some proportion or size of a stock, estimating the size of populations protected within reserves is the goal of an evaluation.

2. If instead the objective is to determine how well a reserve protects populations relative to less protected populations, then a comparison of populations inside and outside reserves is necessary.

3. An additional level of evaluation may be to demonstrate that larvae are exported from reserves to enhance populations outside reserves. This would involve employing new methods for determining their source of origin and dispersal and larvae.



One approach to test the effectiveness of reserves in altering some variable of interest, is to compare differences between reserve and non-reserve populations before and after reserve establishment. If the mean difference (over time) between reserve and non-reserve populations differs significantly before and after reserve establishment, such changes are attributable to the creation of a reserve. This approach requires, and illustrates the importance of initiating monitoring programs prior to reserve establishment.

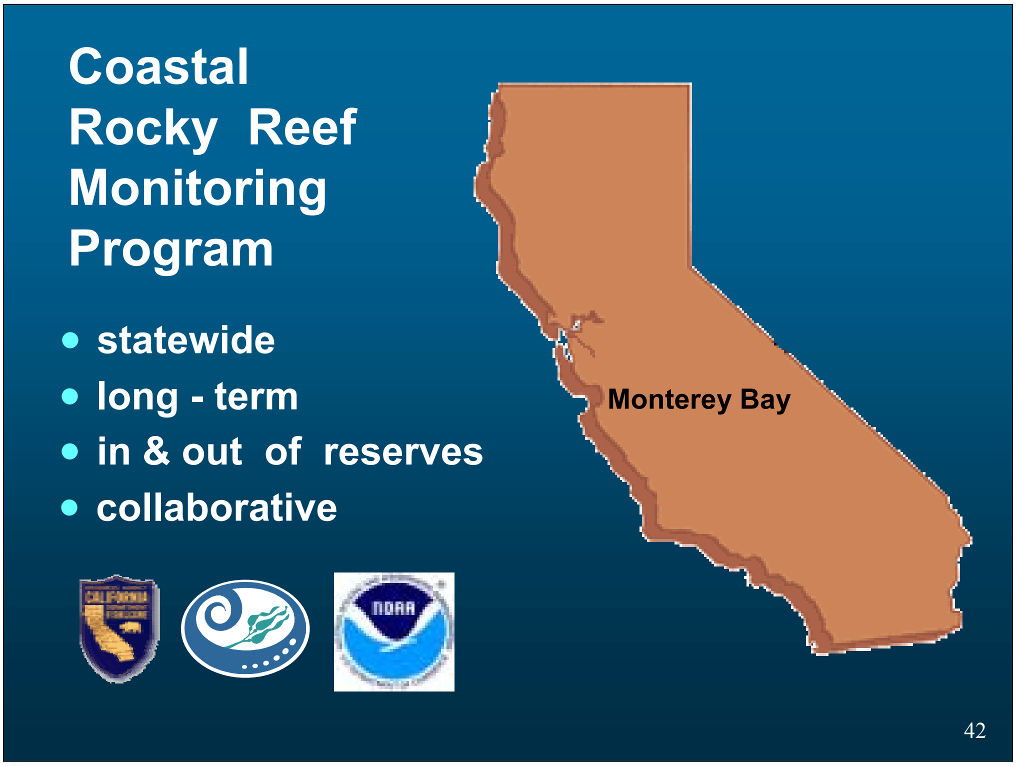


If instead no pre-establishment data is available, the trajectory of populations inside and outside of reserves can be compared using “analysis of covariance” statistical designs. Note that regardless of starting conditions and the net direction of changes, the increasing deviation between the two populations over time is the predicted response to test as illustrated in the graph to the right.

Evaluating Reserve Effectiveness

- Every reserve program needs to fund and develop an evaluation program
- Evaluation sampling needs to be initiated as early as possible and continued
- Multiple reserves provide MUCH more info.
- Realistic time-frame and rate of response

The need to determine the effects of establishing reserve implies that every reserve program must include and finance a monitoring and evaluation program.



Because analytical approaches to testing reserve effects depend on changes over time, monitoring programs must be initiated as early as possible and continued into the future.

Simultaneously sampling multiple reserves and non-reserve sites across a network allows for comparison of reserves of varying attributes, which in turn allows for adaptive management and making more informed inferences regarding the general effectiveness of reserves.

Critical to rational evaluation designs is determining realistic time frames to expect detectable differences. Species that grow slowly and whose young recruit episodically and in low numbers, are likely to take longer to respond to protection relative to species that are replenished frequently and in large numbers. Knowledge of species traits that correlate with rates of population growth provide bases for predicting how fast species will respond to protection.

Region-wide collaborative efforts to design and initiate long-term, large-scale monitoring programs, like California's "Collaborative Research and Assessment of Nearshore Ecosystems" (CRANE) program will greatly enhance reserve evaluation programs. Such programs will foster greater collaborations among agencies and academic institutions in response to growing needs of stewardship of coastal marine ecosystems and the services and resources they provide to society.