Marine Protected Areas as a central element of ecosystem-based management: defining their location, size and number

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Marine Protected Areas (MPAs) include many subclasses (e.g. marine sanctuaries, marine parks, wildlife refuges, fisheries closures, no-take MPAs, multiple-use MPAs, marine reserves, ecological reserves) all of which can be defined based mainly upon the level of protection and the primary conservation goal (see www.mpa.gov; Lubchenco et al. 2003). MPAs, and especially the marine reserves subclass (i.e. 'areas of the ocean completely protected from all extractive and destructive activities'; Lubchenco et al. 2003) represent the extreme case of the precautionary approach to managing marine resources (e.g. Lauck et al. 1998).

The strong and rapidly growing interest in MPAs (and particularly in marine reserves) is reflected in the dramatic increase in the number of publications devoted to them (reviewed in Jones 2002, Gell & Roberts 2003, and the articles in '*The Science of Marine Reserves*', a supplemental issue of *Ecological Applications*, Vol 13, Iss 1, freely available for download at www.esa-journals.org/esaonline/?request=get-static&name=s1051-0761-013-01-0001). In addition, there are now a number of sites on the World Wide Web that are either totally devoted to MPAs, or include relevant information on them: UNEP's World Conservation Monitoring Centre (www.unep-wcmc.org/protected_areas), the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO, www.piscoweb.org), and several others. This intense interest is at least partly related to MPAs having been identified and advocated as a conservation (of habitat and biodiversity) *and* managerial (of fisheries) tool of central importance in the Ecosystem Approach to Fisheries (EAF) (e.g. Agardy 2000, Stergiou 2002, Halpern & Warner 2003, Lubchenko et al. 2003, Pauly & MacLean 2003, Hilborn et al. 2004). It is hoped that MPAs will be beneficial in (1) rebuilding overexploited fish stocks, (2) preserving habitat and biodiversity, (3) maintaining ecosystem structure, (4) buffering against the effects of environmental variability, (5) serving as a control group against which populations in exploited regions can be compared, among others. Clearly, the choice of location, spatial extent (horizontal and vertical), and number of MPAs is critical if they are to meet these goals. It is to this issue that we devote our attention here.

Halpern & Warner (2003) state, 'Most reserve locations and boundaries were drawn by a political process that focused on economics, logistics, or public acceptance, while largely overlooking or ignoring how the complex ecology and biology of an area might be affected by reserve protection.' In this sense, establishing the locations and boundaries of MPAs can be seen as analogous to the imperfect process associated with establishing stock management grids — a process that has never really managed to incorporate the key realities of population dynamics of the exploited species. While there is a growing consensus on the need for MPAs, at this point in time there is no clear and well-founded basis upon which their location, spatial extent and number can be decided. In fact, rationales/frameworks that are based upon principles of theoretical and applied ecology have only recently been tapped to address these key questions (e.g. Roff & Evans 2002, Botsford et al. 2003, Roberts et al. 2003a,b, Shanks et al. 2003, Fisher & Frank 2004). Much of this work focuses on the manner in which different aspects of the life histories of marine organisms — spawning locations, dispersal, larval retention and export, juvenile nursery areas, etc. — affect MPA design. In this context, we contend that an eco-evolutionary framework already exists, grounded in marine ecology and fisheries oceanography, that is completely consistent with EAF and MPA objectives.

The Member-Vagrant Hypothesis as a framework for defining the location, size and number of MPAs. The Member-Vagrant Hypothesis (MVH), the development of which can be traced through a series of publications by Mike Sinclair and Derek Iles (Iles & Sinclair 1982, Sinclair 1988, 1992, Sinclair & Iles 1988, 1989), defines 4 attributes of populations that are involved in the regulation of their size. The 'population richness' refers to the number of discrete self-sustaining populations (henceforth simply 'populations') exhibited by any given species. Species such as herring, cod, mackerel, the salmonids, and many others are population rich. The 'spatial pattern' relates to the geographic distribution of these populations. Population rich species are usually also broadly distributed (the north Atlantic region is so far the best studied in this regard). Population richness and spatial pattern are species-level characters. The 'absolute abundance' refers to the instantaneous size of the various populations of any given species, and this size — which can range over several orders of magnitude — varies over time (thus, its 'temporal variability'). These last 2 components of the MVH are population-level characteristics. Sinclair & Iles have applied the MVH to describe the richness, pattern, abundance and variability of several economically im-

*The views expressed here are those of the author only and do not necessarily reflect the official position of The Institute of Marine Research portant fish including herring, cod, haddock, mackerel, and several others. For all of these, (1) the population richness is directly correlated with the number of retention areas for the species' early life history stages (also implying that the adults are able to return to the same geographic locations); (2) the spatial pattern is related to the number of discrete geographic areas allowing closure of the species' life cycle; (3) the absolute abundance is scaled according to the size of the geographic area in which there is closure of the life cycle (corroborated by MacKenzie et al. [2003], who reported that the biomass of cod spawners and recruits is related to habitat size); (4) the geographic locations referred to in (1), (2) and (3) have distinct oceanographic features; and (5) the temporal variability is determined by the intergenerational losses of individuals from any one population (through mortality and/or passive processes such as advection or spatial constraints = 'vagrancy'). It is worth noting that the MVH is completely consistent with the metapopulation concepts that have recently been applied to marine fish populations (e.g. Smedbol & Wroblewski 2002)

Exploited populations are subject to intense size-dependent mortality and drastic reductions in biomass over a short time and a large spatial scale (e.g. Christensen et al. 2003, Myers & Worm 2003, Pauly & MacLean 2003). With modern fishing practices and equipment, this can impact a large proportion of the populations in a species' entire spatial pattern. Thus, commercial fishing imposes new conditions on these populations and, therefore, drastically affects all 4 MVH population attributes.

The MVH '…emphasizes that membership in a population in the oceans requires being in the appropriate place during the various parts of the life cycle. It implies that animals can be lost from their population, and thus become vagrants. Life cycles are considered as continuity solutions within particular geographical settings which impose spatial constraints.' (Sinclair & Iles 1989, p. 169). Thus, for many marine fishes, population richness, pattern, absolute abundance and temporal variability are all a function of geography.

Following from the MVH, the location of MPAs should be chosen to include a subset of the populations within a species' (or species complex) spatial pattern. The size of each such MPA would then be assigned based upon the geographic area within which the corresponding population's life history can achieve closure. In our view, applying the MVH in this manner would satisfy many of the objectives of MPAs.

It has only recently been possible to assess whether MPAs do in fact provide the benefits listed above (reviewed in e.g. S. J. Hall 1998, Jones 2002, Gell & Roberts 2003, Halpern & Warner 2003, Luchenco et al. 2003, Hilborn et al. 2004). These assessments have led to arguments over the degree to which MPAs can or will succeed. There is also some concern over the possibility of an imbalanced reliance upon MPAs as a fisheries management tool (see Hilborn et al. 2004 and several of the contributions to this TS). Nonetheless, if the choice of their location, size and number is well grounded in marine ecology and fisheries oceanography, then MPAs stand to become an effective tool for conservation *and* management. In order for this to be realized, 2 closely related steps are required. First, an operational spatial unit within which MPAs will be embedded must be defined. Such a unit already exists: the Large Marine Ecosystem (LME) (e.g. Sherman & Duda 1998). LMEs are large 'regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margins of the major current systems' characterized by 'distinct: (1) bathymetry, (2) hydrography, (3) productivity, and (4) trophically dependent populations' (www.lme.noaa.gov). When combined with Longhurst's (1998) 'Biogeochemical Provinces', which extend out into the open ocean areas, LMEs can provide a very useful ecosystem framework for fisheries research (see Pauly & MacLean 2003, www.seaaroundus.org). Second, future work in fisheries science could adopt a more ecological/oceanographic orientation, by (1) identifying and mapping the key faunistic components and the biodiversity 'hot spots' (sensu Worm et al. 2003) in the main ecosystems of the world's oceans (as defined above); (2) describing the life cycles of these key components within the context of the MVH framework; (3) spatially mapping the life cycles of key species (see Zeller & Pauly 2001); and (4) identifying the special oceanographic features associated with the retention and nursery areas of these key components (recent work linking population genetics with marine ecology and fisheries oceanography holds promise in this regard, e.g. Reiss et al. 2000).

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Tuning the ecoscope for the Ecosystem Approach to Fisheries

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A multidisciplinary scientific approach is needed for the Ecosystem Approach to Fisheries (EAF). The Reykjavik Declaration of 2001, reinforced at the World