The Science of No-Take Fishery Reserves

A Guide for Managers

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Early in its planning of activities, the Connectivity Working Group undertook a critical review of the evidence for use of no-take fishery reserves as a management tool for coastal fisheries. The presumed fisheries value of no-take reserves depends explicitly on connectivity, and we saw this as both a useful review of the field and an effective way to delineate the most important issues with respect to connectivity science needed for MPA management. The article was published in *Trends in Ecology and Evolution* in 2005. We recognized at the time that the information we had brought together deserved to be made more widely available to coral reef and other coastal managers, and that an article in TREE was unlikely to be seen by many of them. This brochure, which will be available electronically and on paper, is the result.

Although it is essentially a new document authored by my colleague, Hanneke van Lavieren, the text has been reviewed by all 11 authors of the original TREE article. We thank them for their time and expertise.

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Inside cover photo: Coral reef, Caribbean. Photo by: ©Jonathan Bird, Still Pictures.

No-take Reserves

Definition

A No-take Reserve (NTR) is a Marine Protected Area (MPA) within which extractive fishing activities are regulated (usually not permitted). Other activities, such as pollution, construction, research, boating and diving, are also frequently regulated.

Why do we use them?

- No-take Reserves, like all MPAs, are tools used to control human activities in particular locations. They reduce or eliminate fishing pressure.
- No-take Reserves are one of several tools for managing coastal fisheries.
- No-take Reserves may also function to conserve biodiversity.

Theory – what No-take Reserves should do

No-take Reserves can potentially achieve two goals:

1. Provide insurance against unsustainable extraction of fish species
2. Supplement production of fishery species in surrounding fished areas

A No-take Reserve greatly reduces fishing pressure on those animals living within its borders, helping ensure their survival and reproduction even if the surrounding area is severely over-fished. Recruitment to fishery populations is very variable in space and time – there are good years and bad years for each species. Small populations – one consequence of over-fishing – are very susceptible to poor recruitment, and can disappear. No-take Reserves tend to maintain higher population levels of site attached species and help protect site attached ecological functions such as spawning aggregations. By serving as refuges for heavily fished species, NTRs protect overfished species from local extinction.

The reserve may also supplement a fishery species population in the surrounding region if some of the production within its borders is exported. This argument is often used to convince fishing communities to support the introduction of No-take Reserves. This supplementation is expected because of a feature of the ecology of marine organisms. Most marine species occur as local populations interconnected mostly through larval dispersal and sometimes through movement of juveniles or young adults. This connectivity provides a mechanism to enhance fishery production outside a reserve. That is, the more dense populations of larger individuals inside the reserve can be expected to produce large numbers of larvae, many of which will disperse beyond the reserve boundaries (**recruitment subsidy**). In addition, there may also be a net outward movement of juveniles which mature within the reserve and then move out into the fished area (**spillover**).

Do No-take Reserves really function according to the theory? Do the size, location, or spacing of nearby reserves affect how well they function? Do NTRs work for all fishery species in all coastal environments? These are important questions for managers both when designing or managing reserves and when speaking to fishers and other stakeholders about the value of having NTRs.

Rules for building an optimal No-take Reserve?

Is there such a thing as an optimal No-take Reserve?

The following 'rules of thumb' commonly guide planning for No-take Reserves (NTRs), but we need to build a more rigorous set of rules based on sound scientific data.

Conservation of biodiversity - Large reserves should be more effective because they protect larger populations of more species and become largely self-sustaining. Even small effective reserves can protect ecosystems where physical damage of habitat (such as by trawling) is involved.

Management of coastal reef fisheries - Reserves should be large enough to contain and protect a population of adequate size but also small enough to supplement production in surrounding areas. Reserves can also protect key biological features, such as spawning and nursery areas.

Spillover of juveniles moving out of reserves - This should have visible, but modest and local positive effects on fishing success because it usually depends on small-scale movements of individuals across boundaries.

Recruitment subsidy in fished areas because of reproductive activity within reserves - This should supplement production, and therefore enhance fishing success over a much greater area, provided the NTR is large enough to support a breeding population of sufficient size. However, this will be difficult to demonstrate.

Small No-take Reserves - These can be useful if appropriately placed, such as on a spawning aggregation site, or if a network of NTRs is used to create spillover into surrounding fished areas.

Few large or several small? - Theory suggests that fishery value is enhanced in a network of small NTRs rather than a few widely spaced large reserves, because the many small reserves supplement production over a greater proportion of the surrounding fished area.

Optimal network design - Ideally, a network should contain NTRs that are large enough so that populations within reserves can sustain themselves, yet small enough and spaced properly so that a proportion of larvae produced inside is exported to unprotected areas.

Jake Kritzer

The things we do not yet know

How big or how small?

Even small sized NTRs can provide positive benefits in terms of fish biomass, size and abundance. However, if the NTR is too small to sustain itself, it will inevitably decline along with the fished population. If the NTR is too large, it will be self-sustaining but spillover and export will not offset the losses to fisheries because of the reduction in fishing grounds.

- Theoretically, there is a correct size for a No-take Reserve, but what is it?
- How small a fraction of the total fished area needs to be protected in a reserve in order for it to function to sustain or enhance the fishery?
- How does the potential fishery benefit from spillover and recruitment subsidy change as NTR size is increased? Is there a certain reserve size above which no further improvement occurs?
- How small can an NTR be before it is too small to sustain itself?
- Why is it important to make NTRs large enough to be self-sustaining?
- How large can an NTR be before it ceases to have real benefits for the surrounding fishery because most larvae and juveniles remain within its boundaries?
- How does climate change affect the resilience of marine species and ecosystems and (how) can NTRs help build resilience against these effects?


Ken Drouillard

Examples of larval dispersal related to different NTR sizes. Arrows represent dispersing recruits.

Theory tells us there is an optimum size for a No-take Reserve intended to sustain or enhance a surrounding fishery. Here, the ovals represent reserves surrounded by a fishable area, and the arrows represent paths taken by dispersing larvae. Obviously, the correct size will depend on the dispersal envelope of the target species and the geography and hydrodynamics of the particular location.

Too small - Mostly spill over, hardly any self replenishment — the NTR cannot sustain itself

Perhaps larger than needed - Mostly self replenishment and hardly any spill over— does little for fishing outside borders

Right size - Spill over and self replenishment sustains NTR and provides subsidy for fisheries outside borders

Marine reserves cover less than 0.1% of the ocean worldwide and most are small in size. Global targets for the proportion to be protected by MPAs include 10%, 20% or 35%. These percentages are mere “rules of thumb”. They are a well informed consensus but have not been scientifically validated. We do not yet know the correct proportion to protect and this will vary with the biology and life history of the species targeted, location and hydrodynamics of the area.

The things we do not yet know

Do No-Take Reserves work for all fishery species in all habitats?

- The degree to which an NTR provides protection for a species depends to some degree on the behavior of that species, in particular, how far individuals move, how much they move about in their daily lives, and whether they require different habitats at different life stages. The effectiveness of an NTR depends on there being a reasonable chance that animals within its borders will stay long enough to benefit from not being fished. Most marine fishes and invertebrates use more than one habitat during their lives. Hence when protecting certain species, the NTR should include all the habitats used by that species in order for protection to be effective. Increased larval supply of a species into habitats hostile to recruitment will have no demographic effect.

How can data on a species' behavior, activity patterns and habitat needs be used to determine the appropriate size range of NTRs for that species?

- Most NTRs are small (1-20 km^2, median ~ 16 km^2). These should still protect many demersal fishes which are relatively sedentary (living spaces of < 1 km^2 suit many coral reef fish species). However, these are seldom the species targeted by a fishery.

Will these small NTRs provide significant protection for the many larger (often more economically important) and more seasonally mobile coastal fishery species (e.g. cod, snapper, grouper)?

- Larval and adult movement patterns vary greatly among species. To protect a range of species in an NTR, a range of movement patterns needs to be considered in the design. Considerable inter-specific variations are found in timing and extent of spawning migrations in coral reef fishery species and spawning aggregations occur at highly predictable times and sites and are especially vulnerable to fishing. These factors are important when considering NTR design. How broad a range of species (in terms of extent of movements) can be effectively protected in an NTR of given size?

Can an NTR of given size sustain the surrounding fisheries for species with differing patterns and extents of movement?

The NTR is a useful tool for fisheries management and should become more valuable as we define the rules for size and location more explicitly. It is important to remember, however, that the NTR is just one tool available to the fisheries manager. For example, when NTRs are in place, fishing is moved to and increased in unprotected areas. Therefore, other tools will be needed to manage the fishery, such as a reduction of overall fishing effort. Other impacts such as pollution and climate change need to be addressed in other ways. NTRs cannot protect against all human impacts and should be used in combination with other management tools.


Gidi Levi


Jacob Kritzer


Ernesto Weil

No-take reserves are not the only, and not necessarily always the best, tool to use for fisheries management.

The things we really need to find out

The most critical gaps in our knowledge of the science

Management planning always involves compromises among competing needs. But at present, the gaps in our knowledge of the science of connectivity mean that the planning process is weakened by our inability to make the scientific needs clear and explicit. Inadequate effort has been made to build the ecological theory that should play a major role in guiding NTR design.

Five crucial gaps we need to fill

1. **Distance and direction of larval dispersal.**
   Detailed knowledge of the spatial patterns of larval dispersal, the so called dispersal envelope, could help determine whether: (i) the size of a planned NTR will ensure self-recruitment; (ii) the placement and spacing of NTRs will promote persistence of target populations through dispersal amongst them; and (iii) the sizes, spacing and placement of a network of reserves will maximize potential fishery benefits on neighboring fishing grounds through recruitment subsidy. Our knowledge of dispersal envelopes is limited because patterns of larval dispersal are species, site, and time specific and are driven by a complex of sensory, behavioral, physical and hydrodynamic processes.


Carmen Villegas Sanchez

2. **Patterns of movement in later life.**
   We know more about movements of juvenile and adult fishes but there still remain surprising gaps in our knowledge of the basic biology of certain fishery species such as when, where and how far they move about in their daily lives. Placement and sizing of NTRs can benefit from detailed knowledge of juvenile and adult movement patterns. Many fishery species tend to be large and very mobile. Seasonal movements of adults can occasionally be hundreds of kilometers. In these cases, adult connectivity might even be more extensive than larval connectivity.

3. **Knowledge of ecosystem impacts of fishing.**
   Fishing alters an ecosystem by reducing numbers of the fished species and often in other ways as well, such as habitat modification. An NTR stops fishing but might also lead to changes in community structure as species survive better and habitat is restored. The expected increase in the abundance of a fishery species inside an NTR may not occur if such shifts in community structure occur and/or if the habitat or other fish species inside the NTR do not facilitate this. If a reserve does not result in the protected target species population becoming more abundant and more fecund, recruitment subsidy or spillover will not occur.

4. **Adequate knowledge of behavior of water masses in the vicinity of complex coastlines.**
   Complexity in temporal variability of hydrodynamic patterns limits our ability to decide placement and spacing of reserves. Theoretically it makes sense to place reserves at sites that serve as sources of propagules, rather than sites that serve as sinks. Current hydrodynamic knowledge does not allow us to identify source or sink locations without prior monitoring of these characteristics at each location.

5. **Studies of NTRs that demonstrate success.**
   A number of studies exist demonstrating spillover from NTRs, but sound evidence of recruitment subsidy does not exist. While recruitment subsidy is almost certain to occur, managers must be cautious about predicting this effect when advocating NTRs to stakeholders.

Science can be used to make informed decisions about NTRs. However, there remain many gaps in the scientific knowledge needed, such as the connectivity of larger species.

Filling the gaps in our knowledge of science

We need to recognize the serious gaps in our knowledge and take steps to fill them. How? Use existing science in **adaptive management approaches** for the design and implementation of No-take Reserves and reserve networks. With adaptive management we can design management actions (such as the establishment of an NTR) as experiments, with carefully planned monitoring before and after in order to discover the effect that action had. Over a series of such 'experiments', with reserves of differing size, for example, data are compiled to test specific hypotheses (How big should an NTR be?). These adaptive management 'experiments' are done at a scale that can seldom be managed by a scientist working alone.

If scientists and managers worked together, we could advance the theory we need so that fisheries management becomes more effective.

There are gaps in **basic science** that need to be addressed because they prevent development of explicit science for design of reserves. Questions concerning larval dispersal and subsequent movement patterns of particular species as well as information on adult connectivity of mobile species, must be answered before it will be possible to build NTR networks that are optimally effective in sustaining fisheries. This worthwhile goal can be achieved using adaptive management.


Andy Hooten


Andrew Dansie


Cynthia Shaw

There is an urgency to improve our scientific understanding concerning No-take Reserves. Our relative lack of scientific information on such matters as the correct size, spacing or placement of No-take Reserves limits our ability to predict the effects that a proposed No-take Reserve will have on surrounding fisheries or on biodiversity conservation. This reduces the manager's capacity to be explicit about outcomes when talking to stakeholders about existing or proposed reserves. Management that makes only vague promises, or that which promises more than can be delivered is seldom supported by stakeholder groups.

We have no doubt that No-take Reserves are a valuable conservation and fishery management tool.We need to use this tool, while also continuing to develop a clearer understanding of how to use it more effectively. Fortunately, managers and scientists working together can build the new scientific understanding that we all need.

Managing marine ecosystems for both health and resilience, and monitoring multiple indicators of the effectiveness of these actions are the basis for adaptive management. We need to manage adaptively to compensate for changes in species ranges and environmental conditions, and accommodate new science-based strategies as our knowledge increases.

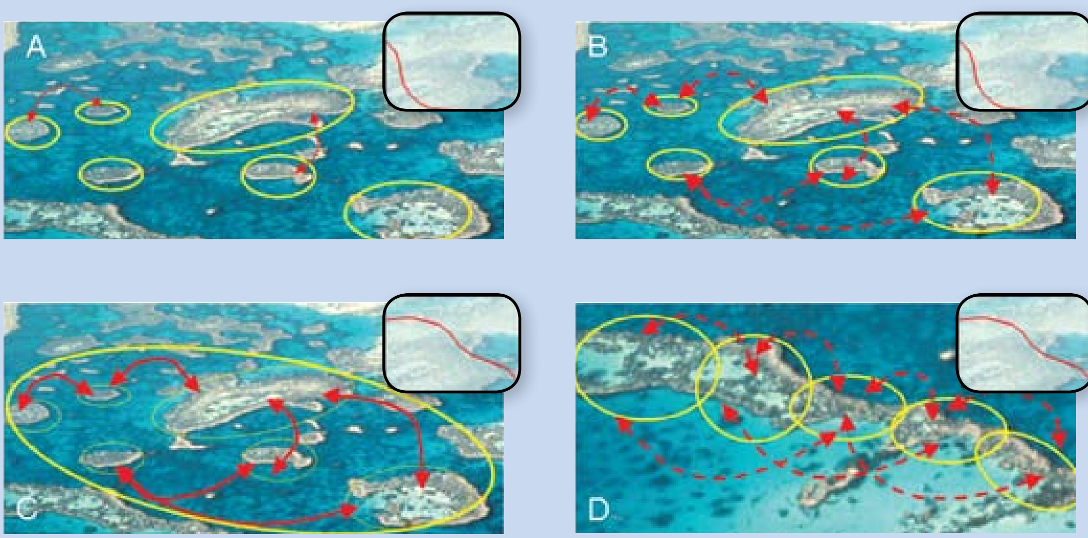
Filling the gaps in our knowledge of science

Topics in basic science that we would like to see investigated by teams of scientists and managers include:

- **Biological information on target species including:** mobility, life history, rates and patterns of settlement and recruitment, adult connectivity, identification of key spawning sites, connectivity amongst neighboring populations, and status of these populations as either sources or sinks.
- **Physical information including:** bathometry, habitat and hydrodynamics at proposed reserve locations.
- Effective ways of using **NTRs in combination with other fishery management tools**. Cost benefit approaches to determine under which situations particular management tools are most effective.
- **Explicit adaptive management projects to establish NTR networks** that will empirically test efficiency of NTRs as a fishery management tool and adapt to climate change impacts.

If we understand the structure of reef fish populations, we will be better able to design NTR networks to manage them.

Each panel shows a patchy array of reef habitat, occupied by a reef fish species (ovals = local aggregations of fish). Dispersal (chiefly by larvae) among sites is shown by arrows, graded to show slight **(A)**, moderate **(B, D)** or extensive exchange **(C)**. Mean scale of dispersal is shown as a graph of proportion of larvae (y axis) against distance from source (x axis) in upper right corner of each panel – mean dispersal distance is least in A, intermediate and identical in B and D, and greatest in C. Cases A, B, and C differ only in the scale of dispersal relative to the scale of patchiness of habitat, yet yield essentially independent local populations **(A)**, a metapopulation **(B)** in which local populations are sufficiently connected by dispersal for some interaction, and a single, but subdivided, population **(C)**, occupying a number of patches of habitat. Case D is typical of regions where coral reef habitat is more contiguous, yet the spatially explicit mating pattern and scale of larval dispersal still provide a functional metapopulation even though patch structure is primarily an analytical construct.



Understanding ecosystem dynamics and the factors that help them to resist or recover from perturbations can help us develop appropriate management responses.

More than science: Socio-economic factors

Socio-economic and political processes play an important role in the design of reserves. Without attention to underlying socio-economic issues, science-based reserve development will be constrained and will unlikely be effective. In addition to scientists and managers collaborating in adaptive management approaches to build the needed science, both scientists and managers must collaborate with local communities, fishers and other stakeholders, and politicians in building management programs. What is needed:

- Well informed stakeholders and community members
- Real consensus on goals
- Effective use of scientific advice
- Sustainable finance
- Capacity and willingness to enforce regulations once enacted
- Design, management and monitoring programs that suit the current state of the fishery and provide alternative livelihood options


Yvonne Sadovy de Mitcheson

No-take Reserves are a valuable tool to be included when building a comprehensive integrated management program.


Ken Drouillard

NTRs can help sustain valuable ecosystem services such as seafood production, protection of coasts from erosion, provision of recreation, and climate regulation. The socio-economic costs and benefits of NTRs can influence planning, design, and eventual outcomes.

Some terms explained

Adaptive management - A resource management program in which management actions are deliberately used as experimental manipulations of the managed system to test predictions of alternative models. In this way, scientific understanding is expanded and management becomes more effective. Adaptive management makes it possible to investigate hypotheses at a large spatial scale and with fishery species – this is seldom possible for a scientist working independently of managers.

Connectivity - The linking of places or populations through movement of organisms, nutrients, pollutants or other items between them. Marine environments exhibit high connectivity because of hydrodynamic movements. For populations, it is common to distinguish demographic connectivity – the linking of populations through dispersal of individuals – and genetic, or evolutionary connectivity – the linking of populations through the exchange of genes carried by those dispersing individuals. The theory underlying No-take Reserves relies on demographic connectivity.

Dispersal envelope - Before settling and commencing juvenile life, individual larvae disperse at varying distances, and directions from where they started larval life. The dispersal envelope is the probability distribution of larvae following completion of their dispersal from a source location, such as a reserve.

Larval dispersal - Pelagic larvae float or swim within the open ocean, and are transported away from the place where they were produced. This transport, or dispersal, is largely, but not entirely passive because most larvae are capable of sensing the environment and able to swim in specific directions. The extent of this transport depends on hydrodynamics and on the duration of larval life and larval behavior characteristic of each species.

Propagules - Eggs, sperm or larvae – the items produced through reproduction by a species, and later become the juveniles of the next generation.

Recruitment - The addition of a new cohort of young animals to a population. In marine species, recruitment is often measured at the age when animals complete the dispersive larval stage, or at the (later) age when maturity is reached and individuals join the breeding population.

Recruitment subsidy - The enhancement of production of a fishery species, within the fished locations surrounding one or more No-take Reserves, owing to the net export from the reserve of pelagic larvae.

Spawning aggregation site - A traditional site to which fish of a particular species return each year to reproduce. In a number of fishery species, such as groupers and snappers, spawning aggregation sites can attract large numbers of fish during a few weeks of the year when spawning takes place. These fish are particularly vulnerable to fishing at this time.

Spillover - The enhancement of fishery species production, within the fished locations surrounding one or more No-take Reserves, owing to the net movement of juveniles and adults out of the reserve.

NTRs will be successful if set up for the right reasons, in the right way, and by using adaptive management combined with scientific information.

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The United Nations University Institute for Water, Environment and Health is a member of the United Nations University family of organizations. It is the UN Think Tank on Water created by the UNU Governing Council in 1996 to strengthen water management capacity, particularly in developing countries, and to provide on the ground project support.

UNU INWEH's coastal programme focuses on improvement of scientific understanding to foster sound decision making for sustainable coastal marine management. This is directly linked to capacity development efforts to address critical gaps, achieved through diffusion of scientific research and promotion of human and institutional capacity.

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Coral Reef Targeted Research & Capacity Building for Management

The Coral Reef Targeted Research & Capacity Building for Management (CRTR) Program is a leading international coral reef research initiative that provides a coordinated approach to credible, factual and scientifically-proven knowledge for improved coral reef management. The CRTR Program is a partnership between the Global Environment Facility, the World Bank, The University of Queensland (Australia), the United States National Oceanic and Atmospheric Administration (NOAA) and approximately 50 research institutes and other third-parties around the world.

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