Species vs. spaces:

A call for a paradigm shift in marine protected area network design

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ABSTRACT

This thesis seeks to develop a methodology that supports assessment of the spatial arrangement of marine protected area (MPA) networks, for the purpose of creating systems of MPAs that are ecologically-coherent at the regional level. I make the case that the use of focal species helps configure effective MPA systems, as they may reveal spaces where key ecological processes take place (*keystone spaces*). Hence, I explore whether focal species can be used to identify areas of ecological importance in the marine environment. In addition, I show how Geographic Information Systems (GIS) can aid in the design of MPA networks. The toolbox developed has also served as a means of generating ecological insight, and brings up questions that are worth further research. In this study, the green sea turtle distribution is studied against the background of several oceanographic characteristics (bathymetry, temperature, chlorophyll) and analyzed with ArcView v. 3.2a with Spatial Analyst™.

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the SeaWiFS Project data products, while sea surface temperature comes from the AVHRR Ocean Pathfinder Project; access to this datasets was facilitated by Ken Casey (from NOAA).

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CHAPTER 1. INTRODUCTION

"(...) He could see the prisms in the deep dark water and the line stretching ahead and the undulation of the calm (...) and he knew no [one] was ever alone on the sea."

E. Hemingway, 1952, p. 67

Facts and needs: statement of the research problem

Marine environments are highly dynamic and complexly interconnected systems, where local processes depend largely on processes occurring elsewhere as well as at longer or shorter time scales (Roberts 1998). Time-space scales involved vary from seconds and centimeters (such as foraging and predation activities) to decades and whole oceanic basins (such as circulation regimes and population dynamics of long-lived species) (Walters *et al.* 1999). In addition, there are a number of complex physical, biological and biogeochemical interactions between systems, which are, in turn, influenced by terrestrial as well as open ocean activities (Moberg and Folke 1999). This makes it a complicated task to manage marine ecosystems in a way that the conservation of both marine diversity and productivity are ensured.

Healthy ocean ecosystems provide a large number of goods and services and hence enormous economic benefits to human society. Among those, fisheries are the most profitable ones, but along with fish production stand others that are just as critical. The oceans play a crucial role in the global

materials cycling that sustains climate and life-support systems on land. In combination with rivers and estuaries, marine systems serve to process, transform, detoxify and sequester many of society's waste products, although abuse of this particular service has resulted in nutrient overloading, eutrophication problems, and toxic algal blooms. In addition to these biogeochemical functions, oceans also sustain valuable human enterprises, such as the tourism, recreation and retirement industries (Peterson and Lubchenco 1997).

These goods and services, often taken for granted, are the result of the functioning of the ocean ecosystem processes and the dynamic interactions between networks of species within and between ecosystems (Moberg and Folke 1999). Excessive pressure on these systems (by means of overfishing, for example) disrupts the delicate balance that keeps the system working, alters community structure, and results in loss of ocean productivity. In order for living-resource extraction to happen in a sustainable manner, the integrity of the ecosystem, sitting at the heart of this bounty, must be respected and maintained (Kaufman and Dayton 1997). Regrettably, there does not exist a magic cookbook on how to best safeguard ecosystem integrity, and we are faced with the necessity to put in practice a trial-and-error system that allows us to reconcile increasing human populations with nature's (finite) capacity to provide goods and services. Of special concern (to this author, at least) are the health of our oceans and the well-documented, widespread decline of the world's living marine resources.

So, again, how do we best manage marine systems to maintain ocean diversity and productivity? Marine Protected Areas (MPAs) represent the

conservation strategy that has been promoted most extensively. They have also been strongly advocated as an ideal tool for the management of fisheries (Roberts *et al.* 2001, Ballantine 1995, Roberts and Polunin 1991, Rowley 1994, Lauck *et al.* 1998, Allison *et al.* 1998, García-Charton and Pérez-Ruzafa 1999, Bohnsack 1998). However, do they really take account of the enormous complexity of the ecosystem functional and structural attributes? In order for this management tool to be effective, MPA planning and design must be based on sound ecological principles, and initiatives should be evaluated in local, national and global contexts (Roff and Taylor 2000). It is argued here that MPAs that have been established neglecting these circumstances do not contribute much to marine diversity conservation and/or marine resource long-term sustainability.

Before going any further it is necessary to clarify what is meant by the term “MPA”, as well as “marine reserve”, in order to avoid misinterpretations. In addition, a more precise definition is included further into this thesis (see Chapter 2). Even though in some cases both terms may be used interchangeably, they do imply different concepts. MPAs are defined as “areas of the ocean designated to enhance conservation of marine resources”. Marine reserves, sometimes referred to as “no-take areas”, are “areas of the ocean completely protected from all extractive and destructive activities” (Lubchenco *et al.* 2003, p. S3). Thus, marine reserves are in fact a special type of MPA, ruled by means of more severe restrictions. Both types of protected areas are created, in any case, with the intention (rather the hope, sometimes) of achieving some or all of the following objectives: biodiversity conservation, tourism, protection of sensitive habitats/species, enhancement of the

production of target species and/or critical spawning stock biomass, development of management frameworks for sustainable multiple uses, and scientific research (Allison *et al.* 1998).

As a result of a symposium on marine reserves held in 1997, at the Annual Meeting of the American Association for the Advancement of Science, a Working Group on Marine Reserves was formed in 1999, based at the National Center for Ecological Analysis and Synthesis (U.S.A.). Some of this working group's principal tasks include: (i) to advance the theory of marine reserves and marine reserve design, (ii) to synthesize data on the performance of existing reserves, and (iii) to develop tools to apply the new theory to practical situations [Lubchenco *et al.* 2003]. The scattered and fragmentary nature of the research that was being undertaken to demonstrate (or refute) the usefulness of MPAs and reserves up until then was the instigating factor to the creation of this research group. Today, however, many of the problems remain unsolved, and a remarkable amount of work is being conducted in different areas (see for example the special issue on marine reserves of *Ecological Applications*, Vol. 13, no. 1, 2003).

This thesis is highly related to one of the areas that is experiencing rapid progress in the science of marine reserves: the development of models of reserve networks that explore how multiple reserves arrayed along a coastline may interact to augment the contribution of individual reserves. This is ultimately an issue concerned with taking into consideration the bigger picture. In order for managers and decision-makers to be able to select the sites that will effectively attain conservation goals, they must ask themselves the following question: are these particular locations essential to the operating of the key

large-scale ecological processes necessary to maintain ecosystem integrity? This is no easy question.

As we continue to witness the impacts of human-driven alterations in the marine environment (such as coral bleaching, abrupt changes in species composition, habitat degradation, invasive species, harmful algal blooms, mass mortalities and fisheries collapses [several authors cited in Lubchenco *et al.* 2003]), the need for research on how to design effective, comprehensive, representative and adequate MPA networks that will help protect, maintain and restore ocean ecosystems becomes increasingly urgent. Under the premise that MPAs that operate in isolation will not necessarily maintain ocean biodiversity over the long term (Roberts 1997), this thesis sets out to investigate the problem of how to design reserve networks that will in fact interact effectively. The central challenge to be handled here lies in the integration of ocean-scale processes into the design of MPA networks (Roberts 1998). Even though “the elements conferring effectiveness have not yet been established” (Allison *et al.* 1998, p. S80), I will use the term “effective” to refer to MPAs, and by extension MPA networks, that succeed in attaining both conservation goals and fishery management objectives.

Theoretical framework and purpose of the study

The theory of reserve selection and design

Before going into the theoretical framework that supports the argument in favor of MPAs as a means to conserve marine diversity and productivity, it is necessary to examine the theoretical concepts underlying the idea that setting

areas aside in the form of nature reserves can in fact capture, and hence preserve, a large enough portion of the world's diversity of life.

Early efforts at reserve design were derived from Island Biogeography Theory, developed by Robert H. McArthur and Edward O. Wilson (McArthur and Wilson 1963, 1967). This theory combined the well-known species-area relationship with the effect of counteracting rates of colonization and extinction to explain why some islands hosted many species and others few.

The conceptual leap from oceanic islands to patches of habitat set aside as reserves was justifiably based on the ecological equivalence between the two, since both represent areas where species can exist surrounded by areas in which species can survive poorly, or not at all (Diamond 1975). The premises provided by this theory were soon applied to conservation practice, and resulted in guidelines aimed at selecting those "habitat islands" predicted to hold more species, and for a longer period of time, than others.

As early as 1975, Diamond put forward the basic six principles of the theory of reserve selection and design (Diamond 1975). Diamond argues that in order for a refuge to hold the maximum number of possible species (or to maximize species richness), its configuration and arrangement in space with respect to other reserves should minimize extinction rates. This is in turn controlled by the following traits of the reserve, or the reserve system: "bigness" (principle A), multiplicity (principle B), proximity (principle C), equidistance (principle D), connectivity (principle E) and "compactedness" (principle F). Thus, (A) bigger reserves are preferred over smaller reserves, (B) a lower number of larger reserves is preferred over a higher number of smaller, disconnected reserves, (C) reserves that stand close to each other are better than those that

are far away, (D) equidistantly-grouped reserves are better than linearly-grouped ones, (E) reserves connected by corridors are better than those disconnected, and lastly, (F) circular-shaped reserves are better than elongate ones.

Some of the assumptions underlying the theory, however, proved to be overly simplistic, and many exceptions to the rules soon began to be found. The dispute over the multiplicity principle (a single large refuge is better [i.e. retains more species] than several small ones of equal total size) became such a huge issue in the conservation biology literature of the 1980s that it generated its own acronym: it came to be known as the SLOSS debate (Single Large Or Several Small). Simberloff and Abele (1976) stood among the first investigators to show skepticism on both theoretical and empirical grounds. They emphasized that turnover (extinction and immigration) occurs in any system, and equilibrium will be reached sooner or later depending on the particular rates of extinction at work. However, they argued that extinction rates do not consistently increase with decreasing reserve size. Increased extinction rates in fragmented patches of habitat may be more than compensated for by the presence of the other “islands” as nearby sources generating high propagule invasion rates. Also, increased competition within the smaller patches should enhance species richness. These authors also noted that “environmental catastrophes (such as certain kinds of forest fires or contagious diseases) that could cause extinction if all conserved lands were united in one large refuge [...] would be inconsequential in one of a network of small refuges” (Simberloff and Abele 1976, p. 286). In addition, they make the point that all species are not

ecologically equal, from which it follows that not all species require the same amount of consideration.

This particular area of debate eventually faded away when the participants came to realization that “bigness” and multiplicity are both important design criteria (Soulé and Simberloff 1986) and that the inconclusive answer to this particular question can only be “it depends” (Possingham 2000). Simberloff and Abele (1982) summarize this question as follows: “How population size is related to area, and extinction probability to population size, determines whether one large or several small refuges will generate the lowest extinction rates. Both these relationships are species-specific, fundamentally empirical, and very poorly known for virtually all species” (p. 44). Nature, one more time, proves itself to be far more complex than initially thought.

The atmosphere of scientific skepticism created the conditions for a shift in focus. Whereas Island Biogeography Theory, and hence species-area relationships, is primarily concerned with the size of communities, genetics redirected attention to populations. This shift in focus was forced about when factors such as inbreeding depression and genetic drift were taken into consideration, to the extent that they are in fact a threat to fragmented populations. The new major area of concern in conservation biology settled on the theory of Minimum Viable Population (MVP theory), and was closely linked to the metapopulation concept.

Metapopulation dynamics predict that for a species which occurs in more than one reserve of a network, the chance of its dying out is a function of the number of reserves it occupies, the chances of losing a population in a single reserve over a specified period, the rate of dispersal among reserves, and the

correlation among the reserves in environmental fluctuations from year to year (Caughley and Gunn 1996). Implicit in this shift towards metapopulation studies are two critical ideas that slowly commence to emerge: firstly, nature reserves are actually *not* islands, but are in fact connected to one another in numerous ways. Secondly, for the first time, emphasis is placed on habitat quality, rather than exclusively on area considerations. The former of the two (i.e., connectedness) will be unfolded in the paragraphs (and chapters) that follow, as is in fact a central point to this thesis.

The theory of Marine Protected Areas: what MPAs promise and what MPAs deliver

Although no one would question the benefits of MPAs and marine reserves as they relate to biodiversity conservation objectives, their potential as fish stock-enhancing tools is still controversial, since not many case-studies have yet provided sound evidence that fisheries outside reserves have actually experienced an improvement as a direct result of the fishing restrictions inside them. The study of the effects of MPAs and/or marine reserves constitutes one of the focal points that the emerging science of marine reserves is concerned with, contributing substantially to the development and refinement of MPA theory.

MPA theory states that MPAs not only sustain, but actually enhance fisheries. The basis of the MPA theory rests on the fact that marine species exist in open populations, with pelagic dispersal phases that may carry offspring far from their parents. This theory is articulated upon two major hypotheses: the biomass-overflow hypothesis and the larval-export hypothesis (Crowder *et al.*

2000). The former implies that relaxation of fishing pressure within an MPA leads to higher density and average size of target species within the reserve, resulting in density-dependent emigration of adult fish out of the reserve and into fished areas (Russ and Alcala 1996, Rakitin and Kramer 1996). The latter suggests that eggs and larvae are produced in larger numbers by the greater spawning-stock biomass within the reserve and are transported to habitats outside the reserve (Roberts 1997). Hence, this theory makes two important claims: first, that MPAs act as recruitment sources that enhance fisheries outside the reserve, and second, that yields from areas surrounding reserves will be supplemented by emigration of adult fish from the reserve (Roberts and Polunin 1991). However, the hypotheses underlying MPA theory have rarely been tested in the field (Crowder *et al.* 2000, García-Charton and Pérez-Ruzafa 1999, Roberts and Polunin 1991), and consequently, concrete scientific information regarding marine reserve effects on fish stocks is insufficient and inconclusive (Lubchenco *et al.* 2003). For reviews of field studies set to test the above hypotheses see Roberts and Polunin (1991), Planes *et al.* (2000).

Although the theory appears to be robust (an assumption strongly supported by the literature), it is still difficult to detect empirically an improvement in fishery production adjacent to marine reserves. In other words, it appears that marine protected areas are not being completely *effective*. This dissertation argues that there are crucial factors involved in MPA siting and design processes that are being neglected. Several arguments have been put forward in various attempts to explain the discrepancy between the theory and the empirical evidence. These include: the overlooking of the effects of spatial heterogeneity on the population dynamics of the harvested species (Tuck and

Possingham 2000, Lundberg and Jonzén 1999, Jonzén *et al.* 2001) and the lack of multi-trophic-level studies (Crowder *et al.* 2000). However, ecology alone does not tell the whole story; socio-economic and (geo)political circumstances under which marine reserves are declared may also have a major impact on their effectiveness as appropriate partnerships among agencies or even governments involved in the management of straddling fish stocks (or other transboundary resources) have not been put in place (Roberts 1997).

There is an increasing awareness that population management techniques should thoroughly take into account the effects that habitat heterogeneity causes on the harvested species (Lundberg and Jonzén 1999, Crowder *et al.* 2000, Tuck and Possingham 2000, Jonzén *et al.* 2001, García-Charton and Pérez-Ruzafa 1999). Habitat heterogeneity, or the co-existence of high-quality and low-quality habitat patches, confers spatial structure to populations. Even though harvesting may only affect certain patches of the population, effects of this pressure will be detected in distant patches, unexploited perhaps because they fall within the limits of a marine reserve, but which are nonetheless linked to the exploited ones by larval or juvenile transfer. This connectivity, the linkage of marine populations from sites of origin to recruitment, has been argued to be central to the effectiveness of MPAs (Roberts 1998). Consequently, reserves that are established ignoring the spatial structure of those populations that they are intended to protect might result in ineffective management tools, as harvesting pressure and conservation efforts become randomly distributed across habitats. If sociological processes reduce the probability of protecting the most productive, high-quality habitats (e.g. those with the highest density and productivity of adult fish) and redirects

protection toward lower-quality habitats, the expected benefits of the MPA are further reduced (Crowder *et al.* 2000).

In addition, our knowledge of how species are related to one another through trophic interactions is so limited that predicting the consequences of alternative fishing policies becomes extremely challenging. The effects of the removal of a given target species from the ecosystem may be completely counter-intuitive (see Yodzis 1998 as an example)¹, and because of the non-linear nature of population dynamics, they are also very hard to model and predict. The initiation of fishing in an unfished system leads to dramatic reductions in the abundance of the target stocks, as well as changes in their growth, production and recruitment levels. These effects propagate themselves throughout the marine food webs in very complex ways, inducing indirect effects on other species. Trophic cascades are one such indirect effect (Pinnegar *et al.* 2000).

Trophic cascades, in its broader sense, occur when removal of one species alters either predation or competition rates in the system, and they can be sensed through three or more trophic levels. Thus, the removal of top predators results in an expansion of prey species, leading to enhanced competition and displacing less competitive species by a few dominants. Also, overfishing of herbivore fish releases grazing pressure, thereby increasing plants or algae abundance (Williams and Polunin 2001); in coral reefs, overfishing of grazing fish, acting in combination with eutrophication, allows

¹ Yodzis (1998) found that fur seal culls had a negative effect on fisheries total yields, in the Benguela ecosystem, contrary to the assumed notion that decreasing marine mammal densities would increase fishery production. This study suggests that “responses to generalized press perturbations may involve highly non-local interactions: many pathways of influence, non-viability of highly simplified food webs, important indirect effects” (Yodzis 1998, p. 638)

macroalgae to overgrow and kill corals (Williams and Polunin 2001, Botsford *et al.* 1997).

In this sense, and according to the theory, MPAs should be capable of mitigating adverse consequences of trophic cascades by enabling species involved to return to their equilibrium levels. But again, design tends to neglect these issues and the potential ecological benefits are more often than not given up in the name of other types of benefits. It is nevertheless becoming more and more accepted that fishery scientists must abandon their focus on individual stocks and adopt a whole-ecosystem perspective that accounts for food web interactions (see for example Botsford *et al.* 1997 and Bohnsack 1998). This is in fact a very active field of research in fisheries science and probably the key to attain ocean sustainability in the future.

Moreover, trophic cascades frequently involve non-local effects (Yodzis 1998), and thus it becomes necessary to consider simultaneously these two aspects, namely, spatial structure of populations and multispecies approach. Stressing the importance of “tropho-spatial” phenomena, Polis and others (1997) call attention to the necessity to integrate landscape ecology and food web ecology. Software packages are being developed to assess the spatial aspects of trophic relations (see Walters *et al.* 1999 and Pauly *et al.* 2000). Probably the most widespread one is “Ecospace”, a spatially explicit, multispecies assessment model meant to provide insights about the likely efficacy of alternative MPA policies in relation to questions related to trophic linkages. It can for example predict “drainage” of large predators from protected areas due to impacts on their prey within, and their dispersal out of an MPA,

while accounting for the distribution of fishing effort on predators and prey (more detailed information is available from www.ecopath.org).

This paper argues that MPAs must be regarded as the components of a larger system, within which they play specific roles by performing specific functions or enabling certain processes. Therefore, in order for the system to be functional as a whole, all components must be *effectively* performing their tasks. In other words, the maintenance of ecosystem integrity and health requires that MPAs “do a good job” of sustaining the occurrence of the critical ecological processes involved. This in turn requires a careful selection of candidate sites, based on in-depth knowledge of the large-scale, key ecological processes. One critical element of such an MPA system would then be adequate connectivity among the individual components (Ballantine 1995, Roberts 1997).

Purpose of the study

The ultimate goal of this study is to provide insights into the development of an integrated, interdependent MPA system in the Caribbean Basin. To that purpose, a multilayer GIS database in ArcView format is compiled. The intended use of the GIS analysis that is presented with this thesis is to help bridge the gap between theoretical knowledge and policy development, by creating a user-friendly toolbox that could be of benefit for researchers as well as managers. Furthermore, this approach advocates the use of available information, in order to demonstrate how to maximize the return on time and money invested. Thus, it has used existing databases. Despite its limitations, discussed in greater detail at the end, some of which relate to the sacrifice of

resolution in the data layers, this approach remains of value because it offers practical applications for MPA managers and decision-makers.

Additionally, this project may be used as preliminary research to identify those sites worthy of more detailed, on-the-ground research aiming at the assessment for MPA suitability, as a means of optimizing research efforts.

Rationale for the approach taken

Because ecosystems are complex systems, with elusive boundaries and unclear definitions, there are a number of ways in which they can be described in both theoretical and applied ecology. These are reviewed below, with the purpose of defining the perspective that this research will use.

Ecosystem vs. single-species

The ecosystem *vs.* single-species approach discussion can no longer be considered so much of a debate, as the latter is increasingly becoming rejected while the former continues to gain reliability. These approaches derived from the two viewpoints that theoretical ecologists have traditionally used to study ecosystem behaviour, and translated into two apparently irreconcilable approaches toward the practice of biodiversity conservation. They differ essentially in the philosophy that lies behind them, and therefore in the principles that drive them, but both have as their main goal the conservation of the world's ecosystems and the diversity of life at all levels. Whereas the single-species approach focuses on the emergent properties of an ecosystem (namely, the species that occur in it), the ecosystem approach is centred on the

processes that make it possible for those species to be there, thereby maintaining ecosystem structure and function.

Bohnsack (1998) explains in a very didactic manner the main difference between single-species and ecosystem management. This author draws a parallel between single-species management and the way automobiles are maintained, as both work under a “fix it when it breaks” philosophy. Parts are repaired or replaced usually after they fail, and only a few of the most critical safety systems are engineered to make failure extremely unlikely. This approach works well when failure of the system, although inconvenient, is not perceived as life-threatening. In contrast, ecosystem management is compared to airplane maintenance, where the ultimate goal is to maintain the entire system working by preventing failure of all its components. In both airplane maintenance and ecosystem management success requires: understanding how the various components operate, building margins of safety into all operational systems, and continuous monitoring of all critical elements. Unlike airplanes, though, “ecosystems do not come with operation manuals”! (Bohnsack 1998, p. 307).

The single-species approach has been proven insufficient time and time again, for instance in fisheries management (e.g. Bohnsack 1998, Botsford 1997). However, an all-embracing approach is clearly impossible to put into practice, at least within the limits of a reasonable time frame that allows for political actions to have an effect on the ground. When we are faced with this reality it is critical to take a pragmatic position and seek the common ground between these seemingly divergent approaches. In fact, it has already been proposed that the single-species approach, by means of the use of focal species, could provide a systematic methodology to help put in practice (otherwise

impossible to tackle) ecosystem approach principles (Bohnsack 1998, Holmes and Kareiva 2000, Roff and Evans 2002). As the author believes this is the right direction to move toward, this is precisely the approach taken in this study. Thus, another way to read this paper is as a further contribution to the ongoing discussion about single-species and ecosystem management techniques, by putting forward a method to reconcile the two.

As neither viewpoint (species and processes) has been able to offer a complete and satisfactory description of the behaviour of ecosystems, in the ecosystems theory arena (O'Neill *et al.* 1986), new theoretical viewpoints are emerging. Hierarchy Theory has been adopted by theoretical ecologists, as it provides a new and powerful perspective that seems to be able to describe and understand the complexity of ecosystems as well as reconcile observations that appeared contradictory when looked at from any of the other viewpoints. A remarkable overview of ecosystems based upon Hierarchy Theory principles is presented in *A Hierarchical Concept of Ecosystems* (O'Neill *et al.* 1986). Some of the ideas embedded in this new concept of ecosystems are slowly beginning to flood applied ecology grounds, and are thus being translated into innovative management principles.

It is widely recognized that natural processes operate over a number of spatiotemporal scales. Processes can in turn be described in terms of the rate at which they operate. Hierarchy Theory explains the fact that this plethora of processes operating simultaneously does so in a coordinated manner, thus avoiding chaos and conferring stability to the system, by looking at the constraints imposed upon rates of processes. Hierarchy Theory recognizes constraints upon rates of processes (rates of energy flow, nutrient recycling

rates, and metabolic, birth, growth, predation, maturity, and mortality rates) as fundamental parameters of ecosystems. Constraints upon process rates are in turn hierarchically organized: scales of constraints expand in space and time as hierarchies of systems are ascended. Accordingly, phenomena of greater spatial extent and operating more slowly constrain a phenomenon of lesser spatial extent and faster dynamics (Apollonio 2002). For example, the establishment of thermal stratification in the marine environment constrains the rate of nutrient replenishment into surface waters, upon which the rate of primary production ultimately depends. Subsequent constraints can be found as one moves down the hierarchy and focuses on more and more local processes. The temporal and spatial extents of thermocline formation are certainly greater than those of phytoplankton, so from this viewpoint the thermocline is the higher hierarchical level, constraining phytoplankton production.

As will be shown through the unfolding of this thesis, conservation efforts that are strongly based on either approach with no room for the other, are not likely to succeed, whether it be because of insufficiency or because of difficulty. Hierarchy Theory principles seem to provide a framework to reconcile these two approaches to conservation biology, by offering a new way to look at how species relate to ecosystem processes.

Here, focal species are defined by Miller *et al.* 1998/99: Focal species are organisms used in planning and managing nature reserves because their requirements for survival represent factors important to maintaining ecologically healthy conditions. Focal species distribution analysis thus serves the purpose of identifying additional high value areas and optimizes research/management efforts. Consequently, it is of critical importance that the

selection of focal species is founded upon solid scientific research, or we will be taking the risk of protecting the wrong places or putting in place the wrong conservation strategies. If done carefully, I suggest that focal species may in fact be the answer to many conservation dilemmas.

Thus far, however, research on how focal species perform as such is scarce, and success of resultant conservation plans is little more than a matter of faith. In this paper, it is stressed that there is a necessity to identify knowledge gaps and develop a focal species research agenda. Focal species may be seen as having two dimensions: ecological, and spatial. Even though the ecological dimension is discussed in the paper, the bulk of this study centers on spatial considerations of focal species analysis.

The research question

Roff and Evans (2002) suggest that focal species (typically, those charismatic species that have traditionally captivated the public's attention) are associated with distinctive habitats, which appear to be distinguished from the surrounding environment because special oceanographic processes are occurring within them, on a local or regional scale. These habitats are found in areas of various structural anomalies related to temperature, chlorophyll *a*, isolation, topography, etc. Such areas may typically be associated with elevated resources at some trophic level, resources which in turn are of vital importance to many coastal species, especially seasonal migrants. Among them stand some of the most "popular" species, such as marine mammals, sea birds, etc. These authors wrote: "These processes lie at the heart of the ecology of distinctive habitats, and are fundamental to the maintenance of ecosystem health,

ecological integrity, distributions, abundances and recruitment of species, patterns of animal migrations, and potential or actual fisheries yields” (Roff and Evans 2002, p. 638). Could these focal species, if carefully chosen, be the link between single-species management and ecosystem management? Furthermore, could these species be used to identify and assess MPA candidate sites when developing ecologically-sound MPA networks?

Roff and Evans (2002) explore the question whether a selection of a set of MPAs based on a designated focal species, provide protection for a greater diversity of species (or a greater heterogeneity of habitats) than a comparable set of MPAs selected at random or simply established in an opportunistic way. I have given this question a slightly different direction so as to incorporate ecological processes, rather than habitat/species diversity, as the main conservation concern. Thus, this thesis investigates the following question: would a system of MPAs designed on the basis of a designated focal species confer protection to areas where key broad scale ecological processes occur? The underpinnings of this question relate to the search for a method to design MPA systems that optimizes effort, since focusing attention on one species is far more efficient than trying to consider all at once.

Goals and objectives

The GIS project developed for this thesis is restricted to a broad scale analysis and seeks to demonstrate that the regional context is an important consideration for marine reserve network design. This project has been developed bearing in mind the two following points: (1) at the broadest scale,

reserve networks must protect ecological processes essential for ecosystem functioning (Roberts *et al.* 2003); (2) changing the scale of the planning region will greatly affect the relative importance of the areas within that region (Aíramé *et al.* 2003). In other words, the results of the analyses performed are scale-specific.

The ultimate goal of this exercise has to do with the development of a toolbox for the design of ecologically meaningful MPA networks. It provides the basic contents that such a toolbox should have.

This will be done by addressing two broad research goals:

Goal 1: To assess the feasibility, practicality and adequacy of the use of the green sea turtle (*Chelonia mydas*) spatial distribution as a basis to design an ecologically-coherent system of marine protected areas. In other words, I examine how this species would perform if chosen as a focal species, when the ultimate goal is to develop an MPA network that meets ecosystem-based principles. To my knowledge, this idea has never been investigated before. The following specific objectives will have to be attained in a sequential manner in order to arrive at the above goal:

1. To put Cayman Turtle Farm Tag Recovery data in ArcView format
2. To incorporate sea turtle distribution information with oceanographic data to better understand the spatial relationship between turtle distribution and ocean environments

Goal 2: To improve the scientific basis for reserve selection and design theory and practice in the marine environment. This involves exploring the elements of

a framework for systematic marine protected area network design. The following objectives relate to this goal:

1. To synthesize data from a variety of sources and store them in one consolidated database, with the same format
2. To use the above consolidated database to devise an objective method for identifying areas of high conservation value (conservation priorities)
3. To use spatial analysis to characterize broad-scale ecological processes and the relationship between key areas and focal species

CHAPTER 2. BACKGROUND

Spatial scales of ocean management

It is widely acknowledged that, due to the hierarchical organization of ecosystems, marine conservation and management strategies must be developed at multiple scales, depending on the goals being pursued. The first step to be taken in working towards developing efficient, hierarchically-nested management plans is therefore to clearly identify the scale to be targeted by a given plan, as well as the extent of the area to be affected by the policy (i.e., its boundaries). Once this is accomplished, specific objectives suitable for the target scale may be articulated. One of the purposes of this chapter is to define the geographical scope as well as set a geographical context within which this study must be understood.

Biogeographers generally agree that the appropriate framework for the development of regional ocean management schemes is at the Large Marine Ecosystem (LME) level (Sherman and Alexander 1986, Morgan 1987, Sherman *et al.* 1990, Alexander 1993). LMEs are defined as “extensive aggregates of fish populations which are linked together in predator-prey relationships” (Alexander 1993, p.186). From a broader perspective, they can be described as internally-homogeneous entities whose internal fluxes are much higher than their exchanges with adjacent entities (Pauly 1998). They comprise regions of the ocean encompassing coastal areas from river basins and estuaries to the seaward boundary of continental shelves and the outer margins of coastal

currents. These units are characterized by distinct bathymetry, hydrography, productivity and trophodynamics (Celone and Damon 2001).

In spite of the relative clarity and wide acceptance of the definition, the LME concept is however “rather amorphous” (Pauly 1998, p. 487), due to a lack of a *functional* definition. Pauly further argues that LMEs are best understood if they identify real ecosystems, i.e. entities with identifiable boundaries (Pauly 1998). In order to arrive at this level of understanding it is necessary to study how primary production input into the oceans is turned into output, which in turn requires in-depth understanding of the functioning of foodwebs. LME research is well underway, and 64 of them have already been identified and outlined on maps (see www.edc.uri.edu/lme/ for detailed information). For 33 of the 64 LMEs, studies have been conducted of the principal driving forces affecting changes in biomass yields. They have been peer-reviewed and published in ten volumes (<http://www.lme.noaa.gov>, data accessed).

Now, what is the spatial scale at which MPA networks should be implemented? Noss (1992) argues that designing reserve networks that will maintain long-term viability of populations must be accomplished at a regional scale measured in millions of hectares. A usage assumption underlying this thesis is that, given that it is accepted that LMEs serve the purpose of regional fisheries management, they must also provide the appropriate geographical framework to design ecologically-meaningful reserve networks. Because many biological processes relevant to the sustainability of living marine resources are ecosystem-level processes, which occur over a large spatial scale, marine reserve systems must also be designed with reference to LMEs. Hereafter, when I refer to the “planning region”, “ecoregion”, or any other similar terms, the

concept that is in fact being invoked is the Caribbean Sea Large Marine Ecosystem (CSLME). This is the LME number 12 according to the Large Marine Ecosystem Program (www.edc.uri.edu/lme/, data accessed).

I have purposefully chosen to consider the CSLME as a whole, in spite of its large size, for two principal reasons: firstly, the large spatial distribution of the focal species calls for a scale of work appropriately suited. Secondly, the partitioning of the basin into natural, smaller units (biogeographical provinces, and so on) entails the selection of a more or less subjective set of criteria, choice that in turn requires specific expertise. However, the boundaries of the LME have already been designated and are largely agreed upon.

This is not, however, a trivial assumption. The regional context is an important consideration for marine reserve network design, since changing the scale of the planning region will greatly affect the relative importance of the areas within that region (Aíramé *et al.* 2003). It follows that areas that appear critical at a particular scale of analysis (because they allow for certain large-scale processes to occur) might not be the same areas that appear important when attention is paid to local processes. Choosing the appropriate work scale is therefore vital in the marine environment. According to this, it should be borne in mind that the results presented in this thesis are scale-specific.

The Caribbean Sea Large Marine Ecosystem

The Caribbean Sea Large Marine Ecosystem (CSLME) is represented in Figure 1. This LME is an enclosed tropical sea located in the Western Hemisphere between North and South America. It is bounded by latitudes 26°N on the north

and 8°N on the south, and longitudes 60°W on the east and 88°W on the west. It has an approximate area of 2,000,000 km² and is noted for its many islands, as well as numerous banks and breaking shoals surrounding the basin (Richards and Bohnsack 1990).

One fundamental fact about the Caribbean outlook on maritime issues is the multiplicity of political, economic, social, juridical and cultural (linguistic) patterns interwoven within its general structure. Over 30 separate political entities share this sea basin. In addition, the natural fragmentation of the land along with the past imperial activities contributed to the development of a region with little internal sense of cohesiveness (Anderson 1984).

The Caribbean is comprised of three deep basins: the Venezuelan Basin in the east, the Colombian Basin, which is partially separated by a ridge from it; and the Yucatan Basin, north of the Cayman Trough in the northwest. The Cayman trench defines the plate boundary of the North American and the Caribbean plates (Heyman and Kjerfve 2001). Half of the water area is over 3600 m deep and 75% is over 1800 m. Its maximum depth (7,686 m) occurs in the Cayman trench. Relatively shallow water depths define the rim of the Caribbean basin with the North Atlantic Ocean.

Regional oceanography and ecology

Ocean circulation in the Caribbean Sea (Figure 2) is driven by the easterly and northeasterly trade winds and the North Atlantic gyre and is generally a westward-flowing surface current that sweeps across the whole expanse of the

Figure 1. The Caribbean Sea Large Marine Ecosystem (1. Guadiana Bay, Cuba; 2. Florida Keys, U.S.A.; 3. Gulf of Batabano, Cuba; 4. Sabana Archipelago, Cuba; 5. Cay Sal Bank; 6. Andros Island, Bahamas; 7. Jardines de la Reina Archipelago, Cuba; 8. Jamaica; 9. Dominican Republic; 10. Costa Rica; 11. Nicaragua, 12. Gracias a Dios Cape, Nicaragua).

Figure 2. Sea surface current system in the Caribbean basin (source: <http://oceancurrents.rsmas.miami.edu/caribbean/caribbean.html>).

Caribbean (<http://oceancurrents.rsmas.miami.edu/caribbean/caribbean.html>). Surface currents are in turn dominated by mesoscale eddies, large anti-cyclonic eddies to the north and smaller cyclonic eddies to the south. These eddies have chaotic characteristics and systematically propagate from east to west, squeeze through the lesser Antilles as eddies associated with the Guyana current, reform inside the Caribbean and advect towards the Yucatan channel, which they mostly reach within 12 months (Kjervf *et al.* 2002).

The water column is vertically stratified with little upwelling of deeper water to the surface, except along the north coast of South America. The seasonal mixed layer depth cycles of the northern and southern basins are quite different because of their different current patterns, which are reflected in the topography of the pycnocline (boundary between mixed and stratified layers). In the winter months, the mixed layer goes down to 100 m around Trinidad but only to about 60-70 m along the Central American coast. In the summer, the mixed layer is 50 m deep in the east and slopes upwards to about 30 m near the American coastline (Longhurst 1998).

The stratification keeps nutrient-rich waters locked into the depths and results in clear surface water, very poor in nutrients and phytoplankton, typical of many tropical seas. Almost paradoxically, within this “biological desert” are some of the most productive and diverse ecosystems known in the world: coral reefs, seagrass beds, and mangroves. This is explained by the mechanisms whereby these ecosystems have overcome the critical nutrient limitations of tropical surface waters. The coral reef is able to exist by means of the symbiotic relationship established between the corals and the microscopic algae living within their tissues (*zooxanthellae*), which function as primary producers for

the corals. The mangroves and seagrasses (mostly *Thalassia testudinum*, or turtle grass) exploit the rich nutrient sources that build up in shallow and near-shore areas (Richards and Bohnsack 1990, Ogden and Gladfelter 1983). Mangrove wetlands, seagrass beds and coral reefs dominate the land-sea margin in the Caribbean (Kjervfe *et al.* 2002).

These three systems, individually and as an integrated web, are the basis of the potential yield of shallow water marine resources in the region (Ogden and Gladfelter 1983). The understanding of the numerous inter-linkages among these systems is critical. Mangrove forests and seagrass beds provide sequential filtration of sediment and nutrients from the land to the sea, thereby creating the adequate conditions for the development of coral reefs off shore. Mangrove forests generally benefit from increases in inorganic nutrients; these forests can process sustained inputs of 300 kg of nitrogen and 30 kg of phosphorus annually (Boto and Robertson 1990). By trapping sediments, mangroves defend seagrass beds, which are vulnerable to eutrophication, and maintain clear oligotrophic water for the coral reefs. Unfortunately, the linkages between them also constitute their main source of weakness: mangroves are often the first coastal system to be destroyed. When this happens, plankton blooms in the shallow subtidal zones, light penetration is thus impeded, and epiphytes flourish, covering the grass blades. Grasses then decline and allow nutrients to flow into the reefs, where they stimulate massive algal growths that smother reefs. This is in fact a widespread situation throughout the Caribbean (Kjervfe *et al.* 2002).

Fisheries resources

Fisheries resources in the CSLME consist of near-shore trap and hook-and-line fisheries that are mostly artisanal over the large reef areas, trawl fisheries in selected areas for shrimp and demersal fish where bottom topography is suitable, and pelagic fisheries for tunas, billfish, and flying fish. Extensive fisheries for invertebrates (spiny lobster, conch, and oysters) also exist, with limited fisheries for sea turtles and whales (see Figure 3).

Venezuela alone accounts for approximately half of the total catch of marine fisheries resources, followed by Cuba (Richards and Bonhsack 1990). Since much of the fishing is artisanal, there is probably a substantial amount of unreported catch. When compared with that of the Gulf of Mexico, though, the total catch of the CSLME is relatively low, due to lower productivity and smaller continental shelf size. The only Caribbean area with high productivity is the shelf off Venezuela, which allows an important fishery for large pelagics, especially yellowfin tuna and swordfish (Richards and Bohnsack 1990).

Figure 3. Fisheries total catches for the CSLME over the last 50 years (source: <http://na.nefsc.noaa.gov/lme/text/lme12.htm>)

The green sea turtle as a focal species

The Caribbean basin and the green sea turtle provide an interesting geographic, ecological and geopolitical context in which to situate this study². For a wide variety of reasons, human societies have viewed marine turtle populations as an abundant resource and potential source of wealth (whether spiritual, economic, or both) and have accordingly shown a keen interest in having sustained access to them. Historically, the green turtle has represented the subsistence basis and cultural identity for many Caribbean indigenous communities, among them the Miskito Indians in Nicaragua and Honduras, the Rama in Nicaragua and the Guaymí and San Blas de Kuna in Panama (Nietschmann 1982). At the same time, this species has also been subjected to massive exploitation for meat supply by European explorers and settlers, beginning as early as the mid-1600s (King 1982).

Turtles were caught by the thousand to provision European fleets. Exploitation pressure was such that by the end of the 1800s, the Cayman Island nesting population, which is considered by some (King 1982) to have been the largest sea turtle rookery in the Caribbean, had already been virtually depleted (Aiken *et al.* 2001). As the population disappeared, the fishery moved first to the coast of Cuba and then to Nicaragua, while simultaneously expanding target markets and eventually reaching international markets.

² N. Doubleday's presentation in the Conservation, Biodiversity and Culture seminar held in the Department of Geography and Environmental Studies (Carleton University, Ottawa, Canada), in 2000.

Intensive commercial exploitation of green turtles for export markets carried on until 1977, when the 1973 Convention of International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the 1973 U.S. Endangered Species Legislation put an end to this fishery. However, subsistence turtle hunting and regional market-oriented exploitation activities continue to take place in some parts of the Caribbean. Some indigenous communities are in fact still culturally and nutritionally dependent upon green turtles (Nietschmann 1982).

As a result, the Caribbean green turtle has become the target of major conservation efforts, pioneered by Archie Carr very early on (see for example Carr *et al.* 1978). Presently, the green sea turtle is included in Appendix I of CITES (species threatened with extinction) and in the International Union for Conservation of Nature (IUCN) Red List as an endangered species. In addition, it is classified as threatened under the U.S. Endangered Species Act.

This species, in the Caribbean basin but also elsewhere in the world, is the focus of innumerable conservation programs, of varying degrees of effectiveness. Factors involved in turtle conservation are varied and complex. Shrimp fishing is often cited as the primary threat to the survival of sea turtles due to entanglement in nets (Committee on Sea Turtle Conservation 1990). Other primary non-natural sources of mortality include habitat destruction due to development in and around nesting habitats, poaching and predation of hatchlings, illegal harvesting and trading of sea turtles and their eggs, dredging of shipping channels, collisions with ships and boats, and oil-rig removal or other underwater explosions (Committee on Sea Turtle Conservation 1990).

The variety of threatening factors is such that they affect all life-cycle stages (hatchlings, juveniles and adults), and both sexes, whether on the beach during nesting or in inshore and offshore waters. Undoubtedly, the extensiveness of the home range of such migratory species as the sea turtle does not make it any easier to put in place adequate conservation strategies.

Some notable efforts are, however, being made. The State of Sabah, in Malaysia, has recently entered into a bilateral conservation and management agreement with the neighbouring Philippines to establish the Turtle Islands Heritage Protected Area. By this newly-established transboundary protected area, they expect to protect not only marine turtles, but also the coral reefs, the seagrass beds, and all other marine ecosystems co-occurring with them, as well as the commercial fisheries. The Sabah-Philippines Turtle Islands Heritage Protected Area represents the world's first attempt to take turtle conservation across international boundaries in an entirely marine context, and it uses the sea turtle geographic distribution as its foundation.³ There is also a proposal for a transboundary protected area between Mozambique and KwaZulu-Natal in South Africa, which could result in a transfrontier World Heritage site centered on the turtle nesting beaches (Sandwith *et al.* 2001).

Leaving aside the fact that the sea turtle deserves protection efforts that are explicitly intended for it, one may ask whether this particular species is indeed suitable to be the focus of conservation schemes that aim at preserving a wider range of species or ecosystems. If the conservation management scheme in question is a network of marine protected areas, we can re-formulate the

³ARBEC Review of Biodiversity and Environmental Conservation (www.arbec.com.my/sea-turtles)

question posed in Chapter 1 as follows: *Does a selection of a set of MPAs based on the green sea turtle area distribution provide better protection for habitats distinguished by anomalous processes than a set of MPAs established in an opportunistic way?*

In the paragraphs that follow, I outline the ecological and biological features of *C. mydas* that would make it desirable as a focal species, in order to begin to disclose the many intricate elements embedded in the above question. It is key to examine first some aspects of the life cycle and behavioral patterns of *Chelonia mydas* in order to pursue this study.

Juvenile sea turtles spend their early life floating passively in currents near the surface and feeding on pelagic food that accumulates in drift lines (Carr and Meylan 1980). This pelagic phase of the life history can last for many years. The young turtles are carried away hundreds or even thousands of kilometers from their departure point and are distributed by current systems over thousands of square kilometers of open ocean. Eventually, older juveniles settle into a more sedentary, bottom-dwelling lifestyle in shallow-water feeding areas. At that stage of the life cycle, *Chelonia mydas* becomes a folivore species: 90% of its diet comprises seagrass leaves, an abundant and uniformly distributed resource (Pough *et al.* 1998).

Sexual maturity may be reached at 8 or 9 years of age (Márquez *et al.* 1982), or as late as at 15-20 (Witham 1980). In some cases, 30-40 years (Carr *et al.* 1980) are necessary for complete development. Once they reach sexual maturity, sea turtles (both males and females) travel several thousand kilometers to get back from the feeding grounds to their nesting beaches

(Meyland 1982). Turtle biologists have pointed out the incredible precision with which females can actually return to breed to the same beach where they hatched (Carr *et al.* 1978). This feature (known as natal philopatry) enhances the genetic differentiation among breeding populations, even when they share feeding grounds.

Green turtles can nest two or more times up to a maximum of five and this they may do in consecutive years, although only rarely, or at 2, 3, 4 or more year intervals. However, turtles that are tagged and depart the nesting beaches as single-time nesters, never to be seen again, far exceed those returning as remigrants. It is therefore uncertain what is the proportion of sea turtles that nests in more than one season (Hughes 1982).

In summary, two concepts must be clearly understood: the term “dispersal” refers to one-way movement between habitat patches. For the green sea turtle, dispersal occurs passively and is facilitated by ocean currents (Witham 1976, Carr and Meylan 1980). In contrast, “migration” is considered bi-directional (Dingle 1996). Not only does it take place in an active manner, but it may also be made against prevailing currents (Meylan 1982). In the case of sea turtles, “migration” is the bi-directional active movement that links foraging grounds to nesting habitat.

Sea turtles as space and time integrators

Migratory species, by using more than one type of habitat throughout the span of their life, are a critical linking element between habitat patches. Because they connect areas to one another through their traveling activities, they support

essential ecosystem functions. They also play a substantial role in shaping the structure of the ecosystem by influencing the species composition of different habitat types. The importance of their role, in both quantitative and qualitative terms, is only beginning to be thoroughly examined.

When looked at from a functional perspective, these organisms have been characterized in different ways. Lundberg and Jonzén (2003) refer to them as mobile links and point out their role as ecosystem resilience enhancers. They build up ecosystem resilience by taking part in a number of ecosystem processes, such as pollination, seed dispersal, translocation of nutrients and grazing.

Ecosystem resilience is a measure of the capacity of a system to adjust itself to changing environmental conditions. It is defined as the amount of disturbance that can be absorbed before the system shifts from one stable state to another. It entails not only the capacity to reorganize and reestablish following disturbance, but also the ability of the system to renew itself through its maintenance of a diversity of options for development and evolution (Holling *et al.* 1995). Resilience is highly dependent on the ecological memory of the system. The ecological memory of a given system (surviving organisms, organic materials, and the availability of assemblages of plants and animals outside the disturbed area that act as sources for its recolonization) will determine which particular pathway the system will follow after disturbance. Therefore, the ecological memory of the system influences the characteristics of the new stability domain to be reached. The greater the variability, the more the options, and the easier it is to regain stability. Mobile links are an important element of

ecological memory, as they bring in nutrients and energy, genetic material, or even other organisms.

According to Lundberg and Jonzén's (2003) classification scheme, sea turtles would be considered trophic process linkers. This category includes organisms that play a role in food webs across habitats. As outsider grazers, they play a substantial role in influencing plant species composition, biomass, productivity, and nutrient cycling. Sea turtles in fact contribute to seagrass bed productivity due to their characteristic foraging adaptation to improve efficiency in the utilization of their food resource. It is documented that the green turtle maintains grazing plots, by consistently re-grazing specific areas. The regrowth in these plots provides higher quality seagrass blades, with higher content of nitrogen (Bjorndal 1980). Further, the fact that sea turtles are among the very few organisms that graze on *Thalassia* (Bjorndal 1985) emphasizes the relative importance of their role in maintaining seagrass bed structure and function.

Another functions-based interpretation of large migratory organisms is that implied in the notion of space integration, which expands the cross-habitat process linkers concept. Apollonio (2002) calls them space integrators. He underscores their role in reducing inequalities of the amounts of resources available in different regions. He points out that large migrators move along gradients of resource availability, linking areas of low productivity to areas of high productivity. The reader is strongly recommended to refer to S. Apollonio's (2002) "Hierarchical perspectives on marine complexities" for an enlightening and stimulating discussion on whales as time and space integrators in the Gulf of Maine. A number of his insights are highly relevant to this thesis, as will become evident throughout this discussion.

Integration occurs across space, but also across time. Time integration refers to the translocation of the energy of today into the future in the form of long-lived species. Because large migrators are also long-lived species, they tend to occupy higher levels in the ecosystem hierarchy. They operate in large spatial scales and long time frames, thereby placing constraints on lower level ecosystem processes. This translates into inducement of stability. The maintenance of constraints keeps processes working within acceptable degrees of variability (low fluctuations). In a manner of speaking, they keep things in place. The presence of time and space integrators is a sign of maturity in the system; these species slow down the flow of energy, retain and recycle nutrients, constrain dynamics of their system, increase self-organization, and build stability into their systems.

Sea turtles as indicators of ecosystem processes

Whether looked at from the resilience or the integration point of view, the major practical implication of ensuring that these roles are being performed in the ecosystem is that stability is induced. The greater the stability of the system, the greater our capacity to make predictions, which in turn translates into easier manageability. Placing conservation efforts on species that perform these functions will reward us with the reduction of uncertainty and the capacity to develop better-suited management plans for our fisheries, or other resources.

In this context, I argue that species (and by extension species populations) must be thought of as indicators of ecosystem processes. The fact that hundreds of female green sea turtles make landfall on the nesting beaches year after year during the nesting season is essentially an indication that things

are working properly. Hierarchy Theory, once more, provides us with a powerful perspective from which to look at this. If the green sea turtle occupies level A in the hierarchy, the statement “things are working properly” means, on one hand, that whoever (or whatever) occupies level A+1 is successfully placing a constraint on turtle population growth, keeping it within the environmental carrying capacity’s limits. This is an important point, to which I will return later.

On the other hand, the above statement also means that the turtle populations (again, level A), are successfully performing the functions described above and therefore constraining process rates operating in levels A-1 and all the next levels down the hierarchy. Who (or what) constrains turtle population growth and who (or what) turtle populations put a constraint on are both important questions. However, our level of understanding of how ecosystems work and focal species’ roles is, as of yet, relatively poor. It will take a fair bit of speculation and creativity, but I will attempt to put forward in this thesis a number of ideas, and from there develop the conceptual framework necessary to use focal species when trying to emphasize ecosystem processes.

The Caribbean Basin’s currently-existing MPA network: an overview

One of the goals of this project is to create a tool that allows the assessment of the layout of the currently-existing MPA network (see Chapter 1). It could be argued that because the existing MPAs in the Caribbean basin have been established on an opportunistic basis, therefore neglecting ecosystem processes, there are limitations in attempting an evaluation of its

appropriateness. It would follow that creating a tool to design an MPA system “from scratch” would be a more sensible project objective. The assumption underlying the choice of taking the current MPAs into account is that an opportunistic network of marine reserves and MPAs is better than nothing at all (Stewart and Possingham 2002). Therefore, existing MPAs in the Caribbean basin constitute one of the data layers of this project.

Basic concepts and key definitions

As a logical starting point, an overview of the wider Caribbean region marine reserves and other types of MPAs follows. Based on Lubchenco *et al.* (2003), in Box 1 are the definitions of marine reserve, marine protected area and marine protected area network. Marine reserves feature a greater degree of restriction, and hence protection, than MPAs. Accordingly, MPAs permit a greater number of activities to take place within them. However, the term “MPA” is used in a broad sense, and includes all different types of marine protected areas, including marine reserves.

Box 1. Key definitions (source: Lubchenco *et al.* 2003)

Marine Reserve: areas of the ocean completely protected from all extractive and destructive activities.

Marine Protected Area: areas of the ocean designated to enhance conservation of marine resources.

MPA/marine reserve network: a network of MPAs/marine reserves within a biogeographic region, connected by larval dispersal and juvenile or adult migration.

In the Caribbean Sea, MPAs are inserted in a complex geopolitical mosaic, whose design is a result of diverse political and historical factors that

operated within the framework of the Law of the Sea Convention. However, the necessity to coordinate efforts aiming at fisheries resource management and marine conservation is acknowledged. MPAs in the wider Caribbean region have been declared in virtue of the Protocol Concerning Specially Protected Areas and Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region, adopted at Kingston on 18 January 1990.

The protocol provided a legal framework for the establishment of MPAs in the Caribbean region. However, a third of the MPAs in the Caribbean Sea were created before 1990 (see Appendix 1). This is a sign that the marine protected area concept is a familiar one in the Caribbean.

Box 2. Article 4 of the Protocol Concerning Specially Protected Areas and Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region

Article 4. Establishment of protected areas

Each Party shall, when necessary, establish protected areas in areas over which it exercises sovereignty, or sovereign rights or jurisdiction, with a view to sustaining the natural resources of the Wider Caribbean Region, and encouraging ecologically sound and appropriate use, understanding and enjoyment of these areas, in accordance with the objectives and characteristics of each of them.

Such areas shall be established in order to conserve, maintain and restore, in particular:

- representative types of coastal and marine ecosystems of adequate size to ensure their long-term viability and to maintain biological and genetic diversity;
- habitats and their associated ecosystems critical to the survival and recovery of endangered, threatened or endemic species of flora or fauna;
- the productivity of ecosystems and natural resources that provide economic or social benefits and upon which the welfare of local inhabitants is dependent; and areas of special biological, ecological, educational, scientific, historic, cultural, recreational, archaeological, aesthetic, or economic value, including in particular, areas whose ecological and biological processes are essential to the functioning of the Wider Caribbean ecosystems.

Compilation of a Caribbean Basin MPA database

A comprehensive MPA database was created in order to bring together in a systematic and organized manner all available information regarding MPAs in the wider Caribbean Region. The departure MPA list was the one originally put together by M. Mascia (1997), posted on the Island Resources Foundation website (<http://www.irf.org/irmascia.html>). This list however turned out to be far from complete and did not include location information; it was nonetheless a

useful document, with extensive contact information for the different protected area administration institutions.

From there, an initial database was built, displaying for each record the following information (when available): country, MPA name and category (according to the IUCN classification system), geographic location, date of establishment, size in hectares, institution responsible for its management, land tenure, and management constraints. The data were mostly taken from the global on-line databases made available by the World Conservation Monitoring Centre: the UNEP-WCMC Protected Area and Marine databases (available at <http://www.unep-wcmc.org>), in which the protected area summary information was last updated in 2002.

From this initial database, a subset was extracted, of the following format: Country, MPA name, geographic coordinates of central point, IUCN category, year of establishment, and size. Here, blank fields were filled in on an individual basis as thoroughly as possible, through extensive and time-consuming Internet-based research. Also, numerous new records had to be added, as the MPA list of the initial database turned out to be incomplete. This was done through cross-checking with one additional on-line database (the ReefBase Marine Protected Area Database, <http://www.reefbase.org>; Oliver and Noordeloos 2002) and the use of several other on-line sources. The geographic coordinates of the protected areas that did not appear in either database (i.e., WCMC or ReefBase) were looked up by their name in the Online Global Gazetteer available from <http://www.calle.com/world/index.html> (last updated in 2001). As a result, the coordinates of a number of protected areas do not

correspond to the middle point of the MPA, but to the town whose name it bears. The resulting data table is included in Appendix 1.

In order to suit the objectives of this study, and also due to scale restrictions, I chose to leave out a number of protected area types, whose conservation objectives (as inferred by the generic protected area name) did not relate directly with living marine resource management, or whose protection status was unclear. Thus, areas such Flora Reserves, Hunting Reserves, Protected Landscapes/Biotopes, Historic Sites, Natural/National Monuments, Game Reserves/Sanctuaries, Natural Landmarks, Recreation Areas, and Bird Reserves/Sanctuaries, were excluded from my MPA database. This represented less than 10 % of the total amount of MPAs in the region.

The included protected area generic types comprise the following: (Marine) National Park or Marine Park, Natural Park, Park Reserve, Land and Sea (National) Park, Marine Reserve, Natural/Nature Reserve, Replenishment Zone, Marine (or Animal) Sanctuary, Fauna and Flora Sanctuaries, (National) Wildlife Refuge, Biological Reserve, Ecological Reserve, Biosphere Reserve, Protected Area of Managed Resources, (Integrated) Management Area, Scientific Reserve, Underwater Park, Fisheries Sanctuary, Marine Refuge, Reserve Zone for Sea Turtle Protection, Research Reserve, and National Seashore.

Because the Caribbean Sea is a basin shared by over thirty political entities, the variety of protected area types is enormous. The IUCN protected area classification system can be used as a method to standardize the categories found, which enables between-country comparisons. The IUCN categories are defined and described in the "Guidelines for Protected Area Management Categories" (IUCN 1994), put together by the Commission on

National Parks and Protected Areas of the World Conservation Union (IUCN). This document intended to aid in reducing the confusion that had arisen from the adoption of many different terms to describe different kinds of protected areas and provided a framework for the collection, handling and dissemination of data about protected areas.

Box 3 shows the IUCN category definitions.

Box 3. IUCN protected area categories definitions (IUCN 1994)

Ia.- Strict Nature Reserve: protected area managed mainly for science. **Definition:** Area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.

Ib.- Wilderness Area: protected area managed mainly for wilderness protection. **Definition:** Large area of unmodified or slightly modified land, and/or sea, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.

II.- National Park: protected area managed mainly for ecosystem protection and recreation. **Definition:** Natural area of land and/or sea, designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.

III.- Natural Monument: protected area managed mainly for conservation of specific natural features. **Definition:** Area containing one, or more, specific natural or natural/cultural feature which is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities or cultural significance.

IV.- Habitat/Species Management Area: protected area managed mainly for conservation through management intervention. **Definition:** Area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species.

V.- Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation. **Definition:** Area of land, with coast and sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.

VI.- Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems. **Definition:** Area containing predominantly unmodified natural systems, managed to ensure long term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs.

Marine reserves should usually be classified as category IV, whereas the term marine protected area is broader and may refer to any of the other categories. Unfortunately, the degree of confusion is so high on this point that there exists discrepancy even among the IUCN categories. I have attempted to summarize the different MPA types that, according to the sources consulted, fall under the IUCN categories. Some generic types of protected area only appear *occasionally* in certain IUCN categories, making it a little easier to find some consistency. Table 1 displays the types of protected areas, as well as the IUCN category that they have been assigned, that can be found in the Caribbean basin.

Table 1. Caribbean Basin's MPA classes and their IUCN categories. Ia.: Strict Nature Reserve; Ib.: Wilderness Area; II.: National Park; III.: Natural Monument; IV.: Habitat/Species Management Area; V.: Protected Landscape/Seascape; VI.: Managed Resource Protected Area; ?: Represents records whose IUCN category was unknown.

PROTECTED AREA CATEGORY	IA	IB	II	III	IV	V	VI	?	TOTAL
Animal Sanctuary					1				1
Biological Marine Reserve	1								1
Biological Reserve					1			1	2
Biosphere Reserve	1					1		1	3
Biosphere Reserve (National)									2
Biosphere Reserve (Special)					2	2	2		4
Ecological Reserve					3				3
Ecological Zone		1							1
Fauna and Flora Sanctuary	2								2
Fisheries Sanctuary					1				1
Flora and Fauna Protection Area					2				2
Integrated Management Area						5			5
Land and Sea National Park			3		3				6
Management Area								1	1
Marine Management Area							1		1

Marine National Park			11		2				13
Marine Park	1		12		1			5	19
Marine Park (National)									2
Marine Refuge					1				1
Marine Reserve			2		33	1		1	37
Marine Sanctuary					1				1
Marine Sanctuary (National)					3	2			5
National Estuarine Research Reserve					1				1
National Park			46	1	1	1	1		50
National Seashore						3			3
Natural National Park			5						5
Natural Park						3		3	6
Natural/Nature Reserve	2				15				17
Park Reserve					2				2
Protected Area			1	1		1			3
Protected Area of Managed Resources						2			2
Protected Biotope									1
Replenishment Zone					12				12
Reserve Zone for Sea Turtle Protection					3				3
Sanctuary					4				4
Scientific Reserve				1			1		2
State Park						1			1
State Reserve								1	1
Underwater Park			1					1	2
Wildlife Refuge	1				19			1	21
Wildlife Refuge (National)		1			10				11
Wildlife Reserve	1				18				19
TOTAL	9	2	81	3	139	22	5	15	

It is important to highlight from Table 1 that the most popular protection figure in the Caribbean is the National Park, of which there are a total of 50. While the totals of IUCN categories are less reliable, due to the lack of

information, there seems to be more MPAs classified as IV (Habitat/Species Management Area, including marine reserves) than any other.

Characterization of the Caribbean region MPAs

A total number of 322 marine protected areas have been found for the wider Caribbean region. Nearly all MPAs lay nearshore or are coastal (including a terrestrial component). As a result, coral reefs, mangrove forests, and seagrass beds are extensively represented, particularly the former of the three. In many cases, marine parks comprising mangrove forests also include beds of *Thalassia testudinum*. A number of MPAs explicitly acknowledge their importance to several species of marine turtles, whether because they comprise nesting beaches or foraging grounds: Conception Island National Land and Sea Park, and Union Creek Managed Nature Reserve, Bahamas; Parque Nacional Natural Corales del Rosario y San Bernardo, and Parque Nacional Natural Tayrona, Colombia; Parque Nacional Cahuita, and Parque Nacional Tortuguero, Costa Rica; Parque Nacional Del Este, Dominican Republic; Sandy Bay Marine Reserve, Honduras; Sian Ka'an National Biosphere Reserve, Mexico; Portobelo National Park, Panama; Wia-Wia Nature Reserve, and Galibi Nature Reserve, Surinam; Key West National Wildlife Refuge, and Key Largo Coral Reef National Marine Sanctuary, U.S.; U.S. Virgin Islands National Park; and Refugio de Fauna Isla de Aves, Venezuela (for location coordinates see Appendix 1).

An outlook at their management programs reveals that most MPAs have a three-fold purpose: (1) enhancement of the tourism product and recreational opportunities, (2) conservation of critical ecosystems, and (3) sustainable and equitable use of coastal resources. MPAs appear to be seen as being at once

attractions, refuges, and sources of socio-economic development (Geoghegan *et al.* 2001). However, less than half have more than a low level of management, with barely some activities in place, objectives unstated or not addressed, and insufficient resources (Geoghegan *et al.* 2001). Not surprisingly, the major conflicts occurring within MPAs are between fisheries and tourism industries, specifically between fishers and divers, who are interested in using the same resources for different purposes.

A remarkably wide range of protected area institutional arrangements is represented in the region, with the trend over time being towards increasing complexity and involvement of non-governmental actors. Most MPAs that have been in operation for twenty years or more are managed either by a government agency (usually a fisheries administration) or a National Trust established by the government. Many MPAs established more recently have tried more complex forms of management, including delegation to NGOs, co-management with NGOs, and management consortia. Three countries have protected areas managed by private organizations: the Bahamas, the Netherlands Antilles, and some MPAs in Belize. The number of management institutions encountered throughout the Caribbean region is a direct result of the political partitioning of the Caribbean Sea. A summary of the entities responsible for the administration and management, or involved in it in some way, is included below.

Table 2. Countries and institutions involved in the administration and management of the Caribbean Basin MPAs

COUNTRIES	INSTITUTIONS
Antigua and Barbuda	<ul style="list-style-type: none"> - Fisheries Department (Ministry of Agriculture, Lands and Fisheries) - National Park Authority
Bahamas	Bahamas National Trust
Barbados	Unknown
Belize	Unknown
Cayman Islands	Department of the Environment
Colombia	UAESPNN/INDERENA
Costa Rica	Servicio de Parques Nacionales (Ministerio de Agricultura y Ganadería)
Cuba	<ul style="list-style-type: none"> - Centro Nacional de Áreas Protegidas - Plan Baconao Esfera de Áreas Protegidas
Dominica	Fisheries Division (Ministry of Agriculture and the Environment)
Dominican Republic	<ul style="list-style-type: none"> - Dirección Nacional de Parques - FUNDEMAR
Grenada	National Park Authority
Guadeloupe	Unknown
Guatemala	<ul style="list-style-type: none"> - Centro de Estudios Conservacionistas (CECON) - Dirección General de Bosques y Vida Silvestre (DIGEBOS)
Honduras	<ul style="list-style-type: none"> - Administración Forestal del Estado - Corporación Hondureña de Desarrollo Forestal AFE-COHDEFOR - BICA-Guanaja - Mopawi - Bay Islands Conservation Association - Fundación Cuero y Salado (FUCSA) - Fundación PROLANSATE
Jamaica	<ul style="list-style-type: none"> - Montego Bay Marine Park - Fisheries Division (Ministry of Agriculture) - Coastal Zone Management Unit (Natural Resources Conservation Authority) - Negril Coral Reef Preservation Society - PAMP-CC PEPA - South Coast Conservation Foundation
Martinique	Martinique National Park

Mexico	<ul style="list-style-type: none"> - Arrecifes de Cozumel Marine National Park - Comisión Nacional de Áreas Protegidas (Secretaría de Medio Ambiente, Recursos Naturales y Pesca SEMARNAP) - Subdelegación de Medio Ambiente-Campeche - Biocenosis
Netherlands Antilles	Unknown
Nicaragua	Ministerio de Recursos Naturales y del Ambiente MARENA
Panama	Dirección de Areas Protegidas y Vida Silvestre (Instituto Nacional de Recursos Naturales Renovables)
Puerto Rico	<ul style="list-style-type: none"> - Programa de Manejo de la Zona Costanera de Puerto Rico PMZCOR (Departamento de Recursos Naturales) - Jobos Bay National Estuarine Research Reserve - Culebra National Wildlife Refuge
St. Lucia	<ul style="list-style-type: none"> - Soufrière Marine Management Association - Department of Fisheries (Ministry of Agriculture, Lands, Forestry and Fisheries)
St. Vincent and the Grenadines	Fisheries Division (Ministry of Agriculture)
Suriname	Nature Conservation Division (Surinam Forest Service, Ministry of Natural Resources)
Trinidad and Tobago	<ul style="list-style-type: none"> - Botanic Station - Wildlife Division (Ministry of Agriculture, Land and Marine Resources)
Turks and Caicos Islands	Department of Environment and Coastal Resources
USA	<ul style="list-style-type: none"> - Division of Resource Management (Florida Department of Natural Resources) - Office of Coastal Zone Management (National Oceanic and Atmospheric Administrations NOAA) - Canaveral National Seashore Headquarters - National Park Service - Several park-specific organizations
Venezuela	<ul style="list-style-type: none"> - Instituto Nacional de Parques - P.N. Morrocoy; Tucacas, Frente al Comando de la F.A.C. Edo. Falcón - San Esteban National Park - Medanos de Coro National Park
Virgin Islands (British)	BVI National Park Trust (Ministry of Natural Resources)
Virgin Islands (US)	U.S. Virgin Islands National Park

There is little information available to correlate level of management with management effectiveness in terms of achievement of objectives, particularly the conservation-related ones. Van't Hof (1992) reports that half of the protected areas in the Caribbean present a wide range of disturbances, which have led to degradation of the resources. The result is that about three fourths of the Caribbean coastal and marine protected areas are not fulfilling their functions in protecting vital ecosystems or wildlife habitat, providing for sustainable use of resources, or for recreational opportunities and public education.

Regarding fisheries resources, J. Bonhsack (1998b, 1999) has proposed that they can be best maintained by creating marine fishery reserves, which offer a potential way to manage reef fish fisheries by protecting species composition, population age structure, spawning potential, and intraspecific genetic variability. Reserves will insure against recruitment failure due to environmental variability. However, if the marine reserve network currently in place were appropriately designed and thus efficiently enhancing fish stocks, fisheries catch figures would probably show a more steady trend than that shown in Figure 2. Can this system be improved? In the following chapter this question is addressed more closely.

CHAPTER 3. OVERVIEW OF THEORIES AND METHODS

Principles and methods for reserve network design

A critical lesson learned from conservation biology, which has largely driven the rapid evolution of conservation planning science, is that ecological processes, as well as species diversity, are distributed neither homogeneously nor randomly on the face of the earth. It follows, then, that adequate conservation networks must be designed on the basis of spatially explicit quantitative and qualitative data (Sala *et al.* 2001). In other words, conservation planning is inherently a map-based science. Conservation biologists are thus committed to the task of assessing spatial information in order to identify adequate arrays of areas to be set aside to the purpose of accomplishing conservation-related goals. The objective of this section is to review the methods for reserve network design that are being applied worldwide in the context of their historical evolution, as well as to identify their strengths and weaknesses, in order to set out the basic attributes of the framework developed here. I present some of the problems conservation planners are faced with and review the tools and techniques being used to overcome these.

The methods used for the design of conservation area networks are highly dependent on the goals and objectives that the network in question is being designed to accomplish. The objectives that reserve networks are expected to fulfill will vary depending on the characteristics of the ecoregion at hand. However, the broadly-accepted, most inclusive set of goals that a conservation network should aim at are the following: (1) to represent all kinds of ecosystems

across their natural range of variation, (2) to maintain viable populations of all native species in their natural patterns of distribution and abundance, (3) to sustain ecological and evolutionary processes, and (4) to maintain a conservation network that is resilient to environmental change (Noss and Cooperrinder 1994, Noss *et al.* 1999). Note that the two former points relate to preserving species diversity, or species assemblages, and the two latter points refer to the maintenance of ecological processes.

These general goals may be broken down into multiple specific objectives; the above four categories, however, are the ones that place the main restrictions on reserve networks and therefore determine to a large extent the methodological approach to be employed in their design. As I will show, attempts to place the focus on species/diversity-related goals, and processes-related goals at the same time may translate in conflicting objectives; this proves the point that a framework to reconcile these two apparently incompatible approaches is needed.

The process of selecting adequate conservation areas whose interaction will effectively lead to the success of the network presents a number of tricky issues: which habitat types should be included in the conservation network, in which locations (or how far apart should they be), which size should they be, how much total area should they cover. The first principles and guidelines to be applied to reserve selection and design practice emerged from Island Biogeography Theory, as was explained in Chapter 1. The still-prevailing (and less controversial) ones are the following: (1) larger reserves are better than smaller reserves (2), and spatially contiguous reserves are *generally* better than

highly fragmented systems (Stewart and Possingham 2002, McDonnell *et al.* 2002, Noss *et al.* 1997, Soulé and Simberloff 1986).

Unfortunately, it is not straightforward to put these principles into practice. The controversy in many cases rests on where to draw the line between what constitutes an efficient reserve and what does not. For example the reserve size must be big enough to allow for long term viability of populations and communities, but small enough to minimize the loss of revenue and economic impacts (Airamé 2003). In addition, frequent or highly localized catastrophes call for reserves that are far apart from each other rather than clustered together, to ensure that at least a portion of the system will remain intact after the disturbance (McDonnell *et al.* 2002, Allison *et al.* 2003). The size, number, and spacing of the reserves within a network continues to be a critical issue due to the trade-offs that stem from the interrelationships among the three. Attempts to develop theoretical principles that will provide a universally-applicable solution have consistently failed. Research has only led to the conclusion that these issues can only be addressed on a case-by-case basis.

In regards to the actual contents of the reserve system, authors agree that it should encompass, at least, those habitats that are representative of the biogeographic provinces they belong to, as well as those elements or habitats that are unique in the planning region. Interestingly, the relative importance given to habitats that harbour species of special concern, or focal species, varies greatly among authors (see for example Noss 1990, Noss *et al.* 1999, Roff and Evans 2002, Rangeley *et al.* 2003, Airamé *et al.* 2003, Roberts *et al.* 2003). It is in any case self-evident that attention is overwhelmingly focused on

habitats, despite the fact that it is widely acknowledged that a systems-oriented approach is preferred over a species diversity approach (Noss *et al.* 1999, Roff and Evans 2002, Roberts *et al.* 2003). Habitats are used as surrogates of conservation-relevant landscape features (such as biodiversity hotspots, for example). The idea of habitat representation is based on the notion that conserving all habitats, the maximum number of species will be represented, including those not used to define the habitats (Margules *et al.* 1988). However, it is more debatable whether key process occurrences will be covered by a reserve system that is designed on the basis of habitat diversity.

It is important to emphasize that reserve design principles have mostly been derived from terrestrial case studies, where the science of conservation planning has already gone a long way. From the time where protected areas were selected on the basis of opportunity and set aside in an effort to remove them from expanding development plans, we appear to be moving toward a more science-based, systematic method of designing reserve systems that accounts for a broad scale analysis of ecological processes and biodiversity distribution. These new methods are allowing researchers and planners to deal with reserve network design issues in a systematic way, and they are therefore gaining more and more reliability.

A remarkable early example of scientific rigor in habitat-based conservation planning is found in Murphy and Noon (1992), where map-based hypotheses were posed and subsequently tested in order to design a scientifically sound conservation strategy for the threatened northern spotted owl. These authors thus developed a hypothetico-deductive method for habitat conservation, based on hypothesis testing and sequential map revision, that is

credible, repeatable and defensible⁴. This exercise is an impeccable application of Minimum Viable Population theory, though highly single-species based and therefore open to criticism for not being likely to protect any additional species other than the northern spotted owl, as well as not addressing process-related objectives.

In land conservation, the tendency nowadays appears to be the merging together of the results at which the three separate mapping tracks mentioned above arrive, when pursued independently. In other words, the newest conservation planning projects propose to include in reserve systems (1) representative elements/habitats, (2) special features, unique elements, or distinctive habitats, and (3) habitat patches occupied by focal species, or species of special conservation concern (see for example the Wildlands Project, in Noss 1992, Noss *et al.* 1999). The question then becomes how to develop an appropriate habitat classification scheme, and how to decide how much of each habitat-type should be protected. Building upon the map-based hypothesis testing approach, several conservation projects are being developed today that, with the aid of GIS, bring into the picture all three mapping tracks simultaneously, in an attempt to arrive at the most comprehensive solution to the reserve selection problem (Noss 1992, Noss and Cooperrinder 1994 and Noss *et al.* 1999).

⁴ Three hypotheses were tested, using field data, in an attempt to demonstrate this species' need for a conservation strategy in the Pacific Northwest: (1) that populations of owls were actually declining, (2) that they are in fact habitat specialists, requiring late-successional forest for population persistence, and (3) that those forest habitats were indeed diminishing in extent. Results from these tests justified a conservation program designed to reverse the decline of this particular species. They also allowed researchers to determine how much habitat was needed and how it should be distributed, in terms of size, shape, and spacing of habitat patches, in order to ensure the persistence of the species (Murphy and Noon 1992).

Two main factors impede us to implement such comprehensive (and idealistic) conservation networks on the ground. Firstly, socioeconomic constraints are an important force. In order to maximize both ecological and economic benefits in the long run, reserve network configurations must minimize short-term economic impacts. This means that even though ideally we would try to accumulate as much area as possible, realistically, this needs to be done as efficiently as possible, as the greater the area, the higher the cost (Possingham *et al.* 2000). The optimal reserve system will represent regional diversity in the least number of available candidate sites (Stewart and Possingham 2002). This has been referred to as the *minimum representation problem* (first defined by Kirkpatrick 1983). Secondly, we also need to incorporate spatial considerations into the reserve network (McDonnell *et al.* 2002). The spatial arrangement of the candidate sites imposes one further limitation to the final reserve selection. Questions like whether a fragmented reserve system is more appropriate than a spatially-cohesive one, or whether a system made up of fewer larger reserves is more suitable than one comprising more reserves of smaller size, will have to be evaluated in light of the ecological and sociological characteristics of the planning region.

In other words, after having overcome the problem of how to select relevant habitat-types that need to be included in the network, the issue becomes how to be efficient, and remove the sites that are not strictly necessary for the network to be fully representative of regional habitat diversity. Efficiency in site selection, however, might not be the most desirable approach toward network design when the network goals to be emphasized relate to preservation of processes and enhancement of resilience. Particularly, networks that intend

to provide room for resilience could never, by definition, do so by using the minimum representation approach.

Science presents us with a number of ways to handle these problems: both cost (as measured by total area) and spatial arrangement (as defined by boundary length) of reserve systems can be optimized by means of decision support software based on site-selection algorithms. Three main packages have insofar been developed and are being applied throughout the world: SPEXAN (Ball and Possingham 1999), MARXAN (Ball and Possingham 2002) and SITES (Andelman *et al.* 1999, Possingham *et al.* 2000).

Ecoregional planning: methods for selecting optimal marine reserve systems

Site-selection algorithms are only beginning to be applied in marine ecoregional planning and marine reserve network design (see references in Table 3), but they have long held a good reputation in the terrestrial systems arena (Kirkpatrick 1983, Margules *et al.* 1988, Bedward *et al.* 1992, Williams *et al.* 1996). They do seem to promise growing usefulness and popularity among marine conservation planners and researchers, as a systematic and strategic method for reserve selection such as this one “maximizes the chances of creating a representative system of reserves and makes the most efficient use of the available resources” (Leslie *et al.* 2003, p. S186). Even though marine conservation science still lags behind land conservation science (Roff and Evans 2002), fresh concepts, techniques and ideas are now coming into play and are helping create the foundation of a conservation science that is robust enough to take account of current conservation problems of the marine environment.

Although algorithms used and factors that can be modified for the sake of optimality vary among all three packages, they share similar basic features and principles. Any one program works on a certain (eco)region that has been divided up into separate planning units, for each and every one of which, spatially-explicit ecological and/or sociological data have been gathered. The program will scan and assess the planning units on an individual basis and return a set of sites, also called conservation portfolio, that collectively represents user-defined targets (amounts of habitat, populations or other features). The adequacy of the final solution not only depends on the program itself, but also, to a large extent, on the adequacy of the input parameters. The more comprehensive and systematic the data collection, the more suitable becomes the use of the software.

This represents indeed the latest trend in marine ecoregional planning and it is being portrayed as an exciting emerging technique in protected area congresses around the world (for example, refer to the Fifth International Science and Management of Protected Areas Association [SAMPAA] Conference proceedings, May 11-16 2003). A summary of the research projects that are using site-selection algorithms in marine systems around the world is presented in Table 3 (based on an excerpt of the database being compiled by H. Leslie [in prep.], available at <http://www.ecology.uq.edu.au/marxan.htm>).

Table 3. Summary of research initiatives in marine ecoregional planning using site-selection algorithms throughout the world

LOCATION	METHODOLOGY	ORGANIZATION	PUBLISHED SOURCE
Florida Keys, USA	SPEXAN 3.1/SITES	Oregon State University	Leslie <i>et al.</i> 2003

Channel Islands, USA	SITES	Cannel Islands National Marine Sanctuary	Airamé <i>et al.</i> 2003
Northern Gulf of Mexico, USA	SITES	The Nature Conservancy	Beck and Odaya 2001
British Columbia, Canada	MARXAN	Living Oceans Society	Ardron <i>et al.</i> 2002
Willamette Valley-Puget Trough-Georgia Basin, USA/Canada	SITES	The Nature Conservancy	Ferdana 2002
Gulf of Mexico, Mexico	SITES	Scripps Institution of Oceanography	Sala <i>et al.</i> 2002
Galapagos Islands, Ecuador	MARXAN	CSIRO Marine Research	Bustamante <i>et al.</i> 2000
South Australia	MARXAN	University of Queensland	Stewart and Possingham 2002
Gulf of Maine and Scotian Shelf	MARXAN	WWF Canada	Rangeley <i>et al.</i> 2003

The method most widely used in marine conservation planning involves the identification and delineation of boundaries of the biogeographic provinces within the planning region (ecoregion) and the subdivision of each of them into the “planning units” or “management units”. In the case of marine systems, this is accomplished by the overlay of a grid that breaks the area down into square (some times hexagonal; Ardron *et al.* 2002), regular sized-cells. The cell size used varies depending on the resolution at which data are being collected, as well as the total area of the planning region. In some instances, two grids (a finer resolution one and a coarser resolution one) are used. Leslie *et al.* (2003) used a 1 km x 1 km-grid, as well as a 10 km x 10 km one, for a total area of 10,000 km². In South Australia, Stewart and Possingham (2002) used a 5-km² grid resolution, in a region that contained 3119 planning units. Rangeley *et al.* (2003) are using a grid measured in degrees, with 10-minute planning units.

The GIS project included in this thesis has been created according to this context. However, the fact that the planning region is extremely large and therefore the resolution relatively coarse will definitely have an impact on the results. To compensate for this, appropriate literature is used. In addition, the various databases that make up the project of this thesis are in principle suitable to be built into a site-selection algorithm. A more detailed description of the datasets used follows.

Hierarchical structure of ecosystems and the spaces and species perspectives in the marine environment

In working towards reconciling the functional and the population-based views of ecosystems, I begin by speculating about what makes the functional approach particularly challenging and why it has been difficult to apply it to real world situations. Ecology as a discipline has traditionally had species, communities and/or populations (as well as the interactions among them) as the object of study, something which, even when boundaries around these concepts may sometimes blur, still has a conspicuous and tangible nature (Weiss 1971 cited in O'Neill *et al.* 1986). In this context, the functional, process-based interpretation of ecosystems emerged as a result of a paradigm shift, which not everyone in the scientific community was willing to adopt. To date, both approaches are still strongly present and theoretical ecologists can be quite clearly classified according to which approach they profess. This dichotomy has also arisen as a major source of debate in the applied ecology and conservation management grounds, as seen in Chapter 1.

One of the identified difficulties in understanding the functional viewpoint of ecosystems, and which helps to explain why it has been so challenging to put it into practice in the form of management strategies, lies in the difficulty to conceptualize the idea of ecosystem processes. These are not discrete entities that can be readily abstracted and thus explored, as are species, or populations. Often, one goes through the literature (not only scientific, but also non-academic literature, legal texts, etc.) and comes across lines pointing out the importance of preserving ecological processes, as well as ecosystem function (see for example Box 2), but very rarely any attempt is made to clarify those concepts. It is frequently assumed that the reader is aware of what they imply. I argue that such concepts, contrarily to concepts such as “species”, “communities” or “populations”, do require further attention and careful clarification of what is meant by them.

I propose that the best way to conceptualize the notion of ecosystem process is by means of examples, and through these, touch on how these processes operate and what factors exert control over them. The purpose of this section is to provide some insight into what types of processes are being looked at in this study, and the characteristics that are being searched for that will best describe the nature of what I have termed *keystone spaces* (see below). This will hopefully bring the spaces and species schools of thought one step closer to orienting themselves in the same direction, so they can be seen as complementary rather than contradictory. This is done by borrowing some elements from Hierarchy Theory.

Remembering that the scale of study has already been established as Caribbean-wide, I will proceed to describe the oceanographical processes that

operate at such a scale, and then touch on the potential constraining mechanisms that they impose upon ecosystem dynamics and their ecological implications.

Processes occurring at the scale of 100-1000 km: mesoscale processes

I have adopted Haury's *et al.* (1978) system of classification of spatial scales. To these authors, a spatial scale of 100 to 1000 km, which is the one I am concerned with in this study, belongs to the "mesoscale" category. Oceanographic processes operating at this mesoscale, and typically, at time scales of 1 month to 1 year (see Haury *et al.* 1978) are responsible for the generation and maintenance of mesoscale patterns related to annual cycles. These are in turn reflected in attributes like phytoplankton patchiness or sea surface temperature spatial distribution. These physical dynamic processes include broad upwelling events and the formation of fronts and eddies.

Upwelling events are induced by wind and they relate to the break-up of the layered density structure of the ocean. Wind blowing across the surface of the sea causes water to begin to move in the same direction. The Coriolis force, resulting from the earth's motion, causes the current to deviate to the right in the northern hemisphere and to the left in the southern hemisphere. After some time, the net movement of the surface water is at right angles to the direction of the wind, a condition known as Ekman transport. When Ekman transport is away from the coast, surface waters moving away from the shore are replaced by deeper, colder water that upwells close to shore. This water is usually nutrient-rich and primary production is stimulated (Mann and Lazier 1996).

Ocean fronts, just like in meteorology, are narrow regions where a given variable (temperature, salinity, density, etc.) presents a sharp gradient, or in other words, horizontal variation is very high. Fronts determine the boundary between ocean masses of very different characteristics. For example, in the coastal upwelling situation described above, upwelled (colder) water arrives at a region where surface water will be pushed no further, so the upwelled water sinks under it. When looked at from a two-dimensional perspective (from overhead), what is detected is that, across that narrow region, surface temperature will increase very quickly as one moves from the upwelled to the stratified water.

The line on the surface of the water that indicates the presence of a front tends to be irregular in shape, rather than straight. These irregularities often evolve into eddies, that twist the cold and warm waters together in a circular fashion. These large bodies of water (200-300 km in diameter) spin off the frontal region into areas of different biological and physical characteristics. Frontal eddies cause water to be exchanged across the front and thereby contribute a significant flux of nutrients. They represent a sort of invasion of one ecosystem by a complex of species from another system where the habitat structure and community composition may be very different (*Haury et al.* 1978). As will become apparent through the unfolding of this thesis, ocean waters must be thought of as mosaics of water masses with different properties.

Relevant constraints on ecosystem functioning

To understand the productivity of continental shelf and open water tropical ecosystems it is necessary to understand the difference between new

production and regenerated production. New production is fueled by physical inputs of nutrients from sources external to the ecosystem. Regenerated production is fueled biologically by recycling of nutrients already accumulated in the ecosystem (Longhurst and Pauly 1987). Depending on whether the water column is vertically stratified or completely mixed, the benthic biota will or will not play a role in the regeneration of nutrients. The extent to which nutrients are regenerated by the benthic community by decomposition of organic material produced in the photic zone above will depend entirely on the density and turbulence structure of the water column; where a two-layer structure exists, with a chlorophyll maximum within the discontinuity layer, benthic regeneration is constrained by the amount of turbulent mixing and eddy diffusion at the discontinuity layer. Where a well-mixed, single-layered water column occurs, the nutrients regenerated by the benthos are available with little delay to the plants in the photic zone. The dynamics between these two regimes determines to what extent continental shelf productivity is enhanced by the continuous recycling of nutrients between benthic and planktonic systems (Longhurst and Pauly 1987).

Regenerated or biologically recycled production can function to slow down the passage of nutrients through an ecosystem (i.e., it puts a constraint on rate of nutrient recycling). This allows the buildup of biomass and diversity, although it must ultimately be fueled by the import of fresh nutrients to replace what are lost. The impact of broad scale oceanographic processes on communities' functioning may thus be enormous, as they are the main drivers of nutrient availability. Which particular pathways nutrients will follow and energy budgets will depend ultimately on the structure and species composition

of the communities embedded in the system. I will consider these issues further in following chapters, in light of the results presented.

CHAPTER 4. DATA AND METHODOLOGY

Data layers: data acquisition and pre-processing

In describing the ecological and biological characteristics of “vague and abstract underwater places” (Morgan and Etnoyer 2002, p. 138), it is realized that data are scarce, inconsistently-available, and of varying quality; considerably more so than is the case for terrestrial systems. Fortunately, GIS researchers have developed analytical proxies that provide the opportunity to substitute known physical variables for unknown biological characteristics. Topographical complexity can substitute for species richness based upon species/area curves (Etnoyer 2001). Sea surface temperature fronts may be used to predict bluefin tuna distributions (Schick 2002), and swordfish distributions (Podestá 1993). Sea surface height strongly correlates with sperm whale sightings (Biggs *et al.* 2000). Scientific experts agreed in a meeting hosted by the Marine Conservation Biology Institute (held in Monterey, California, May 2001) that four basic data types provide sufficient information to evaluate benthic and pelagic habitats as well as to depict broad scale oceanographic processes: bathymetry, sea surface temperature, currents, and primary production (Morgan and Etnoyer 2002).

Further, different combinations of unusual values of these variables result in what Rangeley *et al.* (2003) refer to as Physically Distinct Areas (i.e. areas of extraordinarily high/low primary production, current intensity, and so on). Incidentally, these areas are believed to present a strong correlation with the presence of distinctive habitats (Roff and Evans 2002), although conclusive evidence for this is as of yet scarce. Roff and Evans (2002) suggest that these

spaces can in fact be classified according to the particular combination of temperature, chlorophyll concentration, seafloor topography and current intensity that they feature. They go further and suggest that different combinations of these values have high explanatory value and can in fact be used to predict species diversity. Thus, areas with low temperature and high chlorophyll (such as upwellings) will typically show low diversity but might be of importance for focal species, or areas with varying temperature or chlorophyll values combined with complex topography will normally be associated with high diversity of species.

Highly relevant to this research project is the project that has become dubbed the “B2B Initiative” (see Morgan and Etnoyer 2002, Morgan 2003): the Baja California To Bering Sea Priority Areas Mapping Initiative. L. Morgan and his research team, based at the Marine Conservation Biology Institute (Glen Ellen, California), working in cooperation with the North American Commission for Environmental Cooperation and the Ocean Wilderness Network, are compiling a GIS database of the Pacific Coast of North America that will aid in identifying areas of conservation importance. The broad scale GIS database being developed by this team includes high-resolution bathymetry as the primary dataset, as well as additional satellite-derived data for sea surface currents, temperature and chlorophyll *a*. Their framework aims at describing poorly known areas based on their similarities in bathymetry and remotely-sensed data to areas of better known species diversity and abundance. This process provides the foundation for designing an effective, tri-national system of marine protected areas from Baja California to the Bering Sea.

Implicit throughout this chapter is the idea that the scale of analysis limits to a large extent the data types to be built into the database. When dealing with small geographical areas, increasing levels of detail can be considered, to the point of including fine-resolution habitat data. As one increases the spatial extent of the study area, the possibility of considering broad scale processes is gained at the expense of losing detail. In this research project, I have examined the spatial variation of, and the spatial relationships between, the following variables: seafloor topography (bathymetry), sea surface temperature (SST), and chlorophyll *a* concentration (Chl), as well as occurrence of the focal species (green sea turtle). Accordingly, habitat data (a layer displaying community types) has been excluded.

The potential use of the focal species distribution as a predictor for high conservation value areas is explored. I will attempt to examine these areas in light of the processes that produce them, in search for those that hold the greatest importance in the functioning of the ecosystem as a whole, or in other words, in search for the *keystone spaces*. These keystone spaces are thus defined as spaces whose physical attributes differ significantly from those of the surroundings due to the occurrence of relatively anomalous oceanographic processes.

In the enclosed database, I have also included a layer showing the existing MPAs in the region, as I see is no reason why conservation efforts that have been put in place so far should be neglected (see previous discussion in Chapter 2., "The Caribbean Basin's currently-existing MPA network: an overview".)

Bathymetry

Seafloor topography data were extracted from the National Geophysical Data Center 5-minute Gridded Elevation Data (ETOPO-5), from which elevation/depth data for the wider Caribbean region and Gulf of Mexico was downloaded (<http://www.ngdc.noaa.gov/mgg/global/seltopo.html>). From the downloaded point data file, a new file was created by removing elevation data values (those greater than 0) and leaving out all that fell outside the Caribbean Sea large marine ecosystem (see Figure 1). This resulting file was also made available in GRID format⁵, as some of the analyses could only be performed in raster format. The spacing between datapoints is 5 minutes, or approximately 9 km.

The raw depth data values can be viewed in Figure 4.

⁵ In order not to create confusion between grid files, referring to raster format data layers, and grids, referring to the analysis grids comprising the square planning units, I will refer to the former following the ArcView system, with capital letters (GRID files). Note that the three planning grids are in fact polygon themes.

Raw data sets: bathymetry

Figure 4. Raw bathymetry data

Sea surface temperature

Seasonal averages were calculated from the time period 1985-2001, at 9.28-km cell size, from NOAA polar-orbiters using the AVHRR sensor (AVHRR Ocean Pathfinder Project). The SST seasonal means were computed by first computing all the monthly means between 1985 and 2001, including both daytime and nighttime data. Then, all the “Januaries” (values for January) were averaged to create a January climatological mean, all the “Februaries” averaged to create a February climatological mean, and so on. The January-February-March climatological means were then averaged to create a Season 1 climatological mean, and so on (this part of the processing was carried out in NOAA). This resulted in four ArcView GRID files. Those were made available in point format, and again clipped through the CSLME boundaries.

Figure 5 shows seasonal climatological averages for the Caribbean Sea, for the four seasons.

Raw data sets: average sea surface temperature

Figure 5. Climatological averages: average seasonal sea surface temperature

Chlorophyll a

The datasets have been provided by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project (<http://seawifs.gsfc.nasa.gov/SEAWIFS.html>). “Chl” maps, also known as ocean colour maps, were constructed from the chlorophyll *a* concentration seasonal averages. These average values were calculated from the 9-km cell data taken by SeaWiFS, which covers a 5-year span (1997-2001). The GRID files received the exact same treatment as the SST datasets.

Figure 6. Average seasonal chlorophyll a content

Focal species: tagged turtle recapture data

The Cayman Turtle Farm (CTF) initiated in 1980 a conservation program that included the release of tagged juvenile green sea turtles, produced and raised in the Farm, into the territorial waters of Grand Cayman and Little Cayman. In the period from 1980 through 2000, more than 56,000 turtles were released around the Cayman Islands⁶ (see Figure 1). Many of these have already been recovered in different locations scattered all across the Caribbean region.

For my thesis, I have used this tag return dataset, that is, the returns corresponding to the releases carried out in the last twenty years or so from the Cayman Islands, which was kindly provided by the CTF. The dataset included the geographic coordinates of the locations from where the tagged individuals were released, as well as the date of release. Each record included a return location and date, which allowed me to pair up, for every individual, the site where it was released with the site where it was recaptured (See Appendix 2). For the focal species analysis, though, mainly the recapture location information has been used. This is assumed to give a sense of the extent of the focal species area distribution. A note should be made here that this by no means includes the totality of the Caribbean green sea turtle population, but only a small portion of it. This portion corresponds to the CTF-bred green turtles; arguably, it could be said that this is in reality the Cayman Islands' native nesting population. Whether this is indeed the case falls beyond the objectives of this study, but in any case, it is believed not to affect the analysis presented here.

⁶ Executive Summary of the CTF's application to register a captive breeding operation involving *Chelonia mydas* on Grand Cayman, Cayman Islands, B.W.I., draft document

The individual-based data were summarized and converted into recapture location-based data. Thus, records in the summary table display the number of recaptures taken place at every location. The outcome of this processing was, on one hand, a much more manageable table (which went from over 400 records down to 92), and on the other, a dataset that allowed the project to convey the significance of the recapture locations, in terms of abundance of recaptures, as shown in Figure 7. The original dataset is included in Appendix 2; the summary table is included in Appendix 3.

MPAs

The improved short version of the MPA database constituted the basis of the file that was finally read into ArcView, which portrays the location of the MPAs in the study area. The details of the procedure used have been discussed in Chapter 2.

MPAs were divided into three categories according to size (see below). By assigning MPA location points to grid cells I was able to display MPAs in the form of polygon themes (three in total). Under the assumption that larger MPAs will have a bigger conservation impact, the above procedure enabled portrayal of the MPAs' importance as a colour scheme (as seen in Figure 8, bigger MPAs are shown in darker shades).

Raw data sets: turtle data

Figure 7. Focal species data

Figure 8. MPAs in the CSLME. a) MPAs whose area is greater than 400km²; b) and c) are sample zoom-ins, showing MPAs belonging to the medium size category (b) and the smallest size category (c), that are not displayed in the region-wide map.

Spatial analysis

Preliminary technical considerations

The grid cell size presented a problematic choice. The (extremely broad) scale of study being the main limiting factor to the cell size, two other circumstances imposed further constraints. The cell size of the original data sources was in all cases around 9 km. This means, on the one hand, that the cells could by no means be smaller than that, as no further detail would be gained. On the other hand, in order not to lose any valuable information, or miss important details, a grid cell size had to be determined that included a maximum of two datapoints in any cell (only one in the vast majority of them). The pixel size selected was 10 km.

Another important factor needed to be taken into consideration: the size of the existing marine protected areas. A huge variability in MPA size was encountered in this region: they ranged from 1 hectare to about 1 million hectares. It was decided to divide the whole set of MPAs down into three categories according to area, and then create three hierarchically nested grids to examine each MPA category separately. In this manner, MPA sizes are in the same order of magnitude as the grid cells.

In order to do this, an interpolation was used for those MPAs whose size was unknown (46 out of a total number of 218). The following method was implemented to accomplish this. Because the variability in MPA size was so large, and the values did not follow a normal distribution, the largest MPAs had the effect of pushing the mean area up towards a far too large size. MPA size values that fell within the top 10 % in the range of variation were removed from

the dataset and then the mean size value was re-calculated. I then adjusted this value to what could be a reasonable grid cell size, one that would embody a whole number of the fine-resolution cells. This value was 40,000 hectares (400 km²). The assumption that all these MPAs have an approximate size of 400 km² is more than likely wrong. However, it may be reasonable enough to say that this estimate does not have a strong impact on the total area of all MPAs put together, assuming that many of them will certainly be bigger, and others will be indeed smaller. Additionally, this value was not used in any calculation or analysis. In fact, it was only used to force all MPAs with unknown size into one of the three area categories. I therefore created three grids: a 10 km x 10 km one (100 km²), a 20 km x 20 km (400 km²) one, and finally a 40 km x 40 km (1600 km²) one.

All above datasets were processed in ArcView (version 3.2a) with Spatial Analyst™. The datasets were first projected. This was necessary for the sake of some of the analyses performed, but mainly, so cells throughout the study area had the same area (which would not have been the case, had the cells been laid out on the basis of distances in degrees). I used a cylindrical equal-area projection (Theobald 2000, Earl pers. comm.), which is an area-preserving projection suitable for equatorial regions, and set the standard parallel to be the middle one (17.25°N). The central meridian, automatically calculated by the program, was 74.18°W. The map units were metres.

Some of the files (clipped bathymetry, SST, Chl) were converted back into GRID files, as analyses could only be carried out in raster format. In accordance with the methodology described above, and for the purpose of building a database suitable for site-selection software, cells in all three grids (polygons)

were assigned a value according to each data layer. For the two coarser resolution grids, this value was the average value of all data points that fell within each cell. In the case of the focal species dataset, the sum, as opposed to the average, of all recaptures that occurred within the boundaries of the cell was assigned; when more than one MPA occurred in a cell, the value for that cell was also the sum of the areas.

Several exploratory analyses were performed, in search for the features that reveal key ecological processes or other conservation-relevant areas (keystone spaces). This methodology is in accordance with the framework developed by Rangeley *et al.* (2003), as well as the approach taken by Morgan (2003), and Evans *et al.* (2003). Rangeley and Evans are both involved in research projects aiming at the development of a conceptual framework for an MPA system in the Greater Gulf of Maine and Scotian Shelf. Evans' research is of particular interest, and its outcome, once it becomes available, will likely prove to be complementary to this dissertation. She is trying to determine the proportion of habitat diversity that is not captured by a set of MPAs designed on the basis of focal species distributions, and therefore, testing the suitability of focal species for conservation planning.

The outcome of the analyses performed on the oceanographic data (bathymetry, SST and Chl) corresponds to the identification of Physically Distinct Areas, or areas where important processes occur and where species may aggregate. The focal species analysis results in the identification of Biologically Distinct Areas, or areas that are important for the growth, reproduction or survival of species of concern (the above authors looked at

demersal fish, cetaceans and seabirds). The combination of both is suggested to be an adequate method to arrive at the keystone spaces.

Chl Anomalies

The concept of “anomaly” raised some complications. SST anomaly is usually interpreted as temperature values that are significantly different from the average as compared to other years’ temperatures, at the same location. It refers to interannual variability (see for example Cole and Villacastin 2000). However, in the case of chlorophyll, this term seems to refer rather to regional variability. The research team who is developing this methodology considers anomalous cells those whose Chl values are within the top 10 % of the range of variation of Chl throughout the ecoregion of study, in their case, the Scotian Shelf. Thus, “anomaly” is interpreted as “significantly different” as compared to the *regional* average, at a given point in time. Nonetheless, their methodology accounts for the temporal dimension by using only those cells with *enduring* high Chl, and discarding the others. For this persistency criterion, these authors have chosen a threshold of three years out of five (Larade pers. comm.).

In the case of the Chl dataset used in this project, I limited the analysis to the spatial domain; within-year (seasonal) variability was somewhat accounted for. Seasonal variability was felt more relevant than interannual variability, according to the scope of this project. Remember that the pattern-generating processes that operate at the scale of study (mesoscale) also operate at a temporal scale of months (see above). The methodology used was a means to pinpoint pixels of anomalously high Chl, in at least one season a year.

However, much of the real seasonal variability is already lost in the process of averaging out Chl values (it should be kept in mind that the dataset presented here is a composite of five years worth of data). We can only assume that this is the pattern that Chl follows during an *average* year. For each season, I calculated: (1) the regional mean; (2) the regional range of variation; (3) the regional variance; and (4) the regional standard deviation. These values were calculated for the whole of the study area.

I also calculated spatial variability using a number of local statistics. Local statistics were calculated using the four seasonal maps as input values. The resulting images show statistics calculated from these four values that pixels take across all four input maps. Local variability is thus displayed in two different ways: as the local range of variation in Chl (which shows how widely Chl values fluctuate throughout the year); and as local standard deviation (which shows how far from the local mean Chl values can go). It should be borne in mind that greater reliability could be gained if more datapoints were available, i.e., monthly values.

What is exactly meant by “anomalously high”? This term is inherently associated to defining a threshold value, above (or even below) which a cell is considered to be anomalous. For the compiled GIS database I purposefully chose not to fix a threshold in order to leave options open. I therefore did the data processing in a slightly different manner as recommended by Larade (pers. comm.) and Rangeley *et al.* (2003). I devised a system by which the user is the one who decides what is anomalous (i.e., the threshold), and I did so by using feature themes (polygon and point files), as opposed to GRID files. This way, the user can query the attributes table for polygons (or points) featuring the desired

threshold value, or falling above that value. For example, a value of 1.28 x Standard Deviation above the mean captures the top 10 % of the range of variation, given data normally distributed. The population of Chl values was indeed normally distributed; this was the threshold used for some of the analyses (this will be shown in Table 5).

It may be of interest, depending on the research question being explored, to display pixels with anomalously low Chl concentrations. This method allows the user to present the problem in this form as well.

SST spatial variability patterns

SST also presents patterns of variability in both the spatial and temporal domains, at multiple scales. In this project, I examined the SST “raw” data (i.e., the averaged SST values, for the four seasons) by mapping out SST spatial variability as expressed by the standard deviation at each point across the four seasonal input values (Cole and Villacastin 2000), as well as range of variation at each point, following the same procedure used in the Chl analysis. Regional statistics were also calculated. Again, this analysis leaves out all that refers to strict interannual variability.

Based on Morgan (2003) and Podestá (1993), I derived horizontal SST gradients, from which the presence of thermal fronts can be reasonably well inferred (Etnoyer, pers. comm.). This was accomplished by deriving the slope of the average SST data files.

Two SST-related criteria have been explored in search for potential keystone spaces: SST frontal regions, measured by SST horizontal gradient, and SST variability, measured as standard deviation from annual mean. SST

horizontal gradients are the sum of the four seasons. Threshold values were chosen in a way that the most evident patterns were captured. SST standard deviation ranged from 0.8 to 2.3 (with the mean value of 0.8). The threshold was set at a value of 2. SST horizontal gradient, in turn, ranged from 0 to 1.3 °C/km. A threshold was set at 0.6.

Benthic complexity

In accordance with Ardron *et al.* (2002) and Rangeley *et al.* (2003), the bathymetry data set was analyzed through a complexity analysis. Seafloor topography complexity is taken to be an indicator of species richness, since areas of high physical complexity usually present a large variety of habitats, more kinds of niches available in which organisms can live, and hence, higher species richness. In complex habitats, because species may coexist in greater diversity, ecosystem resilience may be higher (Ardron 2002).

Benthic complexity can be defined by how often the slope of the sea bottom changes in a given area. This concept differs from relief in that the latter looks at the maximum change in depth. Benthic complexity looks at how convoluted the bottom is. Areas of high relief may present low complexity when the slope is constant all the way through (as in a typical fjord), or high complexity when other structures appear on the bottom, making the slope change frequently, but not affecting the maximum change in depth between the lowest and the highest points of the slope (as in a fjord with a reef).

The analysis was carried out in the following steps (Ardron 2002, Ardron pers. comm.):

1. Depth values were exaggerated by multiplying by 20, in order to bring out any smaller changes.
2. Exaggerated depth values were converted into a GRID file, with an analysis cell size of 10,500 m, or 10.5 x 10.5 km (this was the minimum cell size in order for the grid cells to contain one and only one data value, closest to the analysis pixel size)
3. The slope surface of the exaggerated depth values was derived as an angle so it ranges from 0 to 90° (see Figure 9.a).
4. The rate of change of the slope was derived. This is sometimes referred to as convexity, or concavity (negative convexity) (see discussion in Burrough 1986, p. 49-52 for details). See Figure 9.b.
5. Because the depth had been exaggerated, the lower slope classes reflect inconsequential changes. After numerous trials, the three lower classes were finally removed. The remaining classes (three) were ranked according to a scheme of the form 1 (lowest), 2 (medium), 3 (highest). See Figure 9.c.
6. The benthic complexity is given by the density of the resulting points (number of changes in slope class per unit area). The GRID file resulting from the reclassification was converted into point format (only format to which neighborhood statistics apply) and density was calculated. The weighting was used as population measure. The function used was kernel, as it smooths out the results. Three different search radii were explored (a big search radius brings out trends more clearly): 62.3 km (default), 30 km, and 45 km. These three shapefiles are shown in the next Chapter.

Figure 9. Complexity analysis procedure: a) slope of exaggerated depth values; b) slope of slope; c) reclassified results, showing cells of highest rate of change in slope

CHAPTER 5. RESULTS AND DISCUSSION

Results

Sea Surface Temperature spatial variability patterns

SST in the CSLME ranges approximately from about 23°C to 30°C (see Table 4). In the central Caribbean, peak SST values occur in the summer and fall, and minima in the winter and the spring. Even though SST varied in a similar fashion throughout most of the Caribbean, important variations of this pattern emerge in certain areas. Figure 5 shows those.

Table 4. Regional SST statistics for seasonal averages, in °C

SEASON	MEAN	RANGE	STD.
Winter	26.1765	22.5-29.1	0.6465
Spring	27.2862	24.6-30.3	0.5286
Summer	28.4116	25.05-30.9	0.6558
Fall	27.9543	24.9-30.3	0.4293

In the summer, surface temperature along the north coast of Venezuela is significantly lower than the regional average. At this time of the year SST increases with latitude all the way across the CSLME, and the warmest temperatures are found around the peninsula of Florida and west of the Bahamas (the Bahamas Bank). In the fall a new spatial pattern starts to appear, showing a significant drop in SST over the Florida Straits and the Bahamas Bank. Whereas in the fall the warmest surface temperatures are found all across the middle part of the LME, around parallel 15°N, it is noticeable that a few spots within that area still show significantly low SSTs.

Two of these areas are in the Cuban Shelf region: Juventud Island (Gulf of Batabano) and Jardines de la Reina archipelago; a third cold SST patch stretches along the coast of Honduras and Nicaragua (the Miskito Coast), north and south of the Gracias a Dios Cape. The western coast of Jamaica and Dominican Republic, as well as the coast of Guantanamo and Santiago de Cuba, in Cuba, exhibit the warmest surface temperatures.

Wintertime SST continues to decrease west of the Bahamas, where the yearly minimum SST for the CSLME is registered. The warm SST patch over the middle of the Caribbean Sea shrinks in a northeasterly direction off the coast of Honduras and Nicaragua towards Jamaica and Dominican Republic. In the springtime cold surface water off the Venezuelan coast progresses northward. Cold waters between Florida and Cuba/Dominican Republic are pushed toward the east of the Bahamas. The highest SST is now found along the south coast of Cuba.

SST yearly variability patterns become evident from Figure 10, showing the standard deviation around the annual average at every point. This clearly shows that the area where SST fluctuates most widely throughout the year is around the Bahamas archipelago, particularly off the western islands. Two areas off the south coast of Cuba (Gulf of Batabano and Jardines de la Reina archipelago) show extreme yearly fluctuations as well. SST fluctuations caused by the upwelling off Venezuela, although evident, are not as strong. Conversely, the area where SST remains relatively constant throughout the year lies off the coasts of Nicaragua, Costa Rica and Panama.

The pattern of variation in SST over the course of the year in the Bahamas Bank and in the southern margin of the Caribbean, however, is

remarkably different (same figure). Off the coast of Venezuela, SST peaks in the summer but significantly drops in the fall, whereas in the Bahamas Bank, SST continues increasing after the summer, remains relatively steady through the fall, only to drop drastically in the winter. Different oceanographic processes are the cause of such different patterns of variation, as discussed further in this chapter.

Figure 10. SST variability patterns. a) SST seasonal averages for the Bahamas Bank; b) SST seasonal averages for the coast of Venezuela.

SST horizontal gradient, accordingly, shows remarkable differences throughout the year. In the wintertime thermal fronts are strongest (Figure 11). Several fronts can be seen this time of the year. The sharpest one occurs west and around Andros Island, in the Bahamas, neatly delineating the outer boundary of the region of highest SST fluctuations (the Bahamas Bank). SST horizontal gradients of similar strength expand east and west of Juventud Island, as well as along the northern boundary of the Jardines de la Reina archipelago. Thus, areas of highest SST fluctuations find themselves locked up by strong thermal fronts. Another front occurs parallel to the Florida Keys, running south of them. A short but intense front can be seen off the western tip of Cuba (Guadiana Bay). The Sabana archipelago, along the north coast of Cuba, is also separated from offshore waters by a region of sharp SST gradient. A circular front occurs around the Cay Sal bank (Bahamas), thus laying in the middle of a triangle defined by the Florida Keys, Bahamas Bank and Sabana archipelago thermal fronts. Conversely, the upwelling area off Venezuela presents a less conspicuous outer boundary, where SST decreases gradually, rather than sharply.

In the spring and summer all these fronts lose strength. Only the eastern stretch of the Bahamas Bank front remains relatively strong (area known as Tongue of the Ocean). So does the front blocking the waters of the Gulf of Batabano. It is not until the fall when SST horizontal gradient begins to become stronger again.

Chlorophyll: local variability and Chl anomalies areas

The SeaWiFS sensor provides an estimate of Chlorophyll *a* concentration in the first few meters of the ocean, where light can penetrate and ocean radiance can be measured. Chlorophyll *a* content in the surface layer is in turn a measure of phytoplankton growth and hence it can give an estimate of primary productivity. Under conditions of very clear water light that enters the ocean may be able to propagate to the bottom, be modified by substrate properties, and propagate back to the surface containing spectral information about the bottom (Drake *et al.* 2003). This means that in particular locations, the Chl measure may be confounded with the Chl that is produced by substrate-associated photosynthesizers rather than by phytoplankton (Casey pers. comm.). Even though this could be the case for certain data points in our datasets (and will indeed be taken into account when discussing the results), it is safe to assume that generally, the ocean colour data studied in this thesis refers to surface phytoplankton-produced Chl.

Chl concentration in the mixed layer of the CSLME stays generally close to zero mg/m³ throughout the year. This is a direct result of the vertical structure of the water column, which significantly limits the input of nutrients into the surface layer, thus impeding phytoplankton growth. However, in some places, Chl levels can reach as much as 30 mg/m³, depending on the season. The extreme value of 64 mg/m³ (refer to Table 5) occurs in one single pixel in the whole Caribbean basin, and this is in the Maracaibo Lake (Venezuela). Seasonal differences in the detected Chl patches are almost imperceptible at this scale of analysis (Figure 12). These areas match up exactly with areas of

high SST variability, showing a perfect coupling between SST fluctuations and phytoplankton growth.

Table 5. Regional Chl statistics for seasonal averages, in mg/m³

SEASON	MEAN	RANGE	STD.	ANOMALY THRESHOLD
Winter	0.2985	0.06-15.9	0.7016	1.1965
Spring	0.3071	0.05-64.5	1.0299	1.6253
Summer	0.3933	0.05-27.07	1.2619	2.0085
Fall	0.3320	0.06-33.49	1.1155	1.7598

The only remarkable seasonal change occurs in the south east of the CSLME, off the Venezuelan coast. There, a significant summer phytoplankton bloom originates a Chl patch that stretches up into open waters. This happens with approximately a one-season lag behind the beginning of the strengthening of the upwelling system (time during which nutrients brought up with the deep water enter the food web to result in the growth of phytoplankton). The shape of this patch seems to be influenced by the surface Caribbean current, which pushes it in a northwesterly direction.

Chl local variability (measured as the standard deviation from the annual mean) shows the same patterns but does not provide much further insight, as Chl concentration can fluctuate (and indeed does) only where it occurs (Figure 14). Chl anomalies, again, occur within the above-mentioned Chl patches. Figure 13 shows Chl anomalies (areas where Chl is within the top 10 % range of variation for the corresponding season) according to their persistence.

Figure 12. Chl anomaly areas

Figure 13. Persistency of Chl anomalies

Figure 14. chl variability patterns

The criterion chosen to pinpoint the keystone spaces was Chl variability throughout the year, measured by the standard deviation. This seemed more appropriate than Chl anomalies because it accounts for seasonal fluctuations. The threshold value explored for the purpose of this paper, in terms of the mapping of the keystone spaces (as opposed to Chl anomalies), was a standard deviation of 2.6 (see Table 6).

Seafloor topography: benthic complexity

Benthic complexity is highly dependent on the search radius chosen to calculate density (see Figure 15). For the purpose of the keystone spaces delineation, the middle search radius results were used. This was believed to be appropriate to show general trends in seafloor topography complexity. The resolution of the data was such that a smaller search radius may have resulted in artificial complexity details.

Figure 15. Complexity analysis results

The complexity analysis results, however, should be cross-checked with other indicators of species richness, as well as contrasted with habitat data. Due to the resolution of raw data, changes in slope that occur over distances less than 9 km are not registered, and unfortunately, 9 km is larger than many submarine features. These results then should be taken only as a rough indicator of areas with potentially high diversity of habitats because of the presence of many concavities and convexities on the bottom.

Complexity areas are best interpreted when laid over the bathymetric map. It then becomes apparent that areas of highest complexity occur mostly on the edges of the deep basins, where the seafloor drops abruptly (high slope areas). The average depth class for the highest complexity areas was 2500 m, with a minimum depth of 9 metres and a maximum of 6500. The shallowest areas of high benthic complexity (less than 20 m below the sea surface) occur in Eleuthera and New Providence Islands (Bahamas), Caicos Islands, and Jardines de la Reina Archipelago. Almost half of the grid cells classified as "greatest complexity", however, lay at depths greater than 3000 m. Variability in depth indicates no apparent relationship between depth and complexity. The fact that benthic complexity seems to be associated with high slope gradients rather than with particular depth classes could be a result of the analysis methodology combined with data resolution. It remains unknown whether finer-resolution data would have output results that are so highly influenced by seafloor slope.

The density of changes in slope derived from the GIS algorithm are on the order of magnitude of one-thousandth (0.001). Since the actual units are of little interest, a complexity "score" was calculated, by multiplying the values by 1000. This resulted in a range from 0 to 5.6. The threshold was set at 3.5.

Figure 16. Complexity and bathymetry

Turtle distribution and migration distances

Within the limits of the Caribbean Sea, the vast majority of the turtle tag returns occurred along the southern coast of Cuba, as well as the Miskito Keys, off Nicaragua (Figure 7). In Cuba, the hottest spots are Santa Cruz del Sur (44 % of all returns), Trinidad, Juventud Island (or Isle of Pines) and Cienfuegos. Cayo Largo, Cayo Breton, Doce Leguas, Camagüey and Ensenada de Broa are other important destinations for green sea turtles (see also Figure 23 and 24). Mean migration distance was 1135 km; mean time period between release and return was 917 days (two and a half years), with a maximum of 10 years. The distribution of recaptures per year, including multiple tag recaptures, over the full time period is shown in Figure 17.

Figure 17. Yearly distribution of turtle tag returns

This particular release-recapture dataset shows that most of the turtles released in the Cayman Islands swim north towards Cuba, where most of them are recaptured. Possibly, very few continue their trip past this landmass,

although some turtles have been recaptured in the Bahamas. A closer look at the release sites (see appendices) indicates that it is the tagged turtles released on the north shores of the Cayman Islands are the ones that head predominantly north. This is not very surprising, and has been observed before by other CTF researchers (Wood and Wood 1993).

It also seems that turtles tend to avoid swimming against the current, as very few are found in places upstream from the Cayman Islands (Venezuela).

Assembling the pieces and bridging the gaps

The first thing that becomes self-evident in these results is that they show a within-year variability pattern that does not seem to follow seasons. In order to understand the processes involved a new temporal frame of reference is needed, as the winter-spring-summer-fall structure does not provide the appropriate partitioning system of the annual cycle. Indeed, regional oceanography of the CSLME is driven by the trade wind regime (Longhurst 1998). Because of the great importance of trade winds on phytoplankton dynamics and ecosystem productivity, Longhurst (1998) has considered the trade winds influence to be the distinguishing factor for a whole ecological biome in his *Ecological Geography of the Sea*: the trades biome. The CSLME is considered by Longhurst a province within the trades biome: the Caribbean province. This province, however, also includes continental shelf processes, which are part of a separate biome as there, processes are governed principally by continental shelf topography. Summarizing, seasonality in the CSLME is determined by the

intensity of the trades, rather than by differences in solar radiation, as is the case in higher latitudes.

Thus, it is an external source of energy that sets in motion the whole marine expanse of the Caribbean basin, thereby determining the major oceanographic processes, biological response and regional ecological characteristics. Another major determining factor relates to solar radiation, which is relatively high and constant throughout the year. The combination of these two factors influences the vertical structure of the water column by determining first the existence or not of layers (vertical structure) and second, the depth of the mixed, surface layer. In this study I have only examined surface data, but its interpretation requires understanding of what lies underneath the surface: the water column.

In the CSLME, solar radiation is sufficiently strong throughout the year to avoid cooling down of surface water and convective mixing (as is the case in the winter at higher latitudes). Consequently, the mixed layer presents a constant depth, only with minor fluctuations dominated by geostrophic responses to seasonal variation in the strength and location of the trade winds. (Longhurst 1998).

A final factor that has to be taken into consideration in order to proceed to explain the obtained results is water circulation. The basin is dominated by the Caribbean Current (refer to Figure 2), a westward flowing surface current that connects the tropical Atlantic with the Gulf of Mexico and is the upstream origin of the Florida Current/Gulf Stream system (Fratantoni 2001). Water flows into the Caribbean basin mostly through the Grenada, St. Vincent and St. Lucia Passages (Gordon 1967). Current velocities are highest near the southern

boundary of the basin, along the coast of Venezuela and the Netherlands Antilles (Fratantoni 2001) and there is little flow over the Central American Rise. An intense recirculation gyre forms in the southwest corner of the Colombian basin over 200 km wide, driving strong boundary currents along the Colombian and Panamanian coasts. But most of the northwestward flow gets channeled through a trough southwest of Jamaica. Thereafter, it turns sharply westward while crossing the Cayman basin, and enters the Gulf of Mexico through the Yucatan Channel. After that point it becomes known as the Loop Current. This flow in turn becomes the Florida current as it exits the Gulf of Mexico through the Florida Straits.

In this context, SST patterns give a sense of the vertical structure of the water column, and this in turn provides the background against which to infer phytoplankton dynamics and hence interpret Chl patches. Simultaneously, the distinction between continental shelf and open water processes has to be kept in mind.

In a basin where solar radiation is constant throughout the year and average surface temperature is as high as 27°C, areas of low SST must be interpreted as the surfacing of water coming from deeper, and hence, cooler layers. Off the coast of Venezuela, mainly in the Gulf of Cariaco and Gulf of Venezuela, the lowest SST values coincide with the strongest northeasterly trades (Páramo *et al.* 2003). Between January and mid-April the combination of constant northwestward wind stress blowing parallel to the coast, with a strong western boundary current, results in Ekman suction and upwelling occurs (Simpson and Griffiths 1967). Water upwelled by this mechanism shows a

temperature difference of only 2°C with the regional average, indicating that vertical transport is not from very great depth (Longhurst and Pauly 1987).

In the Bahamas Bank and Cuban Shelf the SST variability pattern throughout the year is entirely different (cold in the winter, warm in the summer), indicating the occurrence of different processes. As can be seen from the bathymetry of the region, these areas (continental shelves) are relatively shallow and flat. There, turbulence imparted by bottom friction appears to be sufficient to break down the stability and stratification of the water mass over the shelf (Longhurst and Pauly 1987).

It is not clear from these maps, though, what exactly is the mechanism that is provoking the mixing of the water column. Mixing driven by tidal waves is a very common oceanographical element of continental shelves, but the Caribbean experiences only minimal tides. Wind stress could potentially be a strong stirring mechanism (Longhurst and Pauly 1987). Another could be the formation of permanent or seasonally recurring coastal gyres. This mechanism has been argued (Bakun *et al.* 1982) to be of great importance to the development of plankton communities and reproduction of coastal fish, as eggs and larvae can be retained in favorable habitat. More insight will be gained about the mechanisms in place when Chl is taken into consideration.

It is very clear from the results, however, that whichever processes are taking place, they result in a shelf-break linear front separating the mixed water over the continental shelf from oceanic or slope, stratified water (Longhurst and Pauly 1987). Such fronts have local consequences for the distribution of plankton and pelagic fish. These fronts appear where the thermocline intersects the surface of the water. There, nutrients can be supplied to the euphotic zone

and biological production is enhanced. Pelagic fish and seabirds often gather in such frontal areas.

When Chl is considered we can see again that seasonal regional scale changes in the mixed layer Chl field appear to be minor. This suggests that the Chl field is dominated by singular processes, associated with coastal topography and circulation patterns, rather than with the passing of the seasons (Longhurst 1998). Thus, the regional annual cycle depicted by the map must be interpreted as the spatial integration of these singular processes. In a nutrient-poor ocean basin such as the Caribbean, growth of phytoplankton requires the entrainment of nutrients to fuel new production. Two main types of mechanisms appear to be at work: runoff from coastal watersheds, and upwelling of deep nutrient-loaded water.

In the southern margin of the Caribbean Sea, both mechanisms could be at work simultaneously, which would partly explain why it is difficult to detect seasonal patterns. Muller-Karger and Aparicio Castro (1994) have thoroughly studied the mesoscale processes involved in phytoplankton production in this area of the CSLME, and the results presented here are extensively consistent with theirs. High Chl concentrations are detected east of the Paraguana Peninsula reflecting the output of organic materials and nutrients from small rivers. Muller-Karger and Aparicio Castro (1994) suggest that the shape of the offshore cold front extending along the shelf break (also evident in these maps) may help interpret other potential oceanographic processes involved. For example, the advection of coastal waters and strong shear between water flowing west of Aruba, Bonaire and Curaçao, and waters on the shelf could be accentuating the retention of nutrients in this Chl patch. These authors also

point out the relative unreliability of the high Chl concentrations detected in the Gulf of Venezuela, because of the unknown optical properties of the outflow from the eutrophic waters of the Lake of Maracaibo, as well as the interference of bottom reflection in shallow waters. Upwelling intensity is recognized to be a major factor involved in phytoplankton production in this area (Mandelli and Ferraz de Reyes 1982). All these characteristics are presumably the basis of the large fisheries established in both the Gulf of Venezuela and around Margarita Island. Because the Chl plume is dispersed offshore, these waters also represent a source of carbon for the Caribbean interior.

The presence of the extensive Chl patches over the Bahamas Bank could be misleading at first sight. Indeed, as Longhurst (1998) points out, these areas are overlain with extremely clear oceanic water of the North Equatorial Current, and the intense Chl signal registered by the satellite is very possibly due to symbiotic and benthic algae (rather than phytoplankton) whose Chl content can easily show through a few meters of clear water. Moreover, in the Gulf of Batabano and the Jardines de la Reina Archipelago, where numerous turtle recoveries occurred, the signal picked up by the satellite could be affected by the underlying turtle grass beds.

The results presented here suggest a very strong coincidence among SST variability patterns, phytoplankton growth and flat shallow bottoms, whether banks or continental shelves. This provides the background against which the components of the Caribbean Sea system can be further disclosed.

Building the data into the planning units of the GIS database

Results from the different analyses performed as well as the raw data were combined into one single all-encompassing table. Therein, every record corresponds to one grid cell and contains all the information associated to that location. This was done for the 400-km² resolution grid, in order to build a table with a reasonable number of records (even though this table contains 16,328 records, it is still one quarter the size of the 100-km² grid!). This of course results in loss of detail, as values throughout the four pixels of every grid cell have been combined into one value (see below).

The database has the following column structure:

Shape, Id, Area_km², Count, Ave_sst_winter, Count, Ave_sst_spring, Count, Ave_sst_summer, Count, Ave_sst_fall, Count, Ave_sst_st, Count, Ave_Hor_grad, Count, Ave_chl_winter, Count, Ave_chl_spring, Count, Ave_chl_summer, Count, Ave_chl_fall, Count, Ave_chl_st, Count, Ave_depth, Count, Ave_score, Count, First_mpa_name, Sum_area_km², Recaptures.

"Count" fields indicate the number of datapoints used to calculate the value in the next column. "Ave" indicates that the calculated value was the average of the datapoints that fell within that grid cell (i.e., the "count" value in the previous column). "Sum" indicates that the sum, instead of the average, was the calculated value. The Recaptures field also contains the total number of tag recaptures recorded within the boundaries of that grid cell, rather than the average.

This table can be easily queried to display different combinations of values, depending on what the user wishes to explore. This procedure was done several times during the Chl anomalies analysis and is shown in Figure 18. Figure 19 shows the selected cells when the table was queried for the records with values higher than the thresholds established.

Figure 18. Query procedure example used in the Chl anomalies analysis

Figure 19. Oceanographic criteria for Physically Distinct Areas

One disadvantage of this approach is that it is impossible to visualize the relative importance of the individual cells, in terms of how many criteria are met simultaneously. In order to overcome this problem the criteria GRID files were reclassified and converted into binary GRIDS, in which all cells with a value higher than the chosen threshold were classified as 1, and those below the threshold were given a value of 0. This way, when they are added up, the output is a four-class GRID (1, 2, 3, and 4) that shows how many 1's (criteria met) occur in each pixel. These results are shown in the following section. Overcoming the inconvenience of the hidden relative importance of cells has been gained at the cost of getting threshold-fixed results.

Table 6. Thresholds used to determine the physically distinct areas/keystone spaces

CRITERION	MINIMUM	MAXIMUM	MEAN	THRESHOLD
SST std.	0.3287	2.3906	0.8836	2
SST horizontal gradient (°C/km)	0	1.37	0.11	0.6
Chl std.	0.003	12.5051	0.1004	2.6
Complexity score	0	5.675	0.6004	3.5

Physically Distinct Areas (PDAs)

The search for the keystone spaces was executed in a step-wise manner in such way that additional layers can be interpreted in light of the existing ones. In each step, the frequency of criteria met was assigned to each cell. The first step was to combine SST variability with SST fronts; step 2 combines step 1 with Chl variability (Figure 20). Step 3, in turn, is the combination of step 2 and complexity; the outcome of this is shown in Figure 21. This (arguably) results in the delineation of the physically distinct areas.

Figure 20. PDAs mapping procedure. a) Step 1: greatest SST variability + greatest SST horizontal gradient; step 1 + greatest Chl variability
b) Step 2:

Rangeley *et al.* (2003) propose that Chl and SST be analyzed according to anomaly areas, rather than variability. This method works well in their study area (the Nova Scotian Continental Shelf, in Canada), because of two main reasons: latitude is high enough to be the driver of the seasonal cycle, greatly influencing SST and causing convective mixing processes. Also, continental shelf processes take prevalence over open water processes. The two systems (Scotian Shelf and Caribbean Sea) are obviously entirely different, and the methodology of analysis was accordingly adjusted to tropical ocean conditions. Unfortunately, no studies of the same kind have yet been carried out in such an environment. Perhaps this thesis will stimulate further experimentation with different oceanographic parameters, in the quest for a robust science of marine ecoregional planning.

Physically Distinct Areas (PDAs) then, as defined here, are the ones that exhibit the greatest SST within-year variability, and/or greatest SST horizontal gradient, and/or greatest Chl within-year variability, and/or greatest benthic complexity.

Figure 21. Physically Distinct Areas

At this data resolution and using the above thresholds, none of the 400-km² grid cells of the CSLME meet all four criteria at once. The only locations where three criteria are met are the following: East of Juventud Island (Los Indios-Cayos de San Felipe area), Cuba, Cayo Cruz del Padre, Matanzas, Cuba, East of Berry Islands-North of Andros Island area (Bahamas), Rose and Booby Islands, west of New Providence (Bahamas), and off Tarpum Bay, Eleuthera Island (Bahamas) (see Figure 21). Interestingly, the one criterion that none of them meets is the Chl anomaly criterion. Thus, these locations include areas where SST fluctuates widely throughout the year, and has a consistently sharp horizontal gradient, and where the seafloor presents numerous convexities and concavities per unit area. They all qualify as shelf-edge fronts. Except for the Rose Island and Booby Island area, whose average depth is approximately 2000 m, all the others lay in relatively shallow waters (never deeper than 800 m). Consequently, most of them are within the photic zone.

These areas represent the boundary of the water masses that are being mixed by friction with the bottom, so they lay in the transition region toward the stratified water. However, sufficient nutrients are not being pumped in to guarantee phytoplankton growth. These are, rather, clear, nutrient-poor waters. Conditions are ideal for the formation and growth of coral reefs, as long as SST fluctuations do not exceed coral tolerance range.

It is very interesting to note the apparent contradiction between the fact that these areas have been identified as having consistently high concentration of Chl (Figures 12 and 13), and yet the variability in Chl throughout the year is very low (i.e., the SeaWiFS sensor detects a high steady signal). This signal is most likely emitted by the symbiotic algae associated with reef-building

organisms, as has been discussed above (Longhurst 1998). This reinforces the choice the Chl variability criterion when the goal is to understand unusual ecological processes.

The fact that these key locations are relatively clustered together in the Bahamas Bank area (except for the Juventud Island site) is presumably not the result of chance. Keeping in mind that different threshold values/data resolution would have likely yielded different results, the importance of the oceanographic processes at work in this region is unquestionable. This does not strike one as so surprising when put in the appropriate regional context, since the Bahamas Islands in fact represent a transition zone between the Caribbean province and the rest of the tropical Atlantic Ocean. Also, it comprises a large area of shallow carbonate platform of continental shelf dimension, providing the appropriate environment for continental shelf processes (Longhurst 1998). Water masses from various surface and deep current systems (North Equatorial Current, Antilles Current) seem to converge in the Bahamas Bank, giving rise to numerous persistent, true shelf-edge fronts. These processes may have major implications in coastal ecology and may be the focus of physical aggregation of biota, the site of enhanced biological production, or the line of separation between two different biological regimes. Further studies are required to understand the role of these continental margin processes in both local ecological phenomena and global nutrient and energy cycles.

Physically distinct areas and green sea turtle recaptures

The spatial relationship between turtle recapture locations and physically distinct areas would represent the cornerstone of focal species research. A preliminary exploration of it is presented here.

Enclosed in this thesis (Appendix 4) is a subset of the compiled GIS database including grid cells (records) where at least one turtle recapture has been recorded. This table gives a sense of the physiographic/oceanographic characteristics of the places that hold importance in the green sea turtle life-cycle. Below is a summary of those characteristics.

Table 7. Summary statistics of ocean data for turtle recapture location areas. (SST is in °C, horizontal gradient is in °C/km, Chl is in mg/m³, and depth is in m)

	AVERAGE	MINIMUM	MAXIMUM	ST. DEVIATION
Recaptures	3	1	74	10
SST_win	26.13	23.55	27.6	0.85
SST_spr	27.93	25.12	28.73	0.66
SST_sum	29.40	25.88	30.38	0.92
SST_fall	27.76	25.88	28.40	0.54
SST_st	1.22	0.40	2.23	0.43
SST_hor_grad	0.3	0.04	1.20	0.25
Chl_win	0.90	0.12	5.30	1.39
Chl_spr	0.83	0.08	5.10	1.33
Chl_sum	1.02	0.08	7.03	1.81
Chl_fall	1.12	0.11	8.02	1.90
Chl_st	0.23	0.01	1.29	0.38
Depth	-460.83	-4113.44	-1	779.80
Complex_score	1.34	0	4.98	1.6

When this table is cross-checked with Table 4 it becomes apparent that all the average values of the examined PDA parameters are below the chosen thresholds. Variability in all cases seems to be too high to conclude that the

green sea turtle “chooses” the destination point of their migratory travels, based on these criteria and thresholds. In other words, no real spatial association seems to exist between this species and the studied parameter thresholds.

That said, new insights emerge when one visualizes the spatial distribution of the recapture points with reference to the PDAs map (Figures 22, 23, and 24). In fact, a substantial proportion of the registered returns concentrate within the boundaries or very close to areas where at least two PDA criteria are met. Remarkably, one tag was recaptured at the Los Indios-San Felipe area (Punta de los Barcos), and two more, in Tarpum Bay (Governor's Harbour). The Miskito Keys area does not qualify as a PDA according to this set of criteria, although just a couple of grid cells north of the keys, the value of SST horizontal gradient is barely above the threshold.

Figure 22. PDAs and turtles

Figure 23. PDAs criteria, individually

Figure 24. PDAs criteria, individually (cont'd.)

Let us examine these results on a criterion-by-criterion basis. With regards to Chl variability, in the Gulf of Batabano, none of the cells whose Chl variability throughout the year is above the chosen threshold includes any recaptures, although many are adjacent to them. When recaptures are compared with cells of persistent high Chl (Chl anomalies), not a great deal of new overlapping cells emerge. Again, grid cells with recaptures in them tend to be adjacent to or very close by areas where Chl is found at anomalously high levels.

As has been discussed, there is a great degree of overlap between areas where the Chl criterion is met and the SST horizontal gradient criterion is met. Consequently, the relationship with focal species occurrence areas is much the same: recaptures tend to appear in cells that are contiguous to thermal front cells. When looking at the greatest SST variability grid cells, a number of them occur again in the Gulf of Batabano, but none of them presents any recaptures. Recaptures there tend to occur again in nearby areas.

According to what has been discussed on green sea turtle biology in previous chapters, benthic complexity would be expected to show the weakest relationship with the occurrence of this species, and indeed does. However, it is worthwhile noting that the area east of Juventud Island (Canarreos archipelago), as well as the Jardines de la Reina archipelago, both featuring high benthic complexity, also encompass (and/or neighbour) a substantial number of recaptures. Furthermore, two of the most important recapture areas (Juventud Island and Santa Cruz del Sur), fall in the immediate neighbourhood of the two above-mentioned complexity areas. It is reasonable to assume that the high frequency of recaptures there is related to the other criteria examined.

The location where the maximum number of recaptures took place (amounting to 74) corresponds to the grid cell number 5998 (Santa Cruz del Sur). There, SST variability is 1.5, SST horizontal gradient is 0.47°C/km, Chl variability is 0.07, and complexity is 1.4 (depth is 179 m). All these values are below the chosen thresholds, albeit above the regional mean values, in all cases except for the Chl criterion.

Further studies considering additional oceanographic variables as well as more extensive turtle distribution and abundance data would be needed to elucidate the spatial correlation between this particular species and different ocean parameters. This track of analysis, however, does seem to lead to a promising area of study.

Focal species occurrence: keystone spaces

Thereafter, the presence of the focal species (occurrence of tag recaptures) was added in as one additional criterion. Areas where green sea turtles tend to gather can be considered Biologically Distinct Areas. As defined by Rangeley *et al.* (2003), these are areas that are important for the growth, reproduction or survival of species of special concern or species groups. Thus, grid cells where at least one recapture had been recorded (recaptures field greater than 0) were reclassified and given a value of 1. All the others were assigned a 0. Figure 25 shows the outcome of combining all five criteria. Do these areas qualify as "keystone spaces"? This question is discussed in the paragraphs that follow.

Figure 25. Proposed keystone spaces

MPAs

In order to illustrate the usefulness of this technique as an assessment tool for the current MPA situation, the MPA network layout was compared with the proposed keystone spaces. There are two obvious ways to plan this type of assessment: by identifying the keystone areas in which no conservation measures have been put in place (conservation gaps), or by characterizing, in terms of the keystone criteria, the areas where marine reserves and protected areas currently exist.

First, the locations that emerged as the ones holding the greatest importance, in terms of allowing the normal occurrence of key broad scale ecological processes are evaluated (see above). Remarkably, in Cuba, the Los Indios-San Felipe area has been included in a large Ecological Reserve. None of the other locations has been designated for protection.

Figure 26. Keystone spaces and largest MPAs

Other large MPAs encompassing our proposed keystone spaces include: the Tobago Keys Marine National Park, the All Awash Island Wildlife Reserve, the Chateaubelair Islet Wildlife Reserve, the Soufrière Marine Management Area, the Praslin Mangroves Marine Reserve, the Maria Islands Nature/Marine Reserve, the Cas-en-Bras Mangroves Marine Reserve, as well as various other smaller reserves (in fact, all St. Vincent and the Grenadines MPAs plus the only one in Grenada are included within this cluster). Archipelago Los Roques National Park and Medanos del Coro National Park (Venezuela); Miskito Coast Biological Marine Reserve (Nicaragua); Jaragua National Park (Dominican Republic); Sur Isla de la Juventud Protected Area of Managed Resources, and Humedal Núcleo de Sabana - Camagüey Integrated Management Area (Cuba), and Banco de la Plata Marine Sanctuary (Dominican Republic), the largest one in the whole Caribbean Sea, also lay very close to these key areas.

However, when comparing the distribution of keystone spaces and the largest MPAs (which are assumed to have the greatest impact on the maintenance of the key large-scale ecological processes) many conservation gaps can be found by a simple glance at the map.

Discussion

Goal No.1: focal species performance

When examining the association between turtle spatial distribution and environmental variables we are faced with some limitations relating to data accuracy and representativeness. Firstly, it has to be kept in mind that the recapture locations presented in this project by no means include the full

amount of the Caribbean green sea turtle population. Furthermore, it is impossible to know whether they actually are a representative sample of it. Once again, we are exclusively looking at those individuals that were bred in the CTF, tagged, released from the various release points across the Cayman Islands, and eventually recaptured elsewhere.

Secondly, tag recaptures are reported to the Cayman Turtle Farm by whoever comes upon an individual turtle bearing a CTF tag. Hence, return locations may be recorded solely as a town name (e.g., Baker's Beach; Key Largo, Cuba) or, best case scenario, in geographic coordinates with an accuracy of two decimal points (degrees and minutes). Consequently, the recapture points portrayed in this project should actually be thought of as having a "radius of uncertainty" around them, and represent areas of probability rather than precise locations. This would not be a problem in itself except that when reported locations were brought into ArcView many of them fell actually inland (making it in turn impossible to tell those sites apart from recoveries coming from beached carcasses). In those locations, for obvious reasons, no ocean data exist. This problem was somewhat overcome by replacing the original point file by polygon files (the analysis grids), wherein the number of returns reported at each particular point gets assigned to a whole grid cell (100 km² or 400 km², depending on the grid used). Even after this procedure, unfortunately, some grid cells with return points in them still encompassed only land. An indirect result of this problem is the fact that keystone spaces are very similar to the PDAs, as the inland locations have not had an effect on the keystone spaces computations.

Most importantly, however, from this data collection method stem issues of randomness. In fact, many tag returns reported to CTF (and therefore included in the dataset herein) come from fishermen, who come upon turtles that mostly get caught in their fishing nets (Doubleday pers. comm.). While it remains true that the reported locations are at least an intermediate point in the migratory routes of this species (or else they would not be found there), this dataset does not tell us whether they are their final destination. We can then only assume that the reported recapture locations do represent areas of high concentration of turtles, on the basis that if this were not the case, they could more easily escape the fishermen gear. Again, these locations must be thought of as areas where chances to find a large amount of turtles are high.

Consequently, the spatial distribution of recaptures is strongly influenced by a “hunter” effect (Doubleday pers. comm.), i.e. turtles are found where “hunters” are looking for them. These locations may perhaps indicate distribution of fishing efforts, or fishing sites, rather than outline the biogeographical distribution of this species. From this follows that the absence of returns in a particular area does not mean that the probability is lower (or zero), but rather that there is no data available. In summary, the return locations reported to the CTF, because they are likely associated with fishing distribution, may represent areas of high concentration of green sea turtles, but may not be the areas where green sea turtle abundance is highest throughout the Caribbean. Because of the lack of accurate and extensive data on distribution and abundance of sea turtles, the findings of this thesis can only be taken as illustrative results, and never as conclusive evidence for the spatial relationship between turtle areas and ocean variables.

With this in mind, the analyses show that the green sea turtle does seem to be somewhat associated with recurrent processes, although this association remains unquantified. This association must also respond to the existence of a functional link between the processes and the species studied, and this is one of the knowledge gaps that unfortunately have not been filled in this thesis. A discussion speculating on the unknown links is included further below.

The fact that recapture locations do not exactly overlap, but rather lay very close by, areas of high Chl/SST variability and/or SST front areas depends to a large extent on the threshold used. The degree of overlap indeed increases when thresholds are set at lower values. However it appears that this increase occurs at a slow rate. I examined the outcome of thresholds set at lower and lower values (process which enlarges the PDAs), and it turned out that only few additional cells would emerge classified as PDAs and having turtle recaptures at the same time: recaptures heavily and consistently tended to take place just around the boundaries of the physically distinct areas. This did not hold true for the complexity criterion, where there did not seem to exist a pattern at all. (The point made above regarding the proximity between recapture hot spots and the Canarreos and Jardines de la Reina Archipelagos seems to be more associated to the occurrence of the Chl and SST-related criteria, rather than the complexity one).

Thus, areas of high probability of turtle presence appear to be enveloping the PDAs. This would in turn translate in keystone spaces that are very similar to PDAs in terms of spatial distribution, only larger in size, as cells with recaptures would get “absorbed” by the PDAs. This does not show as clearly in the results because of the high number of inland recapture locations.

Going back to the research question from where this study departed: can the green sea turtle be used as a basis to design/assess a network of MPAs? (i.e., can it be used as a focal species?) To a certain extent, and under the limitations of the datasets employed, it would be too optimistic to conclude that solely the area distribution of the released and recaptured green sea turtle population provides an appropriate tool to identify conservation gaps, and thus assess the adequacy of the MPA network (or design a new one from scratch). Assigning high conservation value to areas of high turtle presence probability would miss many relevant spaces. In future work, buffers could be applied to capture locations to include neighbouring areas, which, as has been shown, are more closely linked to process occurrence.

However, turtle data would be best used in combination with other variables, or additional focal species data, in order to provide a useful tool for MPA network design, when the ultimate goal is to capture in the network all areas that are physically distinct due to anomalous oceanic processes. (Perhaps, the missing link is as follows: fishing efforts concentrate on areas whose physical attributes enhance biological productivity, providing for rich fishing grounds, or in other words, what has been classified as PDAs in this study. Therefore, returns (more strongly associated with fishing than with the PDAs themselves) are consistently reported from the neighbourhood of these fishing areas. It would follow that a better-suited focal species to identify areas of distinct physical attributes/unusual oceanographic processes would be the species being targeted by these fishermen!)

If habitat data were added in the picture we would probably make sense of all this more easily. Presumably, the recapture locations are in fact tightly

associated with turtle grass beds. It would then be key to unravel the links between the seagrass habitat and the physically distinct areas in order to understand the role of the focal species in relation to the processes defining the PDAs. It is interesting to speculate on the ecosystem-level implications of the numerous inter-community/inter-species interactions taking place in the near shore environment of the Caribbean Sea.

It is known that seagrass beds act as baffles slowing the water movement and increasing sedimentation of organic and inorganic material in the grass flats. A tangled network of roots and rhizomes holds this sediment and creates a nutrient-rich environment, resulting in high ecosystem productivity rates. Further, organic material is also exported in large amounts outside the seagrass system, toward waters poor in nutrients. Thus seagrass beds provide a readily available source of food to organisms living under the severe resource limitations characteristic of the neighbouring coral reef communities. Seagrass beds then emerge as open systems, with close ties to surrounding communities through providing shelter or food to outsider organisms, or by supplying organic material to outside systems (Odgen 1980).

Turtles and seagrass beds are in turn closely tied together, but the dynamics of these interactions are largely unknown. In certain areas of the world, seagrass beds have undergone great changes with continuing extirpation of the green sea turtle (Odgen 1980). This relationship can be described, from an ecosystem-based viewpoint, in the form of carrying capacity. Randall (1965, cited in Bjorndal 1985) has suggested that green turtles could have once been limited by the carrying capacity of the *Thalassia* beds. If this was the case, we have to assume that, given the high productivity rates of the system, the

numbers of turtles were enormous (Bjorndal 1985). What kept the sea turtle population within stability limits? Does a hierarchical perspective of the Caribbean ecosystem help understand the factors involved in turtle-seagrass dynamics? Hierarchy Theory would formulate this question as follows: what places a constraint on sea turtle population growth?

The abundant food source does not seem to be the answer to this question. Unfortunately, this is something that has not been studied before, to the best of my knowledge. However, Bjorndal's (1985) insightful discussion on turtle nutritional ecology provides some hidden hints that help begin to unfold this problem. She compares energy budgets of two distinct turtle populations (Surinam and Tortugero), and concludes that the Surinam green turtle produces almost twice as many eggs per female per year as the Tortuguero turtle, but expends four times as much energy to do so. This difference is due, she argues, to the much longer migration of the Surinam colony. Therefore, the amount of energy that goes into reproduction (and ultimately into population growth) is limited by the amount of energy that has to be stored for the migration. Perhaps, then, the green sea turtle is a self-constrained species, that maintains itself within limits tolerable for the ecosystem through having to perform long-distance, feeding and breeding migrations. In spite of the abundance of its principal food source, this species remains closely attuned to the carrying capacity of its environment, neither exceeding it drastically nor falling below it and running the risk of extinction (Apollonio 2002, p. 144).

In addition to this self-constraining mechanism, the green sea turtle also exhibits slow individual growth rates, which, Bjorndal (1985) argues, result in delayed sexual maturity. This ensures the accumulation of many years of sub-

adult cohorts, and in return, provides, ironically enough, a buffer against extinction during periods of heavy exploitation. If a green turtle takes about 20 years to reach sexual maturity, then every nesting turtle and egg could be taken for 20 years without affecting the number of recruits arriving at the nesting beach. However, this also implies that recovery rates after heavy exploitation periods would be extremely slow.

The green sea turtle has made an evolutionary trade-off: long migration distances and slow growth rates in exchange for a constant, nearly competitor-free food source and self-supplied stability. Taking a step down the ecosystem hierarchy, the turtle grass beds seem to be the next level, whose structure is highly influenced by the turtle population (and whose spatial extent is smaller and rate of growth faster). The importance of understanding the dynamics between turtles and turtle grass begins to become clear. The green sea turtle emerges as a target species that would re-direct management benefits towards a key component of the Caribbean ecosystem (seagrass beds), as well as expand them over large geographic areas.

If the green sea turtle is in fact positioned in one of the highest hierarchical levels conceivable in the CSLME, the massive extirpation of its populations must have also had massive effects in ecosystem structure and function. This loss would have meant the removal of naturally-evolved mechanisms that once lent stability to the system (Apollonio 2002). The total biomass perhaps has not changed much; other organisms are probably using the energy not now used by the depleted turtle population. The kind or quality of the biomass, however, has certainly changed, and that means that the dynamics of the system must have changed too. A hierarchical perspective of

the CSLME might help understand the “drastic unexplained fluctuations in nesting arrivals at the breeding shores” (Carr 1980), as well as the increasing oscillations in fisheries catches shown in Figure 3.

This issue has never been put in these terms before. However, this new perspective, facilitated by Hierarchy Theory principles, has important implications for focal species studies. Because turtle population dynamics occur over similar spatial scales as some of the oceanographical processes reviewed in this thesis, it seems that they would act in orchestration, facilitating the existence of lower levels in the system. It seems worthwhile to further focal species research in this direction and verify that turtle abundance can indeed be used to monitor the normal occurrence of these broad scale processes.

Goal No.2: A toolbox for MPA network design

The idea framed in the following statement, “at the broadest scale, reserve networks must protect ecological processes essential for ecosystem functioning” (Roberts *et al.* 2003, p. S216) has been expressed in many different ways, on many occasions. However, only rarely is an effort made to explain what is meant by it: which are the ecosystem processes essential for ecosystem functioning? How do we protect them? I have shown that, using relatively simple analysis techniques and the right ocean variables, it is in fact possible to determine just what these “processes” are. Furthermore, the set of criteria examined (i.e., SST variability and horizontal gradient, Chl variability, and benthic complexity), in spite of the data limitations (see below), have proven to be appropriate to identify areas where processes that might have a regional

importance occur. The spaces returned by the analyses do seem to be at least some of the *keystone* components of the system. Further and more extensive focal species area distribution data (whether green sea turtle or other additional species) should be added into the analyses to ensure coverage of spaces defined by the occurrence of processes that have not been looked at in this thesis.

This type of analysis could help managers become aware of the function their MPA is expected to perform. A change of mind set is needed. For example, if what characterizes the habitats/communities present in a given marine reserve is extreme temperature fluctuations, activities whose potential impact could alter water temperature variability patterns (industrial wastewater, for example) should not become established in the area. Thus, depending on the type of keystone space the MPA belongs to, conservation measures should not be as much directed at particular coral reef fish or benthic invertebrate species, as to maintaining the environmental conditions that are allowing those to exist (i.e., constraining their rates of population growth). Monitoring should then be aimed at where fronts appear every year, and so on. This is precisely what managing processes means. In a world where there exist Cetacean Sanctuaries, or Seabird Protection Areas, why should it be less valid to create Water Temperature Protection Zones, or Thermal Front Buffer Zones?

Once the various director boards involved in MPA planning become aware of the role that their marine reserves play as components of the Caribbean Sea system, measures can be put in place to ensure the long term persistence of ecosystem function, efficient partnerships can be established with neighbour MPAs, and in summary, an efficient “system” of interdependent marine protected areas may be implemented. For example, MPAs downstream

from the Gulf of Venezuela are probably dependent on upwelling intensity for their supply of larvae or nutrients, without which, regardless of how strict protection measures are, biomass loss would probably occur. A notable pioneer effort to map such connectivity patterns in the Caribbean was made by Roberts (1997), who (under debatable assumptions) identified degrees of dependency for larval supply between MPAs according to their positioning in the stream flow system. He argued that places with large upstream reef areas should be less dependent on local management to support fisheries or maintain biodiversity (i.e., they depend on larval supply from elsewhere), whereas local management will be very important for places with little upstream reef (Roberts 1997).

There are some limitations to these results that have to be pointed out. Firstly, working with seasonal average values for SST and Chl results in the failure to depict true within-year variability, not only because of the coarse temporal resolution but also due to the “northern” definition of season used. The fact the local statistics were calculated only from four input values (the four seasonal averages) further limits the capacity of the results to show accurate patterns of variability. Additionally, inter-annual variability has not been accounted for at all.

It is known that in the Caribbean, surface currents meander and form eddies, such as the surficial eddy in the Miskito Gulf (Kinder 1983). These phenomena happen on scales of 100 km to 500 km; important parameters such as the direction of the flow, the kinetic energy available for mixing near islands, and the depth of the pycnocline all vary on these scales, significantly altering the biological environment near shore (Kinder 1983). When data of higher temporal resolution are considered, the steady picture depicted here is replaced

by one in which mesoscale features come and go. The strong variability in space and time of the Caribbean currents has an important influence on the understanding of many oceanographic and ecological processes in the Caribbean.

Spatial resolution could also potentially cause us to misinterpret the results obtained. Whereas we can be relatively confident that a resolution of 9 km is fine enough to portray mesoscale SST and Chl patterns (while still missing small scale phenomena), this could be more of a problem when looking at bathymetry. Depth changes at much faster rates than do the other two variables, and these changes were neglected.

However, the ultimate purpose of this kind of study should be to incorporate finer and finer resolution datasets (as well as additional data layers), that could be nested into this coarser resolution framework. This research has leapt from the spatial extent of the whole Caribbean basin (2,000,000 km²) to planning units (100 or 400 km²), leaving a large gap of unexplored scales in between.

Not only has the GIS database created for this thesis proven a useful approach for a broad scale analysis of ecological processes, but it has provided the background with which to move ahead in the process of marine ecoregional planning. The next step should be to delineate the various biogeographic provinces embedded in the CSLME, and then probably carry out all these analysis again, on finer resolution datasets. Aíramé *et al.* (2003) suggest that SST slope combined with bathymetry provides enough information to outline biogeographic provinces. Results here also show that the combination of these two layers defines regions where dynamics differ significantly.

In summary, much is left to be done. However, if relationships of focal species with processes and distinct habitats continue to be studied and unraveled, it seems that the science of marine ecoregional planning would advance at a much faster pace, as efforts could be placed on fewer and fewer numbers of variables.

CHAPTER 6. CONCLUSIONS AND FUTURE DIRECTIONS OF RESEARCH

In recognizing the lack of a conceptual framework within which to evaluate and act upon complex assemblages of species, and that such a framework is necessary to put into practice ecosystem-based conservation strategies, I have attempted to demonstrate how focal-species based research can be linked to ecosystem process analysis. I make the case that Hierarchy Theory provides the appropriate tools to understand the link between species and the spaces they occupy. As stated by Apollonio (2002): "Linking species characteristics (...) to ecosystem structure and function by means of constraints on the rates of processes is the answer, in principle, to how systems work. It is this concept that is essential for understanding ecosystems" (Apollonio 2002, p. 131).

The Caribbean Sea is a Large Marine Ecosystem that shows multiple signs of stress (coral degradation, mass mortalities of fish, etc.; Richards and Bohnsack 1990), where the use of living marine resources seems to exist in conflict with biodiversity conservation. Entities involved in the management of natural resources, particularly fisheries, have embraced the idea that keeping certain areas free from exploitation activities is a good tactic for conservation, and have established a plethora of marine protected areas and marine reserves. In fact, an immense variety of similar protection figures has spread across the entire region. The currently existing MPA network has thus been developed *ad hoc*, in an inside-out fashion, with no consideration for the "big picture", and little thought has been given to adjusting the network of MPAs to the way marine ecosystems function. The result is an unstructured network, which is

likely to fail to protect habitats that are classified as rare when put into regional context (Sala *et al.* 2001). Consequently, there is little evidence that MPAs in the Caribbean will effectively succeed in reducing the detrimental effects of human-driven impacts (Pinnegar *et al.* 2000, Williams and Polunin 2001). I have argued that this is the result of both inappropriate management schemes and a poor design of the network.

The difficulty to develop adequate management plans is rooted in the complexity of marine ecosystems and in the lack of adequate proxies to tackle complex problems. It is time to advance past the never-ending debate on what is better, single-species or ecosystem-based strategies and seek a compromising framework that facilitates action.

In this paper I have proposed that, even when it is becoming increasingly acknowledged that only ecosystem, process-based approaches will effectively tackle conservation problems, the conceptualization of ecosystem processes and the “overwhelmingness” of the endeavour of having to manage all species and their interactions at once deter us from putting the ecosystem approach into practice. In this sense, the single/focal species approach does deserve some credit. The key issue rests on carefully choosing the species (or suite of species) on which to focus management efforts, and on backing this choice with sound scientific evidence.

When regarded from the Hierarchy Theory perspective, ecosystems become easily describable in terms of hierarchical levels. Complexity gets organized. In this context, characterizing the position that a certain (focal) species occupies within an ecosystem hierarchy aids in identifying relevant constraints on ecosystem processes, imposed by and upon that species. This in

turn would allow us to pinpoint the levels on which management measures have to be put in place. It would therefore facilitate the choice of target species.

I make the case that focal species analysis helps configure candidate sites into a functional network of reserves, by enhancing connectivity and increasing the overall resilience of the system. The extent to which the Caribbean green sea turtle acts as a space and time integrator, or ecosystem resilience enhancer, should be a priority in future focal species-oriented research. Ultimately, a great deal of understanding of ecosystem processes would be gained through the examination of the ways in which sea turtles provide stability to the system. Implicit in this statement is a crucial element to the argument being unfolded in this thesis: when pursuing ecosystem-based management strategies, single species may be used as focal, insofar as they are seen in the context of the roles that they perform in ecosystem function. That is, the “focus” should not be the species *per se*, but the processes that the species facilitates.

Acknowledging the gaps

The development of this GIS tool has proven a useful approach in that it has helped clarify some of the more important research and data gaps. It is worthwhile highlighting some of the more obvious ones.

Firstly, there is one big missing data layer in the GIS database, and this is current intensity. Surface current patterns would have certainly had high explanatory value to shed light on the dynamics of the studied processes, as well as on the distribution of turtle recapture data. Current intensity is one of

the four basic data layers designated by Morgan and Etnoyer (2002) as indispensable to evaluate benthic and pelagic systems (the other three being the ones included in this project). Currents aid in visualizing patterns of connectivity. Current intensity could be represented as flow maps, by assigning grid cells a vector of a certain length (current intensity) and direction (current flow direction). This would have allowed display of intensity gradients, or identification of high current velocity areas, which in turn contribute to physically distinct areas (Roff and Evans 2002).

However, this type of data is extremely difficult to obtain (as Morgan and Etnoyer, 2002, point out) world wide, and presumably has not been compiled (and/or made available to the public) for the Caribbean basin. Devising ways to put this type of information in GIS format is an area of study that needs advancement.

Secondly, even though its value at this scale of analysis is to a certain extent questionable, habitat data is the next important gap in this project. Both benthic and pelagic habitat must definitely be included when performing biogeographic province-level planning. But again, marine habitat mapping has not been done on an extensive basis, as habitat characterization in the ocean requires enormous investment of time and resources. One further complication is the overlapping of benthic and pelagic habitats. Longhurst (1998) was the first to undertake the task of defining the major pelagic biogeographic regions of the world, but much awaits to be covered. This point can easily be turned around, though, in support of the argument that has been unfolded in this thesis, by saying that due to the difficulty in compiling such datasets (i.e., marine benthic and pelagic habitat maps, preferably in some GIS-treatable

manner), focal species studies should be the area to be strengthened, as it promises ways to get around this obstacle while accomplishing the same results.

I argue that the correct order in which to evaluate marine ecoregions should be process analysis, focal species distribution, and finally, habitats. This thesis has proven that much interesting insight can be gained about large scale processes when habitat is not diverting our attention. Moreover, focusing full attention on habitats is a technique that follows terrestrial conservation paradigms whose application to marine systems could be questionable.

Even though the focal species distribution data collection method could have been improved in many ways, one in particular is worth highlighting. This study would have immensely benefited from satellite tracking data, which would be able to tell us not only where the turtles' journey started, and where it ended (or where they were caught in the undertaking of their migratory trips), but also the particular courses followed to get there. This in turn would give us the chance to analyze oceanographic variables all the way through the migratory routes, and develop accurate predictive models.

Finally, it is not prudent to put forward a framework for the design of marine reserves systems that has no room for human populations. Since marine protected areas and marine reserves are ultimately intended for the benefit of society, human populations' (tight) relationship with the ocean has to be taken into consideration. If the process of planning and developing marine (or for that matter terrestrial) protected areas relies solely on the biological/ecological rationale for establishment, even if it is based on in-depth research, the management scheme is still likely to suffer difficulties. Social and

political organizations, traditional management practices, knowledge about natural resources, customary use patterns, and cultural values and sovereignty are elements that play an important role in the process of establishing MPAs (Fiske 1992). Of particular relevance to this case study is subsistence fishing. The sense of loss of self-reliance on the side of local fishermen, who may feel the establishment of marine reserves as a threat to their livelihoods, instead of a benefit, may engender resistance and the protection figure imposed on them in this way is bound to fail. When taking the ecoregional planning process to the next stage, additional data layers including fishing practices, revenue generated, etc., must be included.

A proposal for a focal species research agenda

When placing the focus of management on a certain species/suite of species with the ultimate intention to account for ecosystem processes, it is of vital importance that the ecological role of the focal species in the ecosystem be well understood. The only defensible way in which to make a choice as to which species are suitable as focal is by means of applying ecological knowledge to understanding the ecological role of species. The first and foremost area in which research should be strengthened is therefore in ecosystems ecology, including foodweb dynamics and landscape/seascape ecology. Our knowledge in this area is still in its infancy, but it seems to lead to very promising grounds. Computer-based modeling techniques, preferably those accounting for the spatial dimension of ecological phenomena, offer more and more stimulating opportunities to undertake the study of ecological relationships.

The main strength of the focal species approach lies in using their distribution areas as the building blocks for systems of interdependent reserves on a regional level. Focal species analysis identifies high-value habitats (potential candidate sites) and addresses some of the key questions regarding reserve network design: how much area is needed? What would the ideal size of the reserves be? What should the configuration of the components of the network be? etc. (Miller *et al.* 1998/98). Migratory species in turn could aid much in the design of ecological corridors between reserves. Focal species abundance and distribution data are of unquestionable importance.

A call is made to encourage research aimed at compiling exhaustive databases of abundance and distribution areas of potential focal species. Demographic studies should also be carried out to determine viability of populations, as focal species whose populations were no longer viable would be of little use to afford protection to other species (see for example Berger's (1997) study on the problems created by using a non viable population of rhinoceros as a focal species).

How focal species distribution relates to representative and/or distinct habitats, as well as enduring features and recurrent processes, emerge as some of the key potential research questions. If we are to rely on focal species spatial distribution to assign conservation value to habitats, the association between the species and their spaces must be thoroughly characterized and quantified.

This tactic is currently being scientifically tested in a number of case studies, both terrestrial and marine. In the Klamath-Siskiyou ecoregion of southwest Oregon and northwest California, R. Noss and collaborators are using the Pacific fisher (*Martes pennanti pacifica*) as a potential focal species for

its association with older forests and sensitivity to landscape-scale habitat fragmentation (Noss *et al.* 1999). Other projects embedded in the Wildlands Project (www.twp.org) are studying other species (gray wolf, grizzly bear, wolverine, etc.).

In marine conservation, ecosystem-based approaches use physical parameters to map habitats. However, while this type of mapping captures representativeness of the marine environment at a certain scale it may not successfully identify distinct areas consisting of physical anomalies. Preliminary research shows that there is an association between large focal species and these distinctive areas. For example, whales tend to migrate to areas of high prey concentrations, caused by upwelling or gyres, for feeding (Evans *et al.* 2003). The University of Guelph and the Atlantic Office of WWF Canada are engaged in focal species research, and are looking at cetaceans, seabirds, and other species, and their relationship with distinct areas in the Nova Scotian Continental Shelf.

In an attempt to integrate spatial with ecological considerations of focal species I have placed the emphasis of the analysis on the spatial dimension of ecological processes. This study has shown that there might also be an association between the green sea turtle and what I have defined as physically distinct areas. Focal species research should evolve toward building ecological principles, such as those proposed by Hierarchy Theory, into spatially-based initiatives.

Re-thinking MPAs

Issues that are strictly related to marine reserve network design have also emerged through this study, as focal species analysis must not be the only pillar on which reserve selection and design theory and practice rests. Other issues aligned with the presence of focal species have to be taken into consideration when selecting and assessing candidate sites in the ocean. Unfortunately, terrestrial systems-derived methodologies are not able to provide the answer to many marine conservation problems, as the literature leads us to infer.

In all the marine ecoregional planning case studies reviewed in this thesis (summarized in Table 3), the approach taken does not differ much from what could be being done on a terrestrial system (with the valuable exception of the Scotian Shelf case, where pelagic systems are also considered). In other words, benthic habitats are mapped out with great accuracy, and efforts are aimed at finding the minimum number of planning units that encompass an adequate proportion of the habitat classes representative of the region, as well as those that are unique. Techniques to do this are in some cases astonishingly sophisticated (see for instance the Living Oceans Society report for central British Columbia; Ardron *et al.* 2002).

A world in which the third dimension (depth) holds as much importance as in the ocean, cannot be looked at (or even less so, managed!) from a two-dimensional perspective. MPA networks should give this third dimension an attention that parallels the importance it holds. Certainly, taking into consideration surface variables in combination with bathymetry, as has been

done in this study and elsewhere (Morgan 2002) is a step in the right direction. The future challenge will be to fill the void of data that represents the ever-neglected water column and work toward the design of 3-D MPA networks.

Tying this back to the value of focal species in the design of MPA systems I argue that a focal species approach could be used to integrate some of the ecological processes that take place within the water column, when the species of choice spends at least part of its life-cycle in the pelagic realm. Furthermore, species that come ashore for their vital functions (reproduction, breeding), such as the one explored here, offer a wider range of different habitats that get linked by it.

Networks of marine reserves have to be adapted to the marine environment, where terrestrial paradigms do not work. I have already suggested the possibility of creating water temperature protection zones. This idea can (and must) be taken as far as one's creativity can go. Other traits that need to be extensively reviewed relate to boundaries and connectivity. In a world where environment changes from one minute to the next, fixed, terrestrial-like boundaries do not seem the most appropriate way to go. Mobile boundaries, however, that adjust to changes according to, for instance Chl plume shapes would appear more adequate.

The case study literature deals with connectivity issues too in very much the same way that connectivity is thought of in terrestrial systems. Thus "connectivity" is seen almost as synonymous with "contiguity". This idea completely ignores the fact that marine sites are already connected to one another through the pelagic realm. This could give rise to a whole new area of study on marine corridors design, just as there is one on terrestrial corridors.

To my knowledge, this has never idea has never been put forward before. This is again closely linked with the focal species approach. 3D GIS techniques, coupled with satellite tracking data, would allow design of marine corridors based on migratory species habitat use patterns.

In light of all the above-mentioned potential tracks for future research and areas for development, it stands out that there is a need for a shift in traditional marine reserve paradigms, far too influenced by terrestrial ecology and thus incapable of accommodating ocean ecology principles. Parallel to this, emerges an increasing necessity to continue improving GIS software packages that permit the handling of 3-dimensional information.

In spite of our widely acknowledged ignorance of marine ecosystems functioning, we use and abuse the ocean in many ways, unaware of the implications that our actions have in the unknown depths. It is time that we bring together the innovative technological tools that we have access to today and human curiosity and set out to develop a sound science of marine conservation. We owe the ocean our care.

REFERENCES

- Aiken, J. J., B.J. Godley, A.C. Broderick, T. Austin, G. Elbanks-Petrie and G.C. Hays 2001. *Two hundred years after a commercial marine turtle fishery: the current status of marine turtles nesting in the Cayman Islands*. *Oryx* **35** (2): 145-151.
- Airamé, S., J.E. Dugan, K.D. Lafferty, H. Leslie, D.A. McArdle, and R.R. Warner 2003. *Applying ecological criteria to marine reserve design: a case study from the California Channel Islands*. *Ecological Applications* (Supplement) **13** (1): S170-S184.
- Alexander, L. M. 1993. Large Marine Ecosystems: A new focus for marine resource management. *Marine Policy* **17** (3): 186-198.
- Allison, G. W., J. Lubchenco, and M. H. Carr 1998. *Marine reserves are necessary but not sufficient for marine conservation*. *Ecological Applications* (Supplement) **8** (1): S79-S92.
- Andelman, S., I. Ball, F. Davis, and D. Stoms 1999. *Sites V.1.0. An analytical toolbox for designing ecoregional conservation portfolios*. Manual prepared for The Nature Conservancy. National Center for Ecological Analysis and Synthesis, Santa Barbara, California, USA.
- Anderson, T. D. 1984. *Geopolitics of the Caribbean: ministates in a wider world*. New York, Praeger.
- Apollonio, S. 2002. *Hierarchical perspectives on marine complexities: searching for systems in the Gulf of Maine*. New York, Columbia University Press.
- Ardron, J., J. Lash, and D. Haggarty 2002. *Modelling a network of marine protected areas for the central coast of British Columbia*. Ver. 3.1.

- Sointula, B.C., Living Oceans Society. Available on-line at http://www.livingoceans.org/documents/LOS_MPA_model_v31_web.pdf
- Ardron, J. 2002. *A GIS recipe for determining benthic complexity: an indicator of species richness*. In: J. Breman (eds.), *Marine Geography: GIS for the Oceans and Seas*. Redlands, California, ESRI Press Pp. 169-175.
- Ardron, J. 2003 Pers. comm.
- Bakun, A., J. Beyer, D. Pauly, J.G. Pope and G.D. Sharp 1982. *Ocean Sciences in Relation to Living Resources*. Canadian Journal of Fisheries and Aquatic Sciences **39** (7): 1059-1070
- Ball, I. R., and H.P. Possingham 1999. *SPEXAN manual: version 3.1*. Adelaide University, Adelaide, South Australia, Australia. Available on-line at www.ecology.uq.edu.au/marxan.htm.
- Ball, I. R., and H.P. Possingham 2002. *MARXAN: a reserve system selection tool*. Available on-line at www.ecology.uq.edu.au/marxan.htm.
- Ballantine, W. J. 1995. *Networks of "no-take" marine reserves are practical and necessary*. In: N. L. Shackell, and J.H.M. Willison (eds.), *Marine Protected Areas and sustainable fishing*. Wolfville, Nova Scotia, Science and Management of Protected Areas Association. Pp. 13-20.
- Beck, M. W., and M. Odaya 2001. *Ecoregionnal planning in marine environments: identifying priority sites for conservation in the northern Gulf of Mexico*. Aquatic Conservation: Marine and Freshwater Ecosystems **11**: 235-242.
- Bedward, M., R.L. Pressey, and D.A. Keith 1992. *A new approach for selecting fully representative reserve networks: Addressing efficiency, reserve*

- design and land suitability with an iterative analysis. Biological Conservation* **61** (2): 115-125.
- Berger, J. 1997. *Population constraints associated with the use of black rhinos as an umbrella species for desert herbivores. Conservation Biology* **11**: 69-78
- Biggs, D., R. Leben, and J. Ortega-Ortiz 2000. *Ship and satellite studies of mesoscale circulation and sperm whale habitats in the northeast Gulf of Mexico during GulCet II. Gulf of Mexico Science* **I**: 15-22.
- Bjorndal, K. A. 1980. *Nutrition and grazing behaviour of the green turtle, Chelonia mydas. Marine Biology* **56** (2), 147-154
- Bjorndal, K. A. 1985. *Nutritional ecology of sea turtles. Copeia* **3**: 736-751.
- Bohnsack, J. A. 1998. *Ecosystem management, marine reserves, and the art of airplane maintenance. Proceedings of the 50th Gulf and Caribbean Fisheries Institute: Pp. 304-311.*
- Botsford, L. W., J.C. Castilla, and C.H. Peterson 1997. *The management of fisheries and marine ecosystems. Science* **277**: 509-515.
- Burrough, P. A. 1986. *Principles of Geographical Information Systems for land resource assessment. Oxford, Clarendon Press.*
- Bustamante, R., K.J. Collins, and R. Bensted-Smith 2000. *Biodiversity conservation in the Galapagos Marine Reserve. Proceedings of the Symposium "Science for Conservation in Galapagos" April 15, 1998. Bulletin de L'Institut Royal des Sciences Naturelles de Belgique* **70**, Supplement.

- Carr, A., M.H. Carr and A.B. Meylan 1978. *The ecology and migrations of sea turtles, 7. The West Caribbean green turtle colony*. Bulletin of the American Museum of Natural History **162**: 5-46.
- Carr, A. and A.B. Meylan 1980. *Evidence of passive migration of green turtle hatchlings in Sargassum*. Copeia **2**: 366-368.
- Casey, K. 2004. Pers. comm.
- Caughley, G., and A. Gunn 1996. *Conservation Biology in theory and practice*. Cambridge, Massachusetts, Blackwell Science.
- Celone, P., and C. Damon 2001. *Large Marine Ecosystems: connecting local efforts to global concerns*. Maritimes **43** (2): 10-13.
- Crowder, L. B., S.J. Lyman, W.F. Figueira and J. Priddy 2000. *Source-Sink population dynamics and the problem of siting marine reserves*. Bulletin of Marine Science **66**(3): 799-820.
- Diamond, J. M. 1975. *The island dilemma: lessons of modern biogeographic studies for the design of natural reserves*. Biological Conservation **7**: 129-146.
- Dingle, H. 1996. *Migration: the biology of life on the move*. New York, N.Y., Oxford University Press.
- Doubleday, N. 2003. Pers. comm.
- Drake, L.A., F.C. Dobbs and R.C. Zimmerman 2003. *Effects of epiphyte load on optical properties and photosynthetic potential of the seagrasses Thalassia testudinum Banks ex Koenig and Zostera marina L.* Limnology and Oceanography **48** (1, part 2): 456-463
- Earl, C. 2003. Pers. comm.

- Etnoyer, P. 2001. *Sources, sinks and the spatial distribution of coral reefs in two large marine ecosystems*. Nicholas School of the Environment. Beaufort, N. C., Duke University Marine Laboratory.
- Evans, S.M.J., J.C. Roff, and H. Alidina 2003. *Linking ecosystem-based and single-species approaches to marine conservation*. Fifth International Conference of the Science and Management of Protected Areas Association, Victoria B.C., May 11-16, 2003. Paper Presentation.
- Ferdana, Z. 2002. *Approaches to integrating a marine GIS into The Nature Conservancy's ecoregionnal planning process*. In: J. Breman (eds.), *Marine Geography: GIS for the oceans and seas*. Redlands, WA, ESRI Pp. 151-158.
- Fiske, S.J. 1992. *Sociocultural aspects of establishing Marine Protected Areas*. *Ocean Coastal Management* **18**: 25-46
- Fratantoni, D. M. 2001. *North Atlantic surface circulation during the 1990's observed with satellite-tracked drifters*. *Journal of Geophysical Research* **106**: 22067-22093.
- García-Charton, J. A., and A. Pérez-Ruzafa 1999. *Ecological heterogeneity and the evaluation of the effects of marine reserves*. *Fisheries Research* **42**: 1-20.
- Geoghegan, T., A.H. Smith, and K. Thacker 2001. *Characterization of Caribbean marine protected areas: an analysis of ecological, organizational, and socio-economic factors*. Caribbean Natural Resources Institute (CANARI).
- Gordon, A. L. 1967. *Circulation of the Caribbean Sea*. *Journal of Geophysical Research* **72**: 6207-6223.

- Haury, L. R., J.A. McGowan, and P.H. Wiebe 1978. *Patterns and processes in the time-space scales of plankton distribution*. In: J. H. Steele (eds.), *Spatial pattern in plankton communities*. New York and London, Plenum Press. Published in coordination with NATO Scientific Affairs Division.
- Hemingway, E. 1952. *The old man and the sea*. New York, Charles Scribner's Sons.
- Holling, C. S., D.W. Schindler, B.W. Walker, and J. Roughgarden 1995. *Biodiversity in the functioning of ecosystems: an ecological synthesis*. In: C. A. Perrings, K-G. Mäller, C. Folke, C.S. Hollings, and B.O. Jason (eds.), *Biodiversity loss: ecological and economical issues*. Cambridge (England), Cambridge University Press. Pp. 44-83.
- Holmes, E. E., and P.M. Kareiva 2000. *Using single-species measurements to anticipate community consequences of environmental contaminants*. In: P. H. Albers, G.H. Heinz, and H.M. Ohlendorf (eds.), *Environmental contaminants and terrestrial vertebrates: effects on populations, communities and ecosystems*, SETAC Press. Pp. 149-178.
- Hughes, G. R. 1982. *Nesting cycles in sea turtles: typical or atypical?* In: K. A. Bjorndal (eds.), *Biology and Conservation of Sea Turtles: revised edition*. Proceedings of the World Conference on Sea Turtle Conservation Washington D.C., 26-30 November 1979, with contributions on Recent Advances in Sea Turtle Biology and Conservation, 1995. Washington and London, Smithsonian Institution Press.
- IUCN 1994. *Guidelines for Protected Area Management Categories*. Gland, Switzerland and Cambridge, UK, IUCN Publications Services.

- Jonzén, N., P. Lundberg, and A. Gårdmark 2001. *Harvesting spatially distributed populations*. Wildlife Biology **7** (3): 197-203.
- Kaufman, L., and P. Dayton 1997. *Impacts of marine resource extraction on ecosystem services and sustainability*. In: G. C. Daily (eds.), *Nature's services: societal dependence on natural ecosystems*. Washington D.C., Island Press. Pp. 275-293.
- Kinder, T. H. 1983. *Shallow currents in the Caribbean Sea and Gulf of Mexico as observed with satellite-tracked drifters*. Bulletin of Marine Science **33** (2): 239-246.
- King, F. W. 1982. *Historical review of the decline of the green turtle and the hawksbill*. In: K. A. Bjorndal (eds.), *Biology and Conservation of Sea Turtles*. Proceedings of the World Conference on Sea Turtle Conservation, Washington D.C. 1979. Washington, D.C., Smithsonian Institution Press. Pp. 183-188.
- Kirkpatrick, J. B. 1983. *An iterative method for establishing priorities for selection of natural reserves: an example from Tasmania*. Biological Conservation **25**: 127-134.
- Kjerfve, B., W.J. Wiebe, H.H. Kremer, W. Salomons, and J.I. Marshall Crossland 2002 *Caribbean basins: Land Ocean Interaction in the Coastal Zone (LOICZ) Global Change Assessment and Synthesis of river catchment/islands-coastal sea interactions and human dimensions; with a desktop study of Oceania Basins*. LOICZ reports and Studies No. 27. The Netherlands, LOICZ IPO, Texel.
- Larade, K. 2003. Pers. comm.

- Lauck, T., C.W. Clark, M. Mangel, and G. R. Munro 1998. *Implementing the Precautionary Principle in Fisheries Management Through Marine Reserves*. Ecological Applications (Supplement) **8** (1): S72-S78.
- Leslie, H., M. Ruckelshaus, I.R. Ball, S. Andelman, and H.P. Possingham 2003. *Using siting algorithms in the design of marine reserve networks*. Ecological Applications (Supplement) **13** (1): S185-S198.
- Longhurst, A. R., and D. Pauly 1987. Ecology of tropical oceans. San Diego, California, Academic Press, Inc.
- Longhurst, A. 1998. Ecological geography of the sea. San Diego, Academic Press.
- Lubchenco, J., S.R. Palumbi, S.D. Gaines, and S. Andelman 2003. *Plugging a hole in the ocean: the emerging science of marine reserves*. Ecological Applications (Supplement) **13** (1): S3-S7.
- Lundberg, P., and N. Jonzén 1999. *Spatial population dynamics and the design of marine reserves*. Ecology Letters **2**: 129-134.
- Lundberg, J., and F. Moberg 2003. *Mobile link organisms and ecosystem functioning: Implications for ecosystem resilience and management*. Ecosystems **6**: 87-98.
- MacArthur, R. H., and E.O. Wilson 1963. *An equilibrium theory of insular zoogeography*. Evolution **17**: 373-387.
- MacArthur, R. H., and E.O. Wilson 1967. The theory of island biogeography. Princeton, N.J., Princeton University Press.
- Mandelli, E.F. and E. Ferraz de Reyes 1982. *Primary production and phytoplankton dynamics in a tropical inlet, Gulf of Cariaco, Venezuela*. Int. Rev. Gesamten Hydrobiol. **67** (1): 85-95

- Mann, K. H., and J.R.N. Lazier 1996. *Dynamics of marine ecosystems: biological-physical interactions in the oceans*. Boston, Blackwell Science.
- Margules, C. R., A.O. Nicholls, and R.L. Pressey 1988. *Selecting networks of reserves to maximize biological diversity*. *Biological Conservation* **43** (1): 63-76.
- McDonnell, M. D., H.P. Possingham, I.R. Ball, and E.A. Cousins 2002. *Mathematical methods for spatially cohesive reserve design*. *Environmental Modeling and Assessment* **7**: 107-114.
- Meyland, A. B. 1982. *Sea turtle migration: evidence from tag returns*. In: K. A. Bjorndal (eds.), *Biology and Conservation of Sea Turtles*. Proceedings of the World Conference on Sea Turtle Conservation, Washington D.C. 1979. Washington D.C., Smithsonian Institution Press. Pp. 91-100.
- Miller, B., R. Reading, J. Strittholt, C. Carroll, R. Noss. M. Soule, O. Sanchez, J. Terborgh, D. Brightsmith, T. Cheeseman, and D. Foreman 1998/99. *Using focal species in the design of nature reserve networks*. *Wild Earth* **8** (4): 81-92.
- Moberg, F., and C. Folke 1999. *Ecological goods and services of coral reef ecosystems*. *Ecological Economics* **29**(2): 215-233.
- Morgan, J. R. 1987. *Large Marine Ecosystems: an emerging concept of regional management*. *Environment* **29**(10): 4-9.
- Morgan, L., and P. Etnoyer 2002. *The Baja California to Bering Sea priority areas mapping initiative and the role of GIS in protecting places in the sea*. In: J. Breman (eds.), *Marine Geography: GIS for the oceans and seas*. Redlands, California, ESRI Press Pp. 137-142.

- Morgan, L. 2003. *Identifying priority conservation areas for the Baja California to Bering Sea region*. Fifth International Conference of the Science and Management of Protected Areas Association, Victoria B.C., May 11-16, 2003. Paper Presentation.
- Muller-Karger, F. E., and R. Aparicio Castro 1994. *Mesoscale processes affecting phytoplankton abundance in the southern Caribbean Sea*. Continental Shelf Research **14** (2/3): 199-221.
- Murphy, D. D., and B.R. Noon 1992. *Integrating scientific methods with habitat conservation planning: reserve design for northern spotted owls*. Ecological Applications **2** (1): 3-17.
- Nietschmann, B. 1982. *The cultural context of sea turtle subsistence hunting in the Caribbean and problems caused by commercial exploitation*. In: K. A. Bjorndal (eds.), *Biology and Conservation of Sea Turtles*. Proceedings of the World Conference on Sea Turtle Conservation, Washington D.C. 1979. Washington, D.C., Smithsonian Institution Press. Pp. 439-445.
- Noss, R. F. 1992. *The Wildlands Project: land conservation strategy*. Wild Earth (Special Issue): 10-25.
- Noss, R. F., and A. Cooperrinder 1994. *Saving Nature's Legacy: protecting and restoring biodiversity*. Washington D.C., Defenders of Wildlife and Island Press.
- Noss, R. F., J. R. Strittholt, K. Vance-Borland, C. Carroll, and P. Frost 1999. *A conservation plan for the Klamath-Siskiyou Ecoregion*. Natural Areas Journal **19** (4): 392-411.

- O'Neill, R. V., D.L. DeAngelis, J.B. Waide, and T.F.H. Allen 1986. A hierarchical concept of ecosystems. Princeton, New Jersey, Princeton University Press.
- Odgen, J.C. 1980. *Faunal relationships in Caribbean seagrass beds*. In: Phillips, R.C., and C.P. McRoy (eds.), *Handbook of seagrass biology: an ecosystem perspective*. New York, Garland STPM Press
- Odgen, J. C., and E.H. Gladfelter (eds.) 1983. *Coral reefs, seagrass beds, and mangroves: their interaction in the coastal zones of the Caribbean*. Report of a workshop held at the West Indies Laboratory, St. Croix, US Virgin Islands, UNESCO Reports in Marine Science 23.
- Oliver, J., and M. Noordeloos 2002. *ReefBase: A Global Information System on Coral Reefs*. , World Wide Web electronic publication (www.reefbase.org).
- Ormerod, S. J., and A.R. Watkinson 2000. *Large-scale ecology and hydrology: an introductory perspective from the editors of the Journal of Applied Ecology*. *Journal of Applied Ecology* **37**: 1-5.
- Páramo, J., R.A. Quinones, A. Ramirez, and R. Wiff 2003. *Relationship between abundance of small pelagic fishes and environmental factors in the Colombian Caribbean Sea: an analysis based on hydroacoustic information*. *Aquatic Living Resources* **16**: 239-245.
- Pauly, D. 1998. *Large Marine Ecosystems: analysis and management*. *South African Journal of Marine Sciences* **19**: 487-499.
- Pauly, D., V. Christensen, and C. Walters 2000. *Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries*. *ICES Journal of Marine Science* **57** (3): 697-706.

- Peterson, C. H., and J. Lubchenco 1997. *Marine ecosystem services*. In: G. C. Daily (eds.), *Nature's services: societal dependence on natural ecosystems*. Washington D.C., Island Press. Pp. 177-194.
- Pinnegar, J. K., N.V.C. Polunin, P. Francour, F. Badalamenti, R. Chemello, M.-L. Harmelin-Vivien, B. Hereu, M. Milazzo, M. Zabala, G. D'Anna, and C. Pipitone 2000. *Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management*. *Environmental Conservation* **27** (2): 179-200.
- Planes, S., R. Galzin, G. Rubies, R. Goni, J-G. Harmelin, L. Le Direach, P. Lenfant, and A. Quetglas 2000. *Effects of Marine Protected Areas on recruitment processes with special reference to Mediterranean littoral ecosystems*. *Environmental Conservation* **27** (2): 126-143.
- Podestá, G. P., J.A. Browder, and J.J. Hoey 1993. *Exploring the association between swordfish catch rates and thermal fronts on U.S. longline grounds in the western North Atlantic*. *Continental Shelf Research* **13** (2/3): 253-277.
- Polis, G. A., W.B. Anderson, and R.D. Holt 1997. *Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs*. *Annual Review of Ecology and Systematics* **28**: 289-316.
- Polovina, J. J. 1984. *The ECOPATH model and its applications to French Frigate Shoals*. *Coral Reefs* **3**: 1-11.
- Possingham, H., I. Ball, and S. Andelman 2000. *Mathematical methods for identifying representative reserve networks*. In: S. Ferson, and M. Burgman (eds.), *Quantitative methods for conservation biology*. New York, Springer-Verlag. Pp. 291-305.

- Pough, F. H., R.M. Andrews, J.E. Cadle, M.L. Crump, A.H. Savitzky and K.D. Wells 1998. *Herpetology*. Upper Saddle River, N.J., Prentice Hall.
- Rakitin, A., and D.L. Kramer 1996. *Effect of a marine reserve on the distribution of coral reef fishes in Barbados*. Marine Ecology Progress Series **131**: 97-113.
- Rangeley, R., J.C. Roff, H. Alidina, J. Laughren, S. Clark-Stuart, and A. Chatwin 2003. *Towards a network of marine protected areas in the greater Gulf of Maine and Scotial Shelf*. Fifth International Conference of the Science and Management of Protected Areas Association, Victoria B.C., May 11-16, 2003. Poster Presentation.
- Richards, W. J., and J.A. Bohnsack 1990. *The Caribbean Sea: a large marine ecosystem in crisis*. In: K. Sherman, Alexander, L.M., and Gold, B.D. (eds.), *Large Marine Ecosystems: patterns, processes and yields*. Washington, D.C., American Association for the Advancement of Science
- 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. 1997. *Connectivity and management of Caribbean coral reefs*. Science **278**: 1454-1457.
- Roberts, C. M. 1998. *Sources, sinks, and the design of marine reserve networks*. Fisheries **23** (7): 16-19.
- Roberts, C. M., J.A. Bohnsack, F. Gell, J.P. Hawkins, and R. Goodridge 2001. *Effects of marine reserves on adjacent fisheries*. Science **294**: 1920-1923.
- Roberts, C. M., S. Andelman, G. Branch, R.H. Bustamante, J.C. Castilla, J. Dugan, B.S. Halpern, K.D. Lafferty, H. Leslie, J. Lubchenco, D. McArdle,

- H.P. Possingham, M. Ruckelshaus, and R.R. Warner 2003. *Ecological criteria for evaluating candidate sites for marine reserves*. Ecological Application (Supplement) **13** (1): S199-S214.
- Roff, J. C., and M.E. Taylor 2000. *National frameworks for marine conservation: a hierarchical geophysical approach*. Aquatic Conservation: Marine and Freshwater Ecosystems **10** (3): 209-223.
- Roff, J. C., and M.J.S. Evans 2002. *Frameworks for marine conservation: non-hierarchical approaches and distinctive habitats*. Aquatic Conservation: Marine and Freshwater Ecosystems **12**: 635-648.
- Rowley, R. J. 1994. *Marine reserves and fisheries management*. Aquatic Conservation **4**: 233-254.
- Russ, G. R., and A.C. Alcala 1996. *Marine reserves: rates and patterns of recovery and decline of large predatory fish*. Ecological Applications **6**: 947-961.
- Sala, E., O. Aburto-Oropeza, G. Paredes, I. Parra, J.C. Barrera, and P.K. Dayton 2001. *A general model for designing networks of marine reserves*. Science **298**: 1991-1993.
- SAMPAA 2003. Fifth International Conference of the Science and Management of Protected Areas Association, Victoria B.C., May 11-16, 2003. In prep.
- Sandwith, T., C. Shine, L. Hamilton, and D. Sheppard 2001. *Transboundary Protected Areas for Peace and Co-operation*. Best Practice Protected Area Series No. 7, IUCN.
- Schick, R. 2002. *Using GIS to track right whales and bluefin tuna in the Atlantic Ocean*. In: D. Wright (eds.), Undersea with GIS. Redlands, California, ESRI Press Pp. 65-81.

- Sherman, K., and L.M. Alexander 1986. *Variability and management of large marine ecosystems*. AAAS Selected Symposium 99 Boulder, CO, Westview Press.
- Sherman, K., L.M. Alexander, and B.D. Gold 1990. *Large Marine Ecosystems: patterns, processes and yields*. AAAS., Washington, D.C.
- Simberloff, D. S., and Abele, G.A. 1976. *Island Biogeography Theory and conservation practice*. Science **191**: 285-286.
- Simpson, J.G., and R.C. Griffiths 1971. *Upwelling and biological production in the Gulf of Cariaco, Venezuela*. Ser. Recurs. Explot. Pesq., Venez. **2** (1): 1-23
- Soule, M. E., and Simberloff, D.S. 1986. *What do genetics and ecology tell us about the design of nature reserves?* Biological Conservation **35**: 19-40.
- Stewart, R. R., and H.P. Possingham 2002. *A framework for systematic marine reserve design in South Australia: a case study*. Presented at the Inaugural World Congress on Aquatic Protected Areas, Cairns, August 2002.
- Theobald, D. M. 2000. GIS concepts and ArcView methods. Fort Collins, Colorado, Natural Resource Ecology Laboratory, Colorado State University.
- Tuck, G. N., and H.P. Possingham 2000. *Marine Protected Areas for spatially structured stocks*. Marine Ecology Progress Series **192**: 89-101.
- Van't Hof, T. 1992. *Coastal and marine protected areas in the Caribbean: how can we make them work?* Parks **3** (1): 32-35.
- Walters, C., Pauly, D, and Christensen, V. 1999. *Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited*

- ecosystems, with emphasis on the impacts of Marine Protected Areas. Ecosystems* **2**: 539-554.
- Ward, V., Vanderklift, M.A., Nicholls and Kenchington 1999. *Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity. Ecological Applications* **9** (2): 691-698
- Williams, P., D. Gibbons, C. Margules, A. Rebelo, C. Humphries, and R. Pressey 1996. *A comparison of richness hotspots, rarity hotspots, and complementary areas for conserving diversity of British birds. Conservation Biology* **10** (1): 155-174.
- Williams, I. D., and N.V.C. Polunin 2001. *Large-scale associations between macroalgal cover and grazer biomass on mid-depth reefs in the Caribbean. Coral Reefs* **19** (4): 358-366.
- Witham, P. R. 1976. Evidence for ocean-current-mediated dispersal in young green turtles, Chelonia mydas (Linnaeus), Master's Thesis: University of Oklahoma.
- Wood, F. and J. Wood 1993. *Release and recapture of captive-bred green sea turtles, Chelonia mydas, in the waters surrounding the Cayman Islands. Herpetological Journal* **3**: 84-89
- Yodzis, P. 1998. *Local trophodynamics and the interaction of marine mammals and fisheries in the Benguela ecosystem. Journal of Animal Ecology* **67**: 635-658.

APPENDIX 1. MPA DATABASE

Country	MPA name	IUCN	lat	long	date	size (ha)
Antigua and Barbuda	Diamond Reef Marine National Park	II	17.195999	-61.862	1973	2000
Antigua and Barbuda	Nelson's Dockyard National Park	II	17.009001	-61.782001	1984	4128
Antigua and Barbuda	Palaster Reef Marine National Park	II	17.518999	-61.747002	1973	500
Antigua and Barbuda	Cades Bay Marine Park	II	17.000000	-61.866667	1999	
Antigua and Barbuda	Half Moon Bay National Park	II	17.033300	-61.683300		
Antigua and Barbuda	Crump Island Coral Reef Marine Park	?	17.1	-61.716667		
Antigua and Barbuda	Green Island Reefs Park Reserve	IV	17.066999	-61.667		
Antigua and Barbuda	Northeast Archipelago Park Reserve	IV	17.132999	-61.733002		
Bahamas	Black Sound Cay National Park	IV	23.833300	-75.116700	1988	1
Bahamas	Conception Island National Land and Sea Park	II	23.833300	-75.116997	1973	809
Bahamas	Exuma Land and Sea National Park	II	24.517	-76.650002	1958	45584
Bahamas	Inagua National Park	II	21.092978	-73.366572	1965	74333
Bahamas	Lucayan National Park	II	26.583300	-78.500000	1982	16
Bahamas	Pelican Cays Land and Sea National Park	II	26.4077	-77.000000	1981	850
Bahamas	Peterson Cay National Park	II	26.549999	-78.516998	1971	1
Barbados	Barbados Marine Reserve	II	13.166600	-59.650000	1980	250
Belize	Glover's Reef Marine Reserve	IV	16.755215	-87.840806	1993	30800
Belize	Hol Chan Marine Reserve	IV	17.867001	-87.992996	1987	1100
Belize	Bacalar Chico Marine Reserve	IV	18.137231	-87.873974	1996	10700
Belize	Laughing Bird Caye National Park	II	16.433300	-88.183300	1991	4300
Belize	South Water Cay Marine Reserve	IV	16.732316	-88.151008	1996	29800
Belize	Sapodilla Cayes Marine Reserve	IV	16.145227	-88.293425	1996	12700
Belize	Gladden Spit Marine Reserve	IV	16.55	-88.05	2000	
Belize	Port Honduras Marine Reserve	IV	16.25604	-88.7	2000	
Cayman Islands	Cayman Dive Lodge Replenishment Zone	IV	19.293524	-81.119743	1986	4
Cayman Islands	Frank Sound Replenishment Zone	IV	19.296545	-81.177197	1986	224
Cayman Islands	Little Sound Ecological Zone	Ib	19.333300	-81.266700	1986	1731
Cayman Islands	North Sound Replenishment Zone	IV	19.341170	-81.312984	1986	3310
Cayman Islands	Preston Bay-Main Channel Marine Park	II	19.650000	-80.083300	1986	81
Cayman Islands	Salt Water Point-Beach Point Replenishment Zone	IV	19.691999	-79.846001	1986	26
Cayman Islands	South Hole Sound Replenishment Zone	IV	19.674000	-80.056999	1986	316
Cayman Islands	South Sound Replenishment Zone	IV	19.333388	-81.284246	1986	317
Cayman Islands	Spanish Cove Resort-Jetty Marine Park	II	19.383300	-81.383300	1986	8
Cayman Islands	Meagre Bay Pond Animal Sanctuary	IV	19.300000	-81.216700	1976	38
Cayman Islands	North-West Point-West Bay Cemetery Marine Park	II	19.369538	-81.416034	1986	155
Cayman Islands	Victoria House-Sandy Cay Apartments Marine Park	II	19.327564	-81.396949	1986	801
Cayman Islands	Bowse Bluff-Rum Point Marine Park	II	19.373537	-81.276247	1986	60
Cayman Islands	Scotts Anchorage-White Bay Marine Park	II	19.683300	-79.866700	1986	56
Cayman Islands	Dick Sessinger's Bay-Beach Point Marine Park	II	19.666600	-79.863998	1986	143
Cayman Islands	Jennifer Bay-Deep Well Marine Park	II	19.712000	-79.788002	1986	61
Cayman Islands	Bloody Bay-Jackson Point Marine Park	II	19.666600	-80.066700	1986	161
Cayman Islands	Head of Barkers-Flats Marine Park	II	19.393768	-81.377837	1986	365
Cayman Islands	West Bay Cemetery-Victoria House Marine Park	IV	19.363087	-81.405843	1986	69
Cayman Islands	Radio Mast-Sand Bluff Replenishment Zone	IV	19.314162	-81.086881	1986	177
Cayman Islands	Spotter Bay-Sand Bluff Replenishment Zone	IV	19.350000	-81.116600	1986	63
Cayman Islands	Mary's Bay-East Point Replenishment Zone	IV	19.712999	-79.980003	1986	180
Cayman Islands	Coral Isle Club Replenishment Zone	IV	19.686900	-79.864998	1986	1
Cayman Islands	Bats Cave Beach Replenishment Zone	IV	19.270942	-81.320073	1986	
Cayman Islands	Spott Bay Replenishment Zone	IV	19.750000	-79.750000	1986	
Colombia	Ciénaga Grande de Santa Marta Fauna and Flora Sanctuary	Ia	10.866900	-74.383000	1977	23000
Colombia	Coraes del Rosario Natural National Park	II	10.150000	-75.733333	1977	19506

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Colombia	Old Providence McBean Lagoon Natural National Park	II	13.350000	-81.350000	1996	995
Colombia	Isla Gorgona Natural National Park	II	2.970697	-78.183685	1984	49200
Colombia	Isla de Salamanca Natural National Park	II	10.983300	-74.666700	1969	21000
Colombia	Los Flamencos Fauna and Flora Sanctuary	Ia	11.750000	-72.500000	1977	7000
Colombia	Sanquianga Natural National Park	II	2.550000	-78.366700	1977	80000
Colombia	Sierra Nevada de Santa Marta Natural National Park	II	10.918000	-73.588997	1959	383000
Colombia	Utria Natural National Park	II	5.966667	-77.350000	1987	54300
Colombia	Tayrona Natural National Park	II	11.333000	-74.032997	1964	15000
Colombia	Isla de Malpelo Fauna and Flora Sanctuary	IV	3.984722	-81.591111	1995	
Costa Rica	Cahuita National Park	II	9.700000	-82.800000	1970	1067
Costa Rica	Corcovado National Park	II	8.500000	-83.583300	1975	54539
Costa Rica	Isla del Coco National Park	II	5.533300	-87.066700	1978	2400
Costa Rica	Manuel Antonio National Park	II	9.375800	-84.136002	1972	682
Costa Rica	Santa Rosa National Park	II	10.980000	-85.650000	1971	37217
Costa Rica	Tortuguero National Park	II	10.383300	-83.483300	1975	18946
Costa Rica	Gandoca-Manzanillo National Wildlife Refuge	IV	9.600000	-82.633300	1985	9449
Costa Rica	Barra del Colorado Wildlife Refuge	IV	10.666600	-83.733300	1985	92000
Costa Rica	Isla del Caño Biological Reserve	Ia	8.722823	-83.889613	1978	
Costa Rica	Marino Ballena National Park	II	9.116000	-83.744003	1990	
Cuba	Los Indios-San Felipe Ecological Reserve	IV	21.8144	-83.2011		46076
Cuba	Cayo Guillermo-Santa Maria National/Natural Park	?	22.483300	-78.466700		13000
Cuba	Caguanes Natural Park	?	22.416900	-79.150000		19983
Cuba	Desembarco del Granma National Park	II	19.883300	-77.583300	1980	25764
Cuba	Alejandro de Humboldt Natural Park	V	20.575000	-74.701944		72412
Cuba	Ciénaga de Zapata National Park/Biosphere Reserve	V	22.391111	-82.076944		31474
Cuba	Punta Francés - Punta Pederales Marine National Park	II	21.600000	-83.183300	1985	17424
Cuba	Pico Cristal National Park	II	20.537001	-75.481003	1930	15000
Cuba	Viñales National Park	II	22.6164	-83.7078		13436
Cuba	Cayo Caguama Marine National Park	II	20.5786	-78.4103		1200
Cuba	Cayo Romano Protected Area of Managed Resources	V	22.275843	-78.053096	1986	92000
Cuba	Sur Isla de la Juventud Protected Area of Managed Res.	V	21.426944	-82.886944	1992	80000
Cuba	Centro y Oeste de Cayo Coco Ecological Reserve	IV	22.483889	-78.526111		24 000
Cuba	Lanzanillo-Pajonal Wildlife Refuge	IV	22.9342	-79.7944		87068
Cuba	Cayo Cantiles Wildlife Refuge	Ia	21.616900	-81.900000	1986	3800
Cuba	Cayos de Ana Maria Wildlife Refuge	IV	21.412052	-78.812391		6900
Cuba	Hatibonico Ecological Reserve	IV	19.950000	-75.416700	1980	5220
Cuba	Las Salinas Wildlife Refuge	IV	22.066600	-81.266700	1936	31800
Cuba	Cabo Corrientes Natural Reserve	Ia	21.800000	-84.450000	1963	1578
Cuba	El Veral Natural Reserve	Ia	21.950000	-84.566700	1963	7535
Cuba	Escambray Integrated Management Area	V	22.2372	-79.8975	1986	187000
Cuba	Gran Parque Sierra Maestra Integrated Management A.	V	20.016600	-76.500000	1980	527000
Cuba	Subarchipiélago de Jardines de la Reina Integrated Man. A.	V	20.827071	-78.692933		30580
Cuba	Humedal Nucleo de Sabana - Camaguey Integrated Man. A.	V	22.626062	-79.120020		178908
Cuba	Subarchipiélago de los Canareos Integrated Man. A.	V	21.608889	-82.276111		33110
Dominica	Cabrits National Park	II	15.583300	-61.483002	1986	531
Dominica	Soufriere/Scott's Head Marine Reserve	V	15.230000	-61.383333		
Dominican Republic	Los Haitises National Park	II	19.050000	-69.598800	1976	154300
Dominican Republic	Banco de la Plata Marine Sanctuary	IV	20.916900	-70.666900	1986	7224000
Dominican Republic	Montecristi National Park	II	19.843889	-71.740000	1983	130950
Dominican Republic	Jaragua National Park	II	17.705000	-71.536900	1983	137400

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Dominican Republic	Del Este National Park	II	18.219999	-68.699997	1975	80800
Dominican Republic	Lagunas Redonda y Limón Scientific Reserve	VI	18.996900	-68.928000	1983	10770
Dominican Republic	La Caleta National Park + Underwater Park	II	18.433001	-69.699997	1986	1010
Dominican Republic	Cabo Frances Viejo Natural Park	V	19.667000	-69.967003	1974	
Dominican Republic	Isla Catalina Scientific Reserve	III	18.366667	-69.000000	1995	
Dominican Republic	Litoral Sur de Santo Domingo National Park	II	18.430000	-69.900000	1968	
Grenada	Levera National Park	II	12.216600	-61.600000		222
Guadeloupe	Grand Cul de Sac Marin Nature Reserve	IV	16.358	-61.587	1987	
Guadeloupe	Petite-Terre Nature Reserve	IV	16.15513	-61.11667	1998	
Guadeloupe	Pigeon/Malendure Nature Reserve	IV	16.17714	-61.78475		
Guadeloupe	Saint Bartholemy Nature Reserve	IV	17.93	-62.83333	1996	
Guadeloupe	Saint-Martin Nature Reserve	IV	18.12	-63	1998	
Guatemala	Chocon-Machacas Protected Biotope	II	15.733300	-88.895800	1981	6265
Guatemala	Rio Dulce National Park	VI	15.716600	-88.833300	1955	7200
Honduras	Rio Platano Biosphere Reserve	?	15.833333	-85.000000	1980	500
Honduras	Sandy Bay Marine Reserve	II	16.166900	-86.500000	1992	33800
Honduras	Islas del Cisne Marine National Park	II	17.42303	-84.000000	1991	
Honduras	Laguna Guaimoreto Wildlife Refuge	IV	15.950000	-85.833300	1992	7000
Honduras	Laguna Caratasca Wildlife Refuge	IV	15.500000	-84.050000		120000
Honduras	Turtle Harbor Marine National Park	II	16.133300	-86.916700		
Honduras	Cuero y Salado Wildlife Refuge	IV	15.716600	-86.933300	1987	13225
Honduras	Punta Isopo Wildlife Refuge	IV	15.81443	-87.38333	1992	11200
Honduras	Jeanette Kawas National Park	II	15.816667	-87.350000	1992	78162
Honduras	Cayos Cochinos Marine National Park	II	15.93397	-86.51667	1993	
Honduras	Port Royal National Park	II	16.400000	-86.366700		
Honduras	Punta Sal National Park	II	15.933300	-87.800000	1992	78162
Honduras	Barbareta Wildlife Refuge	IV	16.416600	-86.133300		
Honduras	Laguna de Caratasca Wildlife Refuge	IV	15.500000	-84.050000		120000
Honduras	Punta Condega Wildlife Refuge	IV	13.116600	-87.416700	1992	3900
Honduras	Ragged Cay Wildlife Refuge	IV	16.100000	-86.95		
Honduras	West End Wildlife Refuge	IV	16.283300	-86.600000		
Honduras	Cayos Zapotillos Biological Reserve	?	16.133300	-88.166700		
Honduras	Rio Negro Biological Reserve	IV	15.633300	-85.366700		60000
Honduras	Bahia de Chismuyo Wildlife Refuge	IV	13.35	-87.483	1992	
Honduras	El Jicarito Wildlife Refuge	IV	13.283333	-86.96667	1992	
Honduras	El Quebrachal Wildlife Refuge	IV	13.25	-87.06667	1992	
Honduras	Guameru Wildlife Refuge	IV	13.166667	-87.25	1992	
Honduras	Guapinol Wildlife Refuge	IV	13.1833	-87.25	1992	
Honduras	La Alemania Wildlife Refuge	IV	13.2	-87.0667	1992	
Honduras	Las Iguanas Wildlife Refuge	IV	13.266667	-87.23333	1992	
Honduras	Montecristo Wildlife Refuge	IV	13.183333	-87.13333	1992	
Honduras	Punta Ratón Wildlife Refuge	IV	13.28946	-87.46118		
Honduras	Teonotal Wildlife Refuge	IV	13.31381	-87.678	1992	
Jamaica	Montego Bay Marine Park	II	18.474878	-77.95751	1991	1520
Jamaica	Middle Morant Caye Nature Reserve	?	17.01327	-78.035		
Jamaica	Bogue Lagoon Fisheries Sanctuary	IV	18.433333	-77.950000	1979	
Jamaica	Ocho Rios Protected Area	II	18.425178	-77.05069	1966	
Jamaica	South East Pedro Cay Nature Reserve	?	17	-77.8333		
Jamaica	Negril Marine Park	?	18.316667	-78.36667		
Jamaica	Port Antonio Marine Park	?	18.1833	-76.4667		
Jamaica	Pedro Bank and Cays Management Area	?	17.000000	-77.833300		
Jamaica	Portland Bight Protected Area	V	17.737487	-77.12146	1999	

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Martinique	Martinique Regional Natural Park	V	14.633300	-60.900000	1976	70150
Mexico	Arrecifes de Cozumel Marine National Park	II	20.318942	-87.039562	1996	11988
Mexico	Costa Occidental de Isla Mujeres Marine Refuge	IV	21.227498	-86.743706	1973	664
Mexico	Isla Contoy National Park	II	21.500000	-86.800000	1998	5174
Mexico	Isla Contoy Biosphere Reserve	Ia	21.500000	-86.800000		
Mexico	Playa de Isla Contoy Reserve Zone for Sea Turtle Protection	IV	21.500000	-86.800000	1986	
Mexico	Sistema Arrecifal Veracruzano National Marine Park	II	19.162527	-95.942403	1992	52239
Mexico	El Veladero National Park	II	16.883300	-99.900000	1980	3159
Mexico	Laguna de Chacahua National Park	II	16.000000	-97.666700	1937	14187
Mexico	Tulum National Park	II	20.216600	-87.433300	1981	664
Mexico	Ria Celestun Special Biosphere Reserve	IV	20.878000	-90.344400	1979	59130
Mexico	Ria Lagartos Special Biosphere Reserve	IV	21.500000	-87.866700	1979	47840
Mexico	Sierra de Santa Marta Special Biosphere Reserve	V	18.350000	-94.833300	1980	20000
Mexico	Volcán San Martín Special Biosphere Reserve	V	18.533300	-95.166700	1979	1500
Mexico	Cabo San Lucas Marine Reserve	IV	22.8833	-109.9		1973
Mexico	La Blanquilla Marine Reserve	IV	19.22859	-96.121	1975	66868
Mexico	Los Arcos Marine Reserve	IV	20.6833	-98.75	1975	
Mexico	Playa de Puerto Arista Reserve Zone for Sea Turtle Protection	IV	15.916900	-93.833000	1986	3000
Mexico	Playa Tierra Colorada Reserve Zone for Sea Turtle Protection	IV	16.416900	-98.650000	1986	135
Mexico	Playa de Escobilla Reserve Zone for Sea Turtle Protection	IV	15.700000	-96.666700	1986	75
Mexico	Playa de la Bahia de Chacahua Reserve Zone for Sea Turtle Pr.	IV	15.933000	-97.616900	1986	1740
Mexico	Playa Rancho Nuevo Reserve Zone for Sea Turtle Protection	IV	23.233000	-97.750000	1986	88
Mexico	Playa adyacente a Rio Lagartos Reserve Zone for Sea Turtle Pr.	IV	21.533300	-87.933300	1986	210
Mexico	Amcefes Alacranes National Marine Park	II	22.510239	-89.698062	1994	333769
Mexico	Yum-Balam Flora and Fauna Protection Area	IV	21.500000	-87.250000	1994	154052
Mexico	Laguna de Tíminos Flora and Fauna Protection Area	IV	18.611900	-9.541900	1994	705016
Mexico	Banco Chinchorro Biosphere Reserve (National)	VI	18.590954	-87.350365	1996	144360
Mexico	Dzilam State Reserve	?	21.4	-88.8833		
Mexico	Sian Ka'an Biosphere Reserve (National)	VI	19.495833	-87.715833	1986	528147
Mexico	Arrecifes de Puerto Morelos National Park	II	20.938827	-86.819516	1998	
Mexico	Isla Mujeres, Punta Cancún y Punta Nizuc National Park	V	21.149118	-86.723568	1996	
Mexico	Laguna de Chankanaab Natural Park	?	20.433333	-87	1983	
Mexico	Xcalak National Marine Park	II	18.25	-87.766667	2000	
Netherlands Antilles	Christoffel National Park	II	12.350000	-69.116600	1978	1860
Netherlands Antilles	Curaçao Underwater Park	?	12.050000	-68.833333	1983	
Netherlands Antilles	Saba Marine Park	VIII	17.650000	-63.233333	1987	
Netherlands Antilles	St. Eustatius Marine Park	?	17.467778	-62.972500	1998	
Netherlands Antilles	Bonaire National Park	II	12.166667	-68.250000	1979	5900
Nicaragua	Cayos Miskitos Biological Marine Reserve	Ia	14.395000	-82.810000	1991	50000
Nicaragua	Rio Escalante-Chococente Wildlife Refuge	IV	11.550000	-88.183300	1983	4800
Nicaragua	Delta del Estero Real Nature Reserve	IV	12.883300	-87.250000	1983	55000
Nicaragua	Laguna Bismuna-Raya Nature Reserve	IV	14.783300	-83.366700	1991	11800
Panama	Isla Bastimentos National Marine Park	II	9.300000	-82.116667	1988	13226
Panama	Portobelo National Park	II	9.550000	-79.616667	1976	35929
Panama	Sand Sand Pond Sank Wildlife Refuge	IV	9.308000	-82.893600	1994	16125
Panama	Darién National Park	II	7.866600	-77.783300	1980	579000
Panama	Sarigua National Park	II	8.050000	-80.466700	1984	8000
Panama	Isla Iguana Wildlife Refuge	IV	7.633300	-79.566700	1981	53
Panama	Isla de Cañas Wildlife Refuge	IV	7.4167	-80.3167	1994	25433
Panama	Taboga Wildlife Refuge	IV	8.800000	-79.550000	1984	258
Puerto Rico	Culebra National Wildlife Refuge	IV	18.333300	-65.333300		633
Puerto Rico	Jobos Bay National Estuarine Research Reserve	IV	17.95	-66.2	1981	1133

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Puerto Rico	Mona Island Natural Reserve	IV	18.100000	-67.900002	1986	5554
Puerto Rico	Cayos de la Cordillera Nature Reserve	IV	18.38	-65.580002	1980	88
Puerto Rico	Caja de Muertos Island Nature Reserve	IV	17.89224	-66.518056	1988	188
Puerto Rico	Boqueron Wildlife Refuge	IV	18	-67.129997	1964	
Puerto Rico	La Parguera Nature Reserve	IV	17.96667	-67.066667	1979	
St. Lucia	Maria Islands Nature Reserve/Marine reserve	IV	13.717	-60.917	1982	12
St. Lucia	Soufriere Marine Management Area	VI	13.850000	-61.133333	1994	
St. Lucia	Cas-en-Bas Mangroves Marine Reserve	IV	14.083000	-60.933000	1986	
St. Lucia	Esperance Harbour Mangroves Marine Reserve	IV	14.050000	-60.916900	1986	
St. Lucia	Marquis Mangroves Marine Reserve	IV	14.016900	-60.900000	1986	
St. Lucia	Grand Anse Beach and Mangroves Marine Reserve	IV	14.000000	-60.883000	1986	80
St. Lucia	Louvet Mangroves Marine Reserve	IV	13.966900	-60.883000	1986	80
St. Lucia	Fond d'Or Beach Marine Reserve	IV	13.916900	-60.883000	1986	
St. Lucia	Praslin Mangroves Marine Reserves	IV	13.866900	-61.066900	1986	
St. Lucia	Savane Bay Mangroves Marine Reserve	IV	13.766900	-60.916900	1986	500
St. Lucia	Anse Pointe Sable-Man Kote Mangroves Marine Reserves	IV	13.733000	-60.932999	1986	
St. Lucia	Marigot Bay Mangroves Marine Reserve	IV	13.966900	-61.033000	1986	
St. Lucia	Choc Bay Mangroves Marine Reserve	IV	14.033900	-60.968900	1986	80
St. Lucia	Bois d'Orange Mangroves Marine Reserve	IV	14.001400	-60.950000	1986	80
St. Lucia	Rodney Bay Artificial Reef Marine Reserve	IV	14.083000	-60.966999	1986	
St. Lucia	Anse Chastanet Reefs Marine Reserve	IV	13.867	-61.083	1990	
St. Lucia	Anse Cochon artificial reef Marine Reserve	IV	13.92597	-61.049999	1990	
St. Lucia	Anse Galet-Anse Cochon reefs Marine Reserve	IV	13.92597	-61.049999	1990	
St. Lucia	Anse L'Ivrogne Reef Marine Reserve	IV	13.8	-61.067001	1986	
St. Lucia	Anse Mamin Reef Marine Reserve	IV	13.867	-61.083	1986	
St. Lucia	Caesar Point to Mathurin Point reefs Marine Reserve	IV	13.717	-60.950001	1990	
St. Lucia	Reef Between Grand Caille and Rachette Point Mar. Res.	IV	13.85	-61.067001	1986	
St. Lucia	Reef at Anse de Pitons Marine Reserve	IV	13.817	-61.067001	1986	
St. Lucia	Reef at Malgretoute Marine Reserve	IV	13.833	-61.067001	1986	
St. Lucia	Vigie Beach Artificial Reef Marine Reserve	IV	14.017	-60.983002	1990	
St. Lucia	Moule-a-Chique artificial reef Marine Reserve	IV	13.71145	-60.935	1990	
St. Lucia	Pigeon Island Protected Area	III	14.1	-60.917	1978	
St. Vincent and the Grenadines	Tobago Cays Marine National Park	II	12.616700	-61.349998	1987	3885
St. Vincent and the Grenadines	All Awash Island Wildlife Reserve	IV	12.916700	-61.150000	1987	
St. Vincent and the Grenadines	Battowia Island Wildlife Reserve	IV	12.966700	-61.133300	1987	
St. Vincent and the Grenadines	Big Cay Wildlife Reserve	IV	12.983300	-61.283300	1987	
St. Vincent and the Grenadines	Catholic Island/Catholic Rocks Wildlife Reserve	IV	12.650000	-61.400000	1987	
St. Vincent and the Grenadines	Chateaubelair Islet Wildlife Reserve	IV	13.300000	-61.250000	1987	
St. Vincent and the Grenadines	Frigate Rock Wildlife Reserve	IV	12.567	-61.417	1987	
St. Vincent and the Grenadines	Isle de Quatre Wildlife Reserve	IV	12.950000	-61.250000	1987	
St. Vincent and the Grenadines	La Paz Island Wildlife Reserve	IV	13.200000	-61.283300	1987	
St. Vincent and the Grenadines	Milligan Cay Wildlife Reserve	IV	13.116700	-61.166700	1987	
St. Vincent and the Grenadines	Northern end of Bequia Wildlife Reserve	IV	13.033300	-61.216700	1987	
St. Vincent and the Grenadines	Petit Canouan Wildlife Reserve	IV	12.783300	-61.283300	1987	
St. Vincent and the Grenadines	Petit St. Vincent Wildlife Reserve	IV	12.533300	-61.383300	1987	
St. Vincent and the Grenadines	Pigeon (Ramier) Island Wildlife Reserve	IV	12.950000	-61.266700	1987	
St. Vincent and the Grenadines	Prune (Palm) Island Wildlife Reserve	IV	12.58389	-61.400002	1987	
St. Vincent and the Grenadines	Sail Rock Wildlife Reserve	IV	12.616700	-61.250000	1987	
St. Vincent and the Grenadines	Savan Islands Wildlife Reserve	IV	12.800000	-61.216700	1987	
St. Vincent and the Grenadines	West Cay Wildlife Reserve	IV	12.983300	-61.279999	1987	
St. Vincent and the Grenadines	Young Island Wildlife Reserve	IV	13.133300	-61.200000	1987	

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Suriname	Bigi Pan Multiple Use Management Area	VI	5.966600	-56.816700	1987	68320
Suriname	Wia-Wia Nature Reserve (Wildlife Sanctuary)	IV	5.883300	-54.500000	1961	36000
Suriname	Coppename Rivermouth Nature Reserve	IV	5.950000	-55.700000	1966	12000
Suriname	Galibi Nature Reserve	IV	5.766700	-54.016700	1969	4000
Trinidad and Tobago	Buccoo Reef Marine Park	Ia	11.16439	-60.83128	1973	650
Trinidad and Tobago	Caroni Swamp Wildlife Reserve	Ia	10.566700	-61.450000	1987	200
Turks and Caicos Ids.	Grand Turk Cays Land and Sea National Park	IV	21.382999	-71.099998	1987	156
Turks and Caicos Ids.	South Creek National Park	III	21.450000	-71.133300	1987	74
Turks and Caicos Ids.	Columbus Landfall Marine National Park	IV	21.466700	-71.150000	1992	518
Turks and Caicos Ids.	Admiral Cockburn Land and Sea National Park	IV	21.483300	-71.516700	1992	480
Turks and Caicos Ids.	Admiral Cockburn Nature Reserve	IV	21.466700	-71.566700	1992	431
Turks and Caicos Ids.	East Bay Islands National Park	II	21.916700	-71.883300	1987	3541
Turks and Caicos Ids.	Fort George Land and Sea National Park	IV	21.900000	-72.083300	1987	494
Turks and Caicos Ids.	Chalk Sound National Park	II	21.766700	-72.283300	1987	1460
Turks and Caicos Ids.	West Caicos Marine National Park	IV	21.666667	-72.483002	1992	397
Turks and Caicos Ids.	Bell Sound Nature Reserve	IV	21.533300	-71.516700	1975	1142
Turks and Caicos Ids.	Vine Point and Ocean Hole Nature Reserve	IV	21.700000	-71.833300	1987	757
Turks and Caicos Ids.	Big Sand Cay Sanctuary	IV	21.183300	-71.233300	1987	151
Turks and Caicos Ids.	Pigeon Pond and Frenchman's Creek Nature Res.	IV	21.666700	-72.333300	1992	2393
Turks and Caicos Ids.	North, Middle, and East Caicos Nature Reserve	IV	21.783300	-71.913700	1992	54400
Turks and Caicos Ids.	Long Cay Sanctuary	IV	21.416700	-71.100000	1987	80
Turks and Caicos Ids.	Three Mary Cays Sanctuary	IV	21.966700	-72.000000	1987	13
Turks and Caicos Ids.	French, Bush and Seal Cays Sanctuary	IV	21.167	-71.650002	1987	
USA	Florida Keys National Marine Sanctuary	IV	24.766497	-81.700143		960373
USA	Flower Garden Banks National Marine Sanctuary	V	27.866667	-93.733333	1992	
USA	Looe Key National Marine Sanctuary	V	24.547875	-81.407514	1981	1554
USA	Key Largo Coral Reef National Marine Sanctuary	IV	25.096384	-80.436668	1975	32388
USA	John Pennkamp Coral Reef State Park	V	25.166	-80.3009	1959	3359
USA	Biscayne National Park	II	25.5473	-80.2682	1980	41967
USA	Gulf Islands National Seashore	V	30.400000	-86.766700	1971	57084
USA	Padre Island National Seashore	V	26.600000	-97.316700	1968	54196
USA	Canaveral National Seashore	V	28.750000	-80.716700	1975	23321
USA	Everglades National Park	II	25.38	-80.92	1978	524677
USA	Dry Tortugas National Park	II	24.648786	-82.870373	1992	26183
USA	Great White Heron National Wildlife Refuge	IV	24.666700	-81.633300	1938	2998
USA	Key West National Wildlife Refuge	IV	24.555372	-81.988305	1908	818
USA	J.N. "Ding" Darling National Wildlife Refuge	IV	26.483300	-82.100000	1945	2164
USA	Pine Islands National Wildlife Refuge	IV	26.666700	-81.283300	1908	163
USA	Matlacha Pass National Wildlife Refuge	IV	26.000000	-82.033300	1908	93
USA	Island Bay National Wildlife Refuge	Ib	26.766700	-82.150000	1970	8
USA	National Key Deer National Wildlife Refuge	IV	24.700000	-81.450000	1954	8109
USA	Gray's Reef National Marine Sanctuary	IV	31.4	-80.93	1981	
Venezuela	Archipiélago Los Roques National Park	II	11.865315	-66.780106	1972	221120
Venezuela	Mochima National Park	II	10.307	-64.478996	1973	94935
Venezuela	Isla de Margarita National Park	II	11.000000	-64.083300	1988	1549
Venezuela	El Avila National Park	II	10.533300	-66.666700	1958	85192
Venezuela	Península de Paria National Park	II	10.666700	-62.250000	1978	37500
Venezuela	Isla de Aves Wildlife Refuge	IV	11.973300	-67.649200	1972	54
Venezuela	Laguna de la Restinga National Park	II	10.983300	-64.116700	1974	18862
Venezuela	Laguna de Tacarigua National Park	II	10.233300	-65.833300	1974	39100
Venezuela	Morrocoy National Park	II	10.823	-68.220001	1974	32090
Venezuela	San Esteban National Park	II	10.40547	-67.9729	1987	43500

Country	MPA name	IUCN	lat	long	date	size (ha)
Venezuela	Turuepano National Park	II	10.566700	-62.716700	1991	72600
Venezuela	Juan Manuel de Aguas Blancas y Aguas Negras W. R.	IV	9.366700	-72.000000	1975	71500
Venezuela	Medanos de Coro National Park	II	11.616700	-69.800000	1974	91280
Venezuela	Cuare Wildlife Refuge	IV	10.866700	-68.283300	1972	11825
Venezuela	Cienaga de los Olivitos Wildlife Refuge	IV	10.900000	-71.350000	1986	25723
Venezuela	Henri Pittier National Park	II	10.433300	-67.616700	1937	107000
Virgin Islands (British)	Wreck of the Rhone Marine Park	III	18.366600	-64.550000	1980	324
Virgin Islands (British)	West Dog Island National Park	II	18.483300	-64.466700	1974	12
Virgin Islands (US)	Buck Island National Wildlife Refuge	IV	17.783300	-64.650000	1969	18
Virgin Islands (US)	Green Cay National Wildlife Refuge	IV	17.76711	-64.66667	1977	12
Virgin Islands (US)	U.S. Virgin Islands National Park	II	18.343084	-64.74084	1956	5308
Virgin Islands (US)	Sandy Point National Wildlife Refuge	IV	17.683300	-64.983300		134
Virgin Islands (US)	St James Marine Reserve and Wildlife Sanctuary	?	18.3	-64.85	1994	

APPENDIX 2. TAGGED TURTLE RECOVERY DATA

Id ⁷	Tag	Release date	Latitude	Longitude	Release X coord	Release Y coord
1	00063 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
2	00173 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
3	00174 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
4	00204 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
6	00307 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
7	00386 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
8	00396 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
9	02019 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
10	00426 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
11	00484 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
13	00543 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
14	00543 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
15	00573 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
16	00574 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
17	00586 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
18	00597 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
19	00622 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
20	00637 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
21	00639 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
22	00643 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
23	00665 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
24	00682 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
25	00685 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
26	00720 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
27	00721 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
28	00724 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
29	2011	19841030	19.3	-81.3	-755632.7933	2204881.915
30	2011 Metal	19841030	19.3	-81.3	-755632.7933	2204881.915
31	00755 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
32	00756 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
33	00781 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
34	00784 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
35	00785 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
36	00786 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
37	00792 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
38	00793 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
39	00813 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
41	00841 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
42	00848 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
43	00855 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
44	00864 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
45	00868 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915

⁷ Note that every record has a unique Id number. The Id field helps match up the sections into which the table had to be broken down in order to fit letter-size paper.
Source of the data: CTF

Id	Release site	Recapture date	Recapture X coord	Recapture Y coord
1	Batabano W.B.	19851016	242584.4397	4216306.491
2	Batabano W.B.	19850708	-768375.992	2212572.472
3	Batabano W.B.	19850415	529306.4109	3345609.084
4	Batabano W.B.	19860226	-808729.4546	2444952.307
6	Batabano W.B.	19860108	-606962.1416	2477417.754
7	Batabano W.B.	19890503	-606962.1416	2477417.754
8	Batabano W.B.	19870717	168249.1139	4189180.32
9	Batabano W.B.	19880510	168249.1139	4189180.32
10	Batabano W.B.	19860906	1559381.641	3958734.023
11	Batabano W.B.	19850924	168249.1139	4189180.32
13	North Sound Estates	19860827	168249.1139	4189180.32
14	North Sound Estates	19860924	162939.4477	4189180.32
15	North Sound Estates	19850917	-749261.1939	2202684.009
16	North Sound Estates	19860818	242584.4397	4216306.491
17	North Sound Estates	19860127	-755632.7933	2204881.915
18	North Sound Estates	19850917	-749261.1939	2202684.009
19	North Sound Estates	19860119	-755632.7933	2204881.915
20	North Sound Estates	19870806	168249.1139	4279150.087
21	North Sound Estates	19851010	136391.1171	4051841.718
22	North Sound Estates	19850925	147010.4493	4051841.718
23	North Sound Estates	19850305	-490149.4866	2455781.614
24	North Sound Estates	19870721	168249.1139	4189180.32
25	North Sound Estates	19870521	-755632.7933	2204881.915
26	North Sound Estates	19860822	168249.1139	4189180.32
27	North Sound Estates	19870626	168249.1139	4189180.32
28	North Sound Estates	19860922	200107.1107	3968099.527
29	North Sound Estates	19890628	242584.4397	4207277.241
30	North Sound Estates	19890714	242584.4397	4207277.241
31	North Sound Estates	19860922	168249.1139	4189180.32
32	North Sound Estates	19870716	178868.4461	3968099.527
33	North Sound Estates	19870804	168249.1139	4189180.32
34	North Sound Estates	19850317	-957400.1064	2455781.614
35	North Sound Estates	19860924	178868.4461	3977452.944
36	North Sound Estates	19870723	168249.1139	4189180.32
37	North Sound Estates	19870721	518687.0787	3996123.402
38	North Sound Estates	19850801	-782181.124	2430863.077
39	North Sound Estates	19860822	168249.1139	4189180.32
41	North Sound Estates	19860911	571783.74	3835895.53
42	North Sound Estates	19860911	577093.4061	3826363.812
43	North Sound Estates	19870625	168249.1139	4189180.32
44	North Sound Estates	19870626	518687.0787	3996123.402
45	North Sound Estates	19860710	-829968.1192	2552904.799

Id	Latitude	Longitude	Recapture site	Days	Distance (km)
1	39.2	-71.9	39.20, -71.90	356	2242.41
2	19.37	-81.42	Barker's Beach	256	4.25
3	30.1	-69.2	30.10, -69.20	172	1719.52
4	21.5	-81.8	CUBA, Cayo Largo	489	236.62
6	21.8	-79.9	CUBA, Trinidad	440	307.97
7	21.8	-79.9	CUBA, Trinidad	1651	307.97
8	38.9	-72.6	38.90, -72.60	995	2185.48
9	38.9	-72.6	38.90, -72.60	1293	2185.48
10	36.4	-59.5	36.40, -59.50	681	2906.51
11	38.9	-72.6	38.90, -72.60	334	2185.48
13	38.9	-72.6	38.90, -72.60	667	2188.83
14	38.9	-72.65	38.90, -72.65	695	2186.6
15	19.28	-81.24	Hubert Bodden's Pond	323	6.74
16	39.2	-71.9	39.20, -71.90	658	2245.5
17	19.3	-81.3	North Sound	455	0
18	19.28	-81.24	Hubert Bodden's Pond	323	6.74
19	19.3	-81.3	North Sound	447	0
20	39.9	-72.6	39.90, -72.60	1011	2270.71
21	37.4	-72.9	37.40, -72.90	346	2051.09
22	37.4	-72.8	37.40, -72.80	331	2055.73
23	21.6	-78.8	CUBA, Jucaro	127	365.28
24	38.9	-72.6	38.90, -72.60	994	2188.83
25	19.3	-81.3	North Sound	934	0
26	38.9	-72.6	38.90, -72.60	662	2188.83
27	38.9	-72.6	38.90, -72.60	970	2188.83
28	36.5	-72.3	36.50, -72.30	693	2005.59
29	39.1	-71.9	39.10, -71.90	1702	2237.41
30	39.1	-71.9	39.10, -71.90	1718	2237.41
31	38.9	-72.6	38.90, -72.60	692	2188.83
32	36.5	-72.5	36.50, -72.50	989	1995.55
33	38.9	-72.6	38.90, -72.60	1009	2188.83
34	21.6	-83.2	CUBA, Punta Frances	138	321.96
35	36.6	-72.5	36.60, -72.50	694	2003.82
36	38.9	-72.6	38.90, -72.60	996	2188.83
37	36.8	-69.3	36.80, -69.30	994	2198.28
38	21.37	-81.55	CUBA, Cayo Cantiles	275	227.54
39	38.9	-72.6	38.90, -72.60	661	2188.83
41	35.1	-68.8	35.10, -68.80	681	2102.91
42	35	-68.75	35.00, -68.75	681	2098.9
43	38.9	-72.6	38.90, -72.60	968	2188.83
44	36.8	-69.3	36.80, -69.30	969	2198.28
45	22.5	-82	CUBA, La Ensenada de Broa	618	355.87

Id	Tag	Release date	Latitude	Longitude	Release X coord	Release Y coord
46	00894 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
47	00894 Meta	19850917	19.3	-81.3	-755632.7933	2204881.915
48	00919 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
49	02026 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
50	00922 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
51	00935 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
52	00971 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
53	01015 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
54	01018 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
55	01061 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
56	01087 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
59	01147 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
60	01158 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
61	01158 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
62	01158 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
63	01158 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
76	01352 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
77	01371 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
78	01392 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
79	01401 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
80	01425 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
82	01467 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
83	01499 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
84	01505 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
85	01506 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
87	01540 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
88	01553 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
89	01554 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
90	01555 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
92	01580 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
93	01618 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
94	01641 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
95	01830 Meta	19841024	19.3	-81.12	-736517.9952	2204881.915
96	01889 Meta	19841024	19.3	-81.12	-736517.9952	2204881.915
97	01909 Meta	19841024	19.3	-81.12	-736517.9952	2204881.915
98	01931 Meta	19841024	19.3	-81.12	-736517.9952	2204881.915
99	01990 Meta	19841024	19.3	-81.12	-736517.9952	2204881.915
102	02024 Meta	19880715	19.29	-81.28	-753508.9268	2203782.996
105	02121 Meta	19880511	38.9	-72.6	168249.1139	4189180.32
106	02132 Meta	19861024	19.37	-81.42	-768375.992	2212572.472
107	02141 or 0	19861125	19.3	-81.3	-755632.7933	2204881.915
108	02194 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
109	02255 Meta	19861121	19.37	-81.42	-768375.992	2212572.472
110	02263 Meta	19861126	19.37	-81.42	-768375.992	2212572.472

Id	Release site	Recapture date	Recapture X coord	Recapture Y coord
46	North Sound Estates	19850917	-749261.1939	2202684.009
47	North Sound	19880513	242584.4397	4207277.241
48	North Sound Estates	19870714	571783.74	3816820.439
49	North Sound Estates	19890712	178868.4461	3968099.527
50	North Sound Estates	19880319	-755632.7933	2204881.915
51	North Sound Estates	19850917	-749261.1939	2202684.009
52	North Sound Estates	19860918	571783.74	3778530.969
53	North Sound Estates	19881121	-918108.577	2462275.61
54	North Sound Estates	19870716	168249.1139	4189180.32
55	North Sound Estates	19870623	168249.1139	4189180.32
56	North Sound Estates	19870723	242584.4397	4207277.241
59	North Sound Estates	19860924	178868.4461	3977452.944
60	North Sound Estates	19860819	168249.1139	4189180.32
61	North Sound Estates	19860926	162939.4477	4189180.32
62	North Sound Estates	19870717	168249.1139	4189180.32
63	North Sound Estates	19870723	168249.1139	4189180.32
76	Public Beach W.B.	19860421	-726960.5962	2505499.568
77	Public Beach W.B.	19840023	1272659.67	3759317.057
78	Public Beach W.B.	19890120	-883064.7805	2606591.477
79	Public Beach W.B.	19900923	-782181.124	2430863.077
80	Public Beach W.B.		-1346067.667	1809675.363
82	Public Beach W.B.	19890909	-869259.6485	2617305.123
83	Public Beach W.B.	19851118	-745013.461	2531375.463
84	Public Beach W.B.	19850306	-1350315.4	1847745.749
85	Public Beach W.B.	19860410	-829968.1192	2552904.799
87	Public Beach W.B.	19851008	-1008372.901	2544296.783
88	Public Beach W.B.	19850319	1570000.973	3873905.263
89	Public Beach W.B.	19870624	-726960.5962	2505499.568
90	Public Beach W.B.	19901010	-1498986.052	1961561.16
92	Public Beach W.B.	19860608	-793862.3895	2504420.449
93	Public Beach W.B.	19860827	168249.1139	4189180.32
94	Public Beach W.B.	19860106	-1008372.901	2544296.783
95	East End	19900120	-936161.4418	2491465.074
96	East End	19880620	-606962.1416	2477417.754
97	East End	19880620	-606962.1416	2477417.754
98	East End	19901101	-918108.577	2462275.61
99	East End	19850128	-728022.5294	2462275.61
102	North Sound	19901001	-911736.9776	1648873.88
105	38.90, -72.60	19880711	242584.4397	4207277.241
106	West Indian Club W.B	19861117	-1093327.559	1810795.996
107	North Sound Estates	19890524	-555989.3467	2402647.148
108	Doublehead Shot W.B.	19870623	571783.74	3835895.53
109	Doublehead Shot W.B.	19870105	-808729.4546	2444952.307
110	Doublehead Shot W.B.	19890627	242584.4397	4207277.241

Id	Latitude	Longitude	Recapture site	Days	Distance (km)
46	19.28	-81.24	Hubbert Bodden's Pond	323	6.74
47	39.1	-71.9	39.10, -71.90	969	2237.41
48	34.9	-68.8	34.90, -68.80	987	2088.15
49	36.5	-72.5	36.50, -72.50	1716	1995.55
50	19.3	-81.3	Duck Pond Bight	1236	0
51	19.28	-81.24	Hubbert Bodden's Pond	323	6.74
52	34.5	-68.8	34.50, -68.80	689	2058.74
53	21.66	-82.83	CUBA, Isle of Pines	1484	304.38
54	38.9	-72.6	38.90, -72.60	990	2188.83
55	38.9	-72.6	38.90, -72.60	945	2188.83
56	39.1	-71.9	39.10, -71.90	975	2237.41
59	36.6	-72.5	36.60, -72.50	673	2003.82
60	38.9	-72.6	38.90, -72.60	637	2188.83
61	38.9	-72.65	38.90, -72.65	675	2186.6
62	38.9	-72.6	38.90, -72.60	969	2188.83
63	38.9	-72.6	38.90, -72.60	975	2188.83
76	22.06	-81.03	CUBA, Playa Giron	542	295.84
77	34.3	-62.2	34.30, -62.20	0	2560.91
78	23	-82.5	CUBA, Cayo Blanco	1547	410.37
79	21.37	-81.55	CUBA, Cayo Cantiles	2158	218.73
80	15.74	-86.86	HONDURAS, La Ceiba	0	704.31
82	23.1	-82.37	CUBA, La Habana (North Coa	1779	417.12
83	22.3	-81.2	CUBA, Playa Larga	388	319.66
84	16.08	-86.9	HONDURAS, Utila	131	686.84
85	22.5	-82	CUBA, La Ensenada de Broa	531	345.86
87	22.42	-83.68	CUBA, Pinar del Rio	347	409.44
88	35.5	-59.4	35.50, -59.40	144	2868.45
89	22.06	-81.03	CUBA, Playa Giron	971	295.84
90	17.1	-88.3	BELIZE, Mullings River	2175	772.53
92	22.05	-81.66	CUBA, Cayo Bonito	590	292.96
93	38.9	-72.6	38.90, -72.60	670	2187.29
94	22.42	-83.68	CUBA, Pinar del Rio	437	409.44
95	21.93	-83	CUBA, Punta de los Barcos	1914	349.27
96	21.8	-79.9	CUBA, Trinidad	1335	301.76
97	21.8	-79.9	CUBA, Trinidad	1335	301.76
98	21.66	-82.83	CUBA, Isle of Pines	2199	315
99	21.66	-81.04	CUBA, Cayo Guano	96	257.53
102	14.31	-82.77	NICARAGUA, Miskito Cays	808	577.03
105	39.1	-71.9	39.10, -71.90	61	76.51
106	15.75	-84.48	HONDURAS, Brus Laguna	24	516.74
107	21.11	-79.42	CUBA, Cayo Breton	911	281.01
108	35.1	-68.8	35.10, -68.80	215	2105.04
109	21.5	-81.8	CUBA, Cayo Largo	45	235.86
110	39.1	-71.9	39.10, -71.90	944	2236.27

Id	Tag	Release date	Latitude	Longitude	Release X coord	Release Y coord
111	02287 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
112	02340 Meta	19861121	19.37	-81.42	-768375.992	2212572.472
113	02368 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
115	02404 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
116	02424 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
117	02512 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
118	02527 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
119	02598 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
120	02598 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
121	02603 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
122	02612 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
123	02613 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
124	02731 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
125	02733 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
126	02750 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
127	02816 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
128	02817 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
129	02817 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
130	02823 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
131	02834 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
132	02836 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
134	02860 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
135	02901 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
137	02934 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
138	02935 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
139	02998 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
140	03005 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
141	03011 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
142	03015 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
143	03025 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
144	03104 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
145	03104 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
146	03109 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
147	03114 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
148	03116 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
149	03127 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
150	03127 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
151	03163 Meta	19881206	25.17	-76.23	-217232.6474	2837239.022
152	03214 Meta	19861126	19.3	-81.3	-755632.7933	2204881.915
153	03214 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
154	03218 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
155	03218 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
156	03306 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
157	03311 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915

Id	Release site	Recapture date	Recapture X coord	Recapture Y coord
111	Doublehead Shot W.B.	19870125	-869259.6485	2617305.123
112	Doublehead Shot W.B.	19880512	168249.1139	4189180.32
113	Doublehead Shot W.B.	19900726	1421330.321	4558161.521
115	Doublehead Shot W.B.	19880714	518687.0787	3996123.402
116	Doublehead Shot W.B.		-860764.1827	2623729.485
117	Doublehead Shot W.B.	19891228	-405194.8285	2359141.622
118	Doublehead Shot W.B.	19880513	571783.74	3821593.58
119	North Sound Estates	19880510	571783.74	3821593.58
120	North Sound Estates	19880511	571783.74	3821593.58
121	North Sound Estates	19880513	178868.4461	3968099.527
122	North Sound Estates	19880713	518687.0787	3996123.402
123	North Sound Estates	19870510	242584.4397	4207277.241
124	North Sound Estates	19890627	168249.1139	4189180.32
125	North Sound Estates	19880712	571783.74	3821593.58
126	North Sound Estates	19870626	571783.74	3835895.53
127	North Sound Estates	19880713	178868.4461	3968099.527
128	North Sound Estates	19880510	178868.4461	3968099.527
129	North Sound Estates	19880513	178868.4461	3968099.527
130	North Sound Estates	19870822	1035848.56	1200818.62
131	North Sound Estates	19890626	168249.1139	4189180.32
132	North Sound Estates	19880714	168249.1139	4189180.32
134	North Sound Estates	19890713	571783.74	3485620.177
135	North Sound Estates	19880713	518687.0787	3996123.402
137	North Sound Estates	19890711	242584.4397	4207277.241
138	North Sound Estates	19890627	242584.4397	4207277.241
139	North Sound Estates	19870722	242584.4397	4207277.241
140	North Sound Estates	19880330	-918108.577	2462275.61
141	North Sound Estates	19880510	168249.1139	4189180.32
142	North Sound Estates	19870527	-642005.9381	3049328.487
143	North Sound Estates	19880712	518687.0787	3996123.402
144	North Sound Estates	19870807	178868.4461	3968099.527
145	North Sound Estates	19880512	178868.4461	3968099.527
146	North Sound Estates	19880511	242584.4397	4207277.241
147	North Sound Estates	19880511	518687.0787	3996123.402
148	North Sound Estates	19870715	242584.4397	4207277.241
149	North Sound Estates	19870626	168249.1139	4189180.32
150	North Sound Estates	19870806	168249.1139	4189180.32
151	Governor's Sound	19890710	-217232.6474	2837239.022
152	North Sound Estates	19880511	178868.4461	3968099.527
153	North Sound Estates	19890711	178868.4461	3968099.527
154	North Sound Estates	19870714	242584.4397	4207277.241
155	North Sound Estates	19870806	242584.4397	4207277.241
156	North Sound Estates	19890626	168249.1139	4189180.32
157	North Sound Estates	19890627	996557.0307	3821593.58

Id	Latitude	Longitude	Recapture site	Days	Distance (km)
111	23.1	-82.37	CUBA, La Habana	66	417.12
112	38.9	-72.6	38.90, -72.60	538	2187.29
113	43.1	-60.8	43.10, -60.80	1344	3208.83
115	36.8	-69.3	36.80, -69.30	602	2199.45
116	23.16	-82.29	CUBA, Cojimar	unkn	421.41
117	20.71	-78	CUBA, Sta. Cruz del Sur	1134	391.64
118	34.95	-68.8	34.95, -68.80	540	2094.03
119	34.95	-68.8	34.95, -68.80	533	2091.84
120	34.95	-68.8	34.95, -68.80	534	2091.84
121	36.5	-72.5	36.50, -72.50	536	1995.55
122	36.8	-69.3	36.80, -69.30	597	2198.28
123	39.1	-71.9	39.10, -71.90	167	2237.41
124	38.9	-72.6	38.90, -72.60	946	2188.83
125	34.95	-68.8	34.95, -68.80	596	2091.84
126	35.1	-68.8	35.10, -68.80	214	2102.91
127	36.5	-72.5	36.50, -72.50	597	1995.55
128	36.5	-72.5	36.50, -72.50	533	1995.55
129	36.5	-72.5	36.50, -72.50	536	1995.55
130	10.37	-64.43	VENEZUELA, Islas Caracas	271	2053.67
131	38.9	-72.6	38.90, -72.60	945	2188.83
132	38.9	-72.6	38.90, -72.60	598	2188.83
134	31.5	-68.8	31.50, -68.80	962	1844.54
135	36.8	-69.3	36.80, -69.30	597	2198.28
137	39.1	-71.9	39.10, -71.90	960	2237.41
138	39.1	-71.9	39.10, -71.90	946	2237.41
139	39.1	-71.9	39.10, -71.90	240	2237.41
140	21.66	-82.83	CUBA, Isle of Pines	492	304.38
141	38.9	-72.6	38.90, -72.60	533	2188.83
142	27.2	-80.23	USA, FL, Snug Harbor	183	852.06
143	36.8	-69.3	36.80, -69.30	596	2198.28
144	36.5	-72.5	36.50, -72.50	256	1995.55
145	36.5	-72.5	36.50, -72.50	535	1995.55
146	39.1	-71.9	39.10, -71.90	533	2237.41
147	36.8	-69.3	36.80, -69.30	533	2198.28
148	39.1	-71.9	39.10, -71.90	232	2237.41
149	38.9	-72.6	38.90, -72.60	213	2188.83
150	38.9	-72.6	38.90, -72.60	254	2188.83
151	25.17	-76.23	Governor's Sound	216	0
152	36.5	-72.5	36.50, -72.50	532	1995.55
153	36.5	-72.5	36.50, -72.50	959	1995.55
154	39.1	-71.9	39.10, -71.90	231	2237.41
155	39.1	-71.9	39.10, -71.90	254	2237.41
156	38.9	-72.6	38.90, -72.60	944	2188.83
157	34.95	-64.8	34.95, -64.80	945	2384.1

Id	Tag	Release date	Latitude	Longitude	Release X coord	Release Y coord
158	03321 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
159	03329 Meta	19861126	19.3	-81.3	-755632.7933	2204881.915
160	03329 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
161	03335 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
162	03339 Meta	19861125	19.3	-81.3	-755632.7933	2204881.915
164	03487 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
165	03504 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
166	03515 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
167	03515 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
168	03572 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
169	03606 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
170	03610 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
171	03638 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
172	03680 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
173	03749 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
174	03924 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
175	03926 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
176	03930 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
177	03942 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
178	03945 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
179	03950 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
180	03954 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
181	03955 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
182	03960 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
183	03966 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
184	03970 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
185	03973 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
186	03975 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
187	03995 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
188	03996 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
189	04065 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
190	04112 Meta	19871028	19.3	-81.3	-755632.7933	2204881.915
191	04329 Meta	19871028	19.3	-81.3	-755632.7933	2204881.915
192	04340 Meta	19871028	19.3	-81.3	-755632.7933	2204881.915
193	04436 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
194	04450 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
195	04454 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
196	04525 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
197	04532 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
198	04562 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
199	04562 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
200	04738 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
201	04763 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
202	04767 Meta	19881025	19.37	-81.42	-768375.992	2212572.472

Id	Release site	Recapture date	Recapture X coord	Recapture Y coord
158	North Sound Estates	19900622	-405194.8285	2359141.622
159	North Sound Estates	19880511	178868.4461	3968099.527
160	North Sound Estates	19880713	178868.4461	3968099.527
161	North Sound Estates	19910131	-405194.8285	2359141.622
162	North Sound Estates	19910131	-405194.8285	2359141.622
164	Doublehead Shot W.B.	19890627	242584.4397	4207277.241
165	Doublehead Shot W.B.	19870721	242584.4397	4207277.241
166	Doublehead Shot W.B.	19870714	242584.4397	4207277.241
167	Doublehead Shot W.B.	19870715	242584.4397	4207277.241
168	Doublehead Shot W.B.	19910114	-405194.8285	2359141.622
169	Doublehead Shot W.B.	19880715	178868.4461	3968099.527
170	Doublehead Shot W.B.	19891226	-606962.1416	2477417.754
171	Doublehead Shot W.B.	19870615	-606962.1416	2477417.754
172	Doublehead Shot W.B.	19890719	242584.4397	4207277.241
173	Public Beach, W.B.	19910312	-1031735.432	2499023.708
174	Public Beach, W.B.	19910415	-405194.8285	2359141.622
175	Public Beach, W.B.	19901227	-405194.8285	2359141.622
176	Public Beach, W.B.	19900514	-405194.8285	2359141.622
177	Public Beach, W.B.	19900402	-405194.8285	2359141.622
178	Public Beach, W.B.	19890723	-405194.8285	2359141.622
179	Public Beach, W.B.	19890706	-405194.8285	2359141.622
180	Public Beach, W.B.	19910620	-405194.8285	2359141.622
181	Public Beach, W.B.	19900708	-405194.8285	2359141.622
182	Public Beach, W.B.	19890802	-405194.8285	2359141.622
183	Public Beach, W.B.	19890411	-405194.8285	2359141.622
184	Public Beach, W.B.	19910123	-405194.8285	2359141.622
185	Public Beach, W.B.	19900322	-405194.8285	2359141.622
186	Public Beach, W.B.	19891205	-405194.8285	2359141.622
187	Public Beach, W.B.	19910520	-405194.8285	2359141.622
188	Public Beach, W.B.	19910530	-405194.8285	2359141.622
189	Public Beach, W.B.	19890803	-1008372.901	2544296.783
190	North Sound Estates	19890627	518687.0787	3996123.402
191	North Sound Estates	19881206	178868.4461	3968099.527
192	North Sound Estates	19880512	571783.74	3835895.53
193	Public Beach, W.B.	19871226	-1449075.19	2091346.464
194	Public Beach, W.B.	19900718	210726.4429	4189180.32
195	Public Beach, W.B.	19890902	-663244.6026	2515208.205
196	Public Beach, W.B.	19891225	-405194.8285	2359141.622
197	Public Beach, W.B.	19881030	-663244.6026	2515208.205
198	Public Beach, W.B.	19880328	-784304.9904	2611949.294
199	Public Beach, W.B.	19900310	-558113.2131	2491465.074
200	Public Beach, W.B.	19890125	-606962.1416	2477417.754
201	Public Beach, W.B.	19900716	168249.1139	4189180.32
202	Public Beach, W.B.	19890706	-868197.7153	2451450.787

Id	Latitude	Longitude	Recapture site	Days	Distance (km)
158	20.71	-78	CUBA, Sta. Cruz del Sur	1305	382.89
159	36.5	-72.5	36.50, -72.50	532	1995.55
160	36.5	-72.5	36.50, -72.50	596	1995.55
161	20.71	-78	CUBA, Sta. Cruz del Sur	1528	382.89
162	20.71	-78	CUBA, Sta. Cruz del Sur	1528	382.89
164	39.1	-71.9	39.10, -71.90	944	2236.27
165	39.1	-71.9	39.10, -71.90	237	2236.27
166	39.1	-71.9	39.10, -71.90	230	2236.27
167	39.1	-71.9	39.10, -71.90	231	2236.27
168	20.71	-78	CUBA, Sta. Cruz del Sur	1510	391.64
169	36.5	-72.5	36.50, -72.50	597	1994.78
170	21.8	-79.9	CUBA, Trinidad	1126	310.16
171	21.8	-79.9	CUBA, Trinidad	201	310.16
172	39.1	-71.9	39.10, -71.90	966	2236.27
173	22	-83.9	CUBA, Cabo Frances	1565	389.12
174	20.71	-78	CUBA, Sta. Cruz del Sur	1599	391.64
175	20.71	-78	CUBA, Sta. Cruz del Sur	1490	391.64
176	20.71	-78	CUBA, Sta. Cruz del Sur	1263	391.64
177	20.71	-78	CUBA, Sta. Cruz del Sur	1221	391.64
178	20.71	-78	CUBA, Sta. Cruz del Sur	968	391.64
179	20.71	-78	CUBA, Sta. Cruz del Sur	951	391.64
180	20.71	-78	CUBA, Sta. Cruz del Sur	1665	391.64
181	20.71	-78	CUBA, Sta. Cruz del Sur	1318	391.64
182	20.71	-78	CUBA, Sta. Cruz del Sur	978	391.64
183	20.71	-78	CUBA, Sta. Cruz del Sur	865	391.64
184	20.71	-78	CUBA, Sta. Cruz del Sur	1517	391.64
185	20.71	-78	CUBA, Sta. Cruz del Sur	1210	391.64
186	20.71	-78	CUBA, Sta. Cruz del Sur	1103	391.64
187	20.71	-78	CUBA, Sta. Cruz del Sur	1634	391.64
188	20.71	-78	CUBA, Sta. Cruz del Sur	1644	391.64
189	22.42	-83.68	CUBA, Pinar del Rio	979	409.44
190	36.8	-69.3	36.80, -69.30	608	2198.28
191	36.5	-72.5	36.50, -72.50	405	1995.55
192	35.1	-68.8	35.10, -68.80	197	2102.91
193	18.27	-87.83	MEXICO, Q.R., X-Calak	59	691.41
194	38.9	-72.2	38.90, -72.20	994	2205.82
195	22.15	-80.43	CUBA, Cienfuegos	675	320.38
196	20.71	-78	CUBA, Sta. Cruz del Sur	789	391.64
197	22.15	-80.43	CUBA, Cienfuegos	368	320.38
198	23.05	-81.57	CUBA, Matanzas	152	399.69
199	21.93	-79.44	CUBA, Sanct Spiritus	864	349.27
200	21.8	-79.9	CUBA, Trinidad	92	310.16
201	38.9	-72.6	38.90, -72.60	629	2187.29
202	21.56	-82.36	CUBA, Cayo Hicacos	254	258.9

Id	Tag	Release date	Latitude	Longitude	Release X coord	Release Y coord
203	04786 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
204	04793 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
205	04841 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
206	04847 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
207	04887 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
208	04890 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
209	04915 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
210	04918 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
211	04939 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
212	04955 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
213	04958 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
214	04970 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
215	05044 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
216	05047 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
217	05054 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
218	05129 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
219	05221 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
220	05231 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
221	05278 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
222	05278 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
223	05278 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
224	05290 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
225	05303 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
226	05315 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
227	05330 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
228	05381 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
229	05515 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
230	05519 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
231	05520 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
233	05521 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
234	05524 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
235	05532 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
236	05535 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
237	05536 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
238	05537 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
239	05539 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
240	05545 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
241	05550 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
242	05562 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
243	05570 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
244	05580 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
245	05589 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
246	05593 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
247	05708 Meta	19881026	19.39	-81.37	-763066.3259	2214769.167

Id	Release site	Recapture date	Recapture X coord	Recapture Y coord
203	Public Beach, W.B.	19901206	-405194.8285	2359141.622
204	Public Beach, W.B.	19901220	-405194.8285	2359141.622
205	Public Beach, W.B.	19890120	-1307838.071	1875697.244
206	Public Beach, W.B.	19900106	-606962.1416	2477417.754
207	Public Beach, W.B.	19890207	-2189242.649	3264700.544
208	Public Beach, W.B.	19901231	-405194.8285	2359141.622
209	Public Beach, W.B.	19910315	-405194.8285	2359141.622
210	Public Beach, W.B.	19910501	-405194.8285	2359141.622
211	Public Beach, W.B.	19901126	-405194.8285	2359141.622
212	Public Beach, W.B.	19910415	-405194.8285	2359141.622
213	Public Beach, W.B.	19910517	-405194.8285	2359141.622
214	Public Beach, W.B.	19901026	-405194.8285	2359141.622
215	Public Beach, W.B.	19881206	242584.4397	4207277.241
216	Public Beach, W.B.	19890605	-405194.8285	2359141.622
217	Public Beach, W.B.	19910130	242584.4397	4207277.241
218	Public Beach, W.B.	19900510	-405194.8285	2359141.622
219	North Sound Estates	19900724	168249.1139	4189180.32
220	North Sound Estates	19890626	571783.74	3835895.53
221	North Sound Estates	19890626	168249.1139	4189180.32
222	North Sound Estates	19890721	168249.1139	4189180.32
223	North Sound Estates	19900718	168249.1139	4189180.32
224	North Sound Estates	19900103	-663244.6026	2515208.205
225	North Sound Estates	19890627	242584.4397	4207277.241
226	North Sound Estates	19881206	242584.4397	4207277.241
227	North Sound Estates	19890707	-918108.577	2462275.61
228	North Sound Estates	19890713	571783.74	3835895.53
229	North Sound Estates	19901227	-405194.8285	2359141.622
230	North Sound Estates	19910422	-405194.8285	2359141.622
231	North Sound Estates	19900410	-405194.8285	2359141.622
233	North Sound Estates	19891228	-405194.8285	2359141.622
234	North Sound Estates	19900718	168249.1139	4189180.32
235	North Sound Estates	19901119	-405194.8285	2359141.622
236	North Sound Estates	19900418	-405194.8285	2359141.622
237	North Sound Estates	19900717	168249.1139	4189180.32
238	Public Beach, W.B.	19910420	-405194.8285	2359141.622
239	North Sound Estates	19900128	-394575.4962	2431947.309
240	North Sound Estates	19900722	-405194.8285	2359141.622
241	North Sound Estates	19900330	-405194.8285	2359141.622
242	North Sound Estates	19910116	-405194.8285	2359141.622
243	North Sound Estates	19910129	178868.4461	3968099.527
244	North Sound Estates	19910227	-501830.7521	2372205.45
245	North Sound Estates	19900130	-405194.8285	2359141.622
246	North Sound Estates	19900216	-405194.8285	2359141.622
247	Head of Barkers, W.B	19881206	210726.4429	4088740.788

Id	Latitude	Longitude	Recapture site	Days	Distance (km)
203	20.71	-78	CUBA, Sta. Cruz del Sur	772	391.64
204	20.71	-78	CUBA, Sta. Cruz del Sur	786	391.64
205	16.33	-86.5	HONDURAS, Bay Islands	87	636.01
206	21.8	-79.9	CUBA, Trinidad	438	310.16
207	29.3	-94.8	U.S.A., Texas, Galveston	105	1768
208	20.71	-78	CUBA, Sta. Cruz del Sur	797	391.64
209	20.71	-78	CUBA, Sta. Cruz del Sur	871	391.64
210	20.71	-78	CUBA, Sta. Cruz del Sur	918	391.64
211	20.71	-78	CUBA, Sta. Cruz del Sur	762	391.64
212	20.71	-78	CUBA, Sta. Cruz del Sur	902	391.64
213	20.71	-78	CUBA, Sta. Cruz del Sur	934	391.64
214	20.71	-78	CUBA, Sta. Cruz del Sur	731	391.64
215	39.1	-71.9	39.10, -71.90	42	2236.27
216	20.71	-78	CUBA, Sta. Cruz del Sur	223	391.64
217	39.1	-71.9	39.10, -71.90	827	2236.27
218	20.71	-78	CUBA, Sta. Cruz del Sur	562	391.64
219	38.9	-72.6	38.90, -72.60	637	2188.83
220	35.1	-68.8	35.10, -68.80	244	2102.91
221	38.9	-72.6	38.90, -72.60	244	2188.83
222	38.9	-72.6	38.90, -72.60	269	2188.83
223	38.9	-72.6	38.90, -72.60	631	2188.83
224	22.15	-80.43	CUBA, Cienfuegos	435	323.79
225	39.1	-71.9	39.10, -71.90	245	2237.41
226	39.1	-71.9	39.10, -71.90	42	2237.41
227	21.66	-82.83	CUBA, Isle of Pines	255	304.38
228	35.1	-68.8	35.10, -68.80	261	2102.91
229	20.71	-78	CUBA, Sta. Cruz del Sur	793	382.89
230	20.71	-78	CUBA, Sta. Cruz del Sur	909	382.89
231	20.71	-78	CUBA, Sta. Cruz del Sur	532	382.89
233	20.71	-78	CUBA, Sta. Cruz del Sur	429	382.89
234	38.9	-72.6	38.90, -72.60	631	2188.83
235	20.71	-78	CUBA, Sta. Cruz del Sur	755	382.89
236	20.71	-78	CUBA, Sta. Cruz del Sur	540	382.89
237	38.9	-72.6	38.90, -72.60	630	2188.83
238	20.71	-78	CUBA, Sta. Cruz del Sur	907	391.64
239	21.38	-77.9	CUBA, Camaguey	460	426.52
240	20.71	-78	CUBA, Sta. Cruz del Sur	635	382.89
241	20.71	-78	CUBA, Sta. Cruz del Sur	521	382.89
242	20.71	-78	CUBA, Sta. Cruz del Sur	813	382.89
243	36.5	-72.5	36.50, -72.50	826	1995.55
244	20.83	-78.91	CUBA, Jardines de la Reina	855	303.99
245	20.71	-78	CUBA, Sta. Cruz del Sur	462	382.89
246	20.71	-78	CUBA, Sta. Cruz del Sur	479	382.89
247	37.8	-72.2	37.80, -72.20	41	2111.88

Id	Tag	Release date	Latitude	Longitude	Release X coord	Release Y coord
248	05754 Meta	19881026	19.39	-81.37	-763066.3259	2214769.167
250	05774 Meta	19881026	19.37	-81.42	-768375.992	2212572.472
251	05774 Meta	19881026	19.37	-81.42	-768375.992	2212572.472
252	05858 Meta	19891030	19.37	-81.42	-768375.992	2212572.472
253	05932 Meta	19891030	19.37	-81.42	-768375.992	2212572.472
255	02107 Meta	19810715	19.37	-81.42	-768375.992	2212572.472
258	320 Blue D	19850925	38.9	-72.6	168249.1139	4189180.32
282	02003 Meta	19801031	19.36	-81.27	-752446.9936	2211474.023
339	05518 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
340	03939 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
344	05559 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
345	02535 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
346	03943 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
347	05590 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
350	04610 Meta	19910122	38.9	-72.6	168249.1139	4189180.32
353	05551 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
354	04960 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
355	05536 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
356	05521 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
357	05010 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
358	04954 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
359	04853 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
360	04015 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
361	04977 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
362	04840 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
363	01204 MetN		19.3	-81.3	-755632.7933	2204881.915
364	05549 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
365	05547 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
366	03922 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
367	04931 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
368	03929 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
369	02538 Meta	19861120	19.37	-81.42	-768375.992	2212572.472
370	05589 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
371	05306 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
372	05671 Meta	19881026	19.39	-81.37	-763066.3259	2214769.167
374	05054 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
375	01157 Meta	19841120	19.3	-81.3	-755632.7933	2204881.915
379	05553 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
380	05184 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
381	00385 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
382	05100 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
385	04827 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
386	03927 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
387	03833 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
388	03888 Meta	19861128	19.37	-81.42	-768375.992	2212572.472

Id	Release site	Recapture date	Recapture X coord	Recapture Y coord
248	Head of Barkers, W.B	19881206	518687.0787	3996123.402
250	Doublehead Shot, W.B	19890626	178868.4461	3968099.527
251	Doublehead Shot, W.B	19900720	178868.4461	3968099.527
252	Public Beach, W.B.	19910124	178868.4461	3968099.527
253	Public Beach, W.B.	19891208	-179003.0512	2278354.867
255	Goat Rock, W.B.	19870717	168249.1139	4189180.32
258	38.90, -72.60	19851011	200107.1107	4116284.411
282	Rum Point, N.S.	19860926	168249.1139	4189180.32
339	North Sound Estates	19910514	-405194.8285	2359141.622
340	Public Beach, W.B.	19910430	-405194.8285	2359141.622
344	North Sound Estates	19910725	-405194.8285	2359141.622
345	Doublehead Shot, W.B	19910726	-405194.8285	2359141.622
346	Public Beach, W.B.	19910729	-405194.8285	2359141.622
347	North Sound Estates	19910729	-405194.8285	2359141.622
350	38.90, -72.60	19910913	168249.1139	4189180.32
353	North Sound Estates	19910801	-405194.8285	2359141.622
354	Public Beach, W.B.	19910803	-405194.8285	2359141.622
355	North Sound Estates	19910728	-405194.8285	2359141.622
356	North Sound Estates	19901225	-405194.8285	2359141.622
357	Public Beach, W.B.	19910806	-405194.8285	2359141.622
358	Public Beach, W.B.	19910712	-405194.8285	2359141.622
359	Public Beach, W.B.	19910506	-405194.8285	2359141.622
360	Public Beach, W.B.	19910830	-405194.8285	2359141.622
361	Public Beach, W.B.	19910904	-405194.8285	2359141.622
362	Public Beach, W.B.	19910731	-405194.8285	2359141.622
363	Selkirk Watler, N.S.		-1171910.618	1829838.296
364	North Sound Estates	19910830	-405194.8285	2359141.622
365	North Sound Estates	19910907	-405194.8285	2359141.622
366	Public Beach, W.B.	19910830	-405194.8285	2359141.622
367	Public Beach, W.B.	19910815	-405194.8285	2359141.622
368	Public Beach, W.B.	19910805	-405194.8285	2359141.622
369	Doublehead Shot, W.B	19910724	-405194.8285	2359141.622
370	North Sound Estates	19920117	-755632.7933	2204881.915
371	North Sound Estates	19910901	-755632.7933	2208178.272
372	Head of Barkers, W.B	19920129	168249.1139	4189180.32
374	Public Beach, W.B.	19920206	242584.4397	4207277.241
375	North Sound Estates	19911128	-907489.2447	2579772.696
379	North Sound Estates	19920319	-405194.8285	2359141.622
380	Public Beach, W.B.	19901211	-808729.4546	2444952.307
381	Batabano, W.B.	19920201	-911736.9776	1648873.88
382	Public Beach, W.B.	19910817	-911736.9776	1648873.88
385	Public Beach, W.B.	19911126	-856516.4498	1081515.965
386	Public Beach, W.B.	19911215	-394575.4962	2431947.309
387	Public Beach, W.B.	19920321	-405194.8285	2359141.622
388	Public Beach, W.B.	19920412	-405194.8285	2359141.622

Id	Latitude	Longitude	Recapture site	Days	Distance (km)
248	36.8	-69.3	36.80, -69.30	41	2194.56
250	36.5	-72.5	36.50, -72.50	243	1994.78
251	36.5	-72.5	36.50, -72.50	632	1994.78
252	36.5	-72.5	36.50, -72.50	451	1994.78
253	19.97	-75.87	CUBA, Granma	39	593.03
255	38.9	-72.6	38.90, -72.60	2193	2187.29
258	38.1	-72.3	38.10, -72.30	16	79.55
282	38.9	-72.6	38.90, -72.60	2156	2181.51
339	20.71	-78	CUBA, Sta. Cruz del Sur	931	382.89
340	20.71	-78	CUBA, Sta. Cruz del Sur	1614	391.64
344	20.71	-78	CUBA, Sta. Cruz del Sur	1003	382.89
345	20.71	-78	CUBA, Sta. Cruz del Sur	1709	391.64
346	20.71	-78	CUBA, Sta. Cruz del Sur	1704	391.64
347	20.71	-78	CUBA, Sta. Cruz del Sur	1007	382.89
350	38.9	-72.6	38.90, -72.60	234	0
353	20.71	-78	CUBA, Sta. Cruz del Sur	1010	382.89
354	20.71	-78	CUBA, Sta. Cruz del Sur	1012	391.64
355	20.71	-78	CUBA, Sta. Cruz del Sur	1006	382.89
356	20.71	-78	CUBA, Sta. Cruz del Sur	791	382.89
357	20.71	-78	CUBA, Sta. Cruz del Sur	1015	391.64
358	20.71	-78	CUBA, Sta. Cruz del Sur	990	391.64
359	20.71	-78	CUBA, Sta. Cruz del Sur	923	391.64
360	20.71	-78	CUBA, Sta. Cruz del Sur	1736	391.64
361	20.71	-78	CUBA, Sta. Cruz del Sur	1044	391.64
362	20.71	-78	CUBA, Sta. Cruz del Sur	1009	391.64
363	15.92	-85.22	HONDURAS, Iriona Viejo	unkn	560.31
364	20.71	-78	CUBA, Sta. Cruz del Sur	1039	382.89
365	20.71	-78	CUBA, Sta. Cruz del Sur	1047	382.89
366	20.71	-78	CUBA, Sta. Cruz del Sur	1736	391.64
367	20.71	-78	CUBA, Sta. Cruz del Sur	1024	391.64
368	20.71	-78	CUBA, Sta. Cruz del Sur	1711	391.64
369	20.71	-78	CUBA, Sta. Cruz del Sur	1707	391.64
370	19.3	-81.3	North Sound	1179	0
371	19.33	-81.3	Booby Cay	1041	3.3
372	38.9	-72.6	38.90, -72.60	1190	2183.04
374	39.1	-71.9	39.10, -71.90	1199	2236.27
375	22.75	-82.73	CUBA, Artemisa, Habana	2564	404.48
379	20.71	-78	CUBA, Sta. Cruz del Sur	1241	382.89
380	21.5	-81.8	CUBA, Cayo Largo	777	235.86
381	14.31	-82.77	NICARAGUA, Miskito Cays	2655	582.7
382	14.31	-82.77	NICARAGUA, Miskito Cays	1026	581.64
385	9.33	-82.25	PANAMA, Bocas del Toro	1127	1134.49
386	21.38	-77.9	CUBA, Camaguey	1843	433.42
387	20.71	-78	CUBA, Sta. Cruz del Sur	1940	391.64
388	20.71	-78	CUBA, Sta. Cruz del Sur	1962	391.64

Id	Tag	Release date	Latitude	Longitude	Release X coord	Release Y coord
389	01747 Meta	19841026	19.37	-81.42	-768375.992	2212572.472
390	00840 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
391	03597 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
392	05159 Meta	19881025	19.37	-81.42	-768375.992	2212572.472
393	00822 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
394	03383 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
395	00929 Meta	19841030	19.3	-81.3	-755632.7933	2204881.915
396	03394 Meta	19861126	19.37	-81.42	-768375.992	2212572.472
397	03888 Meta	19861128	19.37	-81.42	-768375.992	2212572.472
398	02892 Meta	19861124	19.3	-81.3	-755632.7933	2204881.915
400	2046 Metal	19930312	19.37	-81.42	-768375.992	2212572.472
402	3655 Metal	19861126	19.37	-81.42	-768375.992	2212572.472
404	00646 Meta	19841029	19.3	-81.3	-755632.7933	2204881.915
405	5283 Metal	19881025	19.3	-81.3	-755632.7933	2204881.915
406	2826 Metal	19861125	19.3	-81.3	-755632.7933	2204881.915
408	6993 Metal	19931028	19.37	-81.42	-768375.992	2212572.472
409	5924 Metal	19891030	19.37	-81.42	-768375.992	2212572.472
410	6547 Metal	19921029	19.3	-81.3	-755632.7933	2204881.915
411	7062 Metal	19931028	19.37	-81.42	-768375.992	2212572.472
412	5111 Metal	19881025	19.37	-81.42	-768375.992	2212572.472
413	7103 Metal	19931028	19.37	-81.42	-768375.992	2212572.472
415	00316 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
417	06356 Meta	19921029	19.3	-81.4	-766252.1256	2204881.915
418	6645 Metal	19930928	19.3	-81.4	-766252.1256	2204881.915
422	6849 Metal	19930928	19.3	-81.4	-766252.1256	2204881.915
423	6695 Metal	19930928	19.3	-81.4	-766252.1256	2204881.915
427	6250 Metal	19921016	19.3	-81.4	-766252.1256	2204881.915
428	6664 Metal	19930928	19.3	-81.4	-766252.1256	2204881.915
429	6680 Metal	19930928	19.3	-81.4	-766252.1256	2204881.915
430	6956 Metal		19.37	-81.42	-768375.992	2212572.472
431	6680 Metal	19930928	19.3	-81.42	-768375.992	2204881.915
438	00500 Meta	19841025	19.37	-81.38	-764128.2591	2212572.472
441	01872 Meta	19841024	19.3	-81.12	-736517.9952	2204881.915
442	01959 Meta	19841024	19.3	-81.12	-736517.9952	2204881.915
446	04385 Meta	19871028	19.37	-81.42	-768375.992	2212572.472
447	05286 Meta	19881025	19.3	-81.3	-755632.7933	2204881.915
456	Y2606 (old tag	19861120	19.3	-81.3	-755632.7933	2204881.915
457	Y2808 (old tag	19861124	19.3	-81.3	-755632.7933	2204881.915
458	Y7592 (old tag	19960520	19.65	-80.25	-644129.8045	2243301.557
461	Y5432 (old tag	19881025	19.3	-81.3	-755632.7933	2204881.915

Id	Release site	Recapture date	Recapture X coord	Recapture Y coord
389	Public Beach, W.B.	19920827	-394575.4962	2431947.309
390	North Sound Estates	19921015	-976514.9044	1617264.881
391	Doublehead Shot, W.B	19920424	-405194.8285	2359141.622
392	Public Beach, W.B.	19920512	-405194.8285	2359141.622
393	North Sound Estates	19920722	-784304.9904	2611949.294
394	Doublehead Shot, W.B	19921116	-405194.8285	2359141.622
395	North Sound Estates	19930312	-267143.509	2411334.269
396	Doublehead Shot, W.B	19930403	-440238.625	2339526.496
397	Public Beach, W.B.	19930720	-405194.8285	2359141.622
398	North Sound Estates	19930601	-856516.4498	1081515.965
400	Doublehead Shot, W.B	19930722	-820410.7201	2582993.553
402	Doublehead Shot, W.B	19930914	-405194.8285	2359141.622
404	North Sound Estates	19930807	-918108.577	2462275.61
405	North Sound Estates	19931126	-918108.577	2462275.61
406	North Sound Estates	19930201	-769437.9252	1630816.368
408	Public Beach, W.B.	19940307	-217232.6474	2837239.022
409	Public Beach, W.B.	19940410	-760942.4594	2202684.009
410	North Sound Estates	19940501	-768375.992	2211474.023
411	Public Beach, W.B.	19940601	-764128.2591	2204881.915
412	Public Beach, W.B.	19940420	-555989.3467	2402647.148
413	Public Beach, W.B.	19931115	-1017930.3	1756944.003
415	Batabano, W.B.	19940308	-569794.4786	2459028.949
417	North Sound Estates	19940316	-670678.1352	1894683.896
418	North Sound Estates	19940913	242584.4397	4207277.241
422	North Sound Estates	19940914	168249.1139	4189180.32
423	North Sound Estates	19940914	168249.1139	4189180.32
427	North Sound Estates	19940915	178868.4461	3968099.527
428	North Sound Estates	19940915	178868.4461	3968099.527
429	North Sound Estates	19940916	242584.4397	4207277.241
430	Public Beach, W.B.		242584.4397	4207277.241
431	North Sound Estates	19940920	242584.4397	4207277.241
438	Batabano, W.B.	19940601	-1012620.634	1386991.723
441	East End, G.C.	19931101	-970143.3051	1472286.212
442	East End, G.C.	19940412	-970143.3051	1472286.212
446	Public Beach, W.B.	19941012	-911736.9776	1647745.66
447	North Sound Estates	19940921	-466786.9557	2352605.824
456	North Sound Estates	19961208	-911736.9776	1648873.88
457	North Sound Estates	19960625	-911736.9776	1648873.88
458	Little Cayman	19960914	-1272794.275	3368750.266
461	North Sound Estates	19961208	-911736.9776	1648873.88

Id	Latitude	Longitude	Recapture site	Days	Distance (km)
389	21.38	-77.9	CUBA, Camaguey	2862	433.42
390	14.03	-83.38	NICARAGUA, Puerto Cabezas	2907	627.76
391	20.71	-78	CUBA, Sta. Cruz del Sur	1976	391.64
392	20.71	-78	CUBA, Sta. Cruz del Sur	1295	391.64
393	23.05	-81.57	CUBA, Matanzas	2822	408.08
394	20.71	-78	CUBA, Sta. Cruz del Sur	2182	391.64
395	21.19	-76.7	CUBA, Puerto Padre	3055	530.32
396	20.53	-78.33	CUBA, Cayo Cabeza del Este	2320	351.84
397	20.71	-78	CUBA, Sta. Cruz del Sur	2426	391.64
398	9.33	-82.25	PANAMA, Bocas del Toro	2381	1127.89
400	22.78	-81.91	CUBA, San Nicolas de Bari	132	374.06
402	20.71	-78	CUBA, Sta. Cruz del Sur	2484	391.64
404	21.66	-82.83	CUBA, Isle of Pines	3204	304.38
405	21.66	-82.83	CUBA, Isle of Pines	1858	304.38
406	14.15	-81.43	NICARAGUA, Plis Raya (?)	2260	574.23
408	25.17	-76.23	Governor's Harbour	130	833.05
409	19.28	-81.35	Red Bay	1623	12.37
410	19.36	-81.42	Seven Mile Beach	549	14.35
411	19.3	-81.38	George Town Harbour	216	8.79
412	21.11	-79.42	CUBA, 12 Leguas, C. Breton	2003	285.02
413	15.27	-83.77	HONDURAS, Puerto Lempira	18	519.49
415	21.63	-79.55	CUBA, Tunas de Zarza	3421	313.86
417	16.5	-80.5	HONDURAS, Rosalen Bank	503	324.59
418	39.1	-71.9	39.10, -71.90	350	2242.17
422	38.9	-72.6	38.90, -72.60	351	2193.34
423	38.9	-72.6	38.90, -72.60	351	2193.34
427	36.5	-72.5	36.50, -72.50	699	2000.55
428	36.5	-72.5	36.50, -72.50	352	2000.55
429	39.1	-71.9	39.10, -71.90	353	2242.17
430	39.1	-71.9	39.10, -71.90	unkn	2236.27
431	39.1	-71.9	39.10, -71.90	357	2243.13
438	12	-83.72	NICARAGUA, Halfway Cay	3506	862.17
441	12.75	-83.32	NICARAGUA, Man O'War Cay	3295	768.95
442	12.75	-83.32	NICARAGUA, Man O'War Cay	3457	768.95
446	14.3	-82.77	NICARAGUA, Witties Cay	2541	582.74
447	20.65	-78.58	CUBA, Doce Legua	2157	324.43
456	14.31	-82.77	NICARAGUA, Miskito Cay	3671	577.51
457	14.31	-82.77	NICARAGUA, Miskito Cay	3501	577.51
458	30.33	-86.17	U.S.A., FLORIDA, Grayton B	117	1289.13
461	14.31	-82.77	NICARAGUA, Miskito Cay	2966	577.51

APPENDIX 3. TAG RECOVERY DATA AGGREGATED BY RECAPTURE SITE

Recapture Site ⁸	Latitude	Longitude	Recaptures
30.10, -69.20	30.1	-69.2	1
31.50, -68.80	31.5	-68.8	1
34.30, -62.20	34.3	-62.2	1
34.50, -68.80	34.5	-68.8	1
34.90, -68.80	34.9	-68.8	1
34.95, -64.80	34.95	-64.8	1
34.95, -68.80	34.95	-68.8	4
35.00, -68.75	35	-68.75	1
35.10, -68.80	35.1	-68.8	6
35.50, -59.40	35.5	-59.4	1
36.40, -59.50	36.4	-59.5	1
36.50, -72.30	36.5	-72.3	1
36.50, -72.50	36.5	-72.5	20
36.60, -72.50	36.6	-72.5	2
36.80, -69.30	36.8	-69.3	9
37.40, -72.80	37.4	-72.8	1
37.40, -72.90	37.4	-72.9	1
37.80, -72.20	37.8	-72.2	1
38.10, -72.30	38.1	-72.3	1
38.20, -71.90	38.2	-71.9	1
38.90, -72.20	38.9	-72.2	1
38.90, -72.60	38.9	-72.6	39
38.90, -72.65	38.9	-72.65	2
39.10, -71.90	39.1	-71.9	28
39.20, -71.90	39.2	-71.9	1
39.90, -72.60	39.9	-72.6	1
43.10, -60.80	43.1	-60.8	1
BELIZE, Mullings River	17.1	-88.3	1
Barker's Beach	19.37	-81.42	1
Booby Cay	19.33	-81.3	1
CUBA, 12 Leguas, C. Breton	21.11	-79.42	1
CUBA, Artemisa, Habana	22.75	-82.73	1
CUBA, Cabo Frances	22	-83.9	1
CUBA, Camaguey	21.38	-77.9	3
CUBA, Cayo Blanco	23	-82.5	1
CUBA, Cayo Bonito	22.05	-81.66	1
CUBA, Cayo Breton	21.11	-79.42	1
CUBA, Cayo Cabeza del Este	20.53	-78.33	1

⁸ Source of the data: CTF

Recapture Site	Latitude	Longitude	Recaptures
CUBA, Cayo Cantiles	21.37	-81.55	2
CUBA, Cayo Guano	21.66	-81.04	1
CUBA, Cayo Hicacos	21.56	-82.36	1
CUBA, Cayo Largo	21.5	-81.8	3
CUBA, Cienfuegos	22.15	-80.43	3
CUBA, Cojimar	23.15	-82.29	1
CUBA, Doce Legua	20.65	-78.58	1
CUBA, Granma	19.97	-75.87	1
CUBA, Isle of Pines	21.66	-82.83	6
CUBA, Jardines de la Reina	20.83	-78.91	1
CUBA, Jucaro	21.6	-78.8	1
CUBA, La Ensenada de Broa	22.5	-82	2
CUBA, La Habana	23.1	-82.37	1
CUBA, La Habana (North Coast)	23.1	-82.37	1
CUBA, Matanzas	23.05	-81.57	2
CUBA, Pinar del Rio	22.42	-83.68	3
CUBA, Playa Giron	22.06	-81.03	2
CUBA, Playa Larga	22.3	-81.2	1
CUBA, Puerto Padre	21.19	-76.7	1
CUBA, Punta Frances	21.6	-83.2	1
CUBA, Punta de los Barcos	21.93	-83	1
CUBA, San Nicolas de Bari	22.78	-81.91	1
CUBA, Sanct Spiritus	21.93	-79.44	1
CUBA, Sta. Cruz del Sur	20.71	-78	74
CUBA, Trinidad	21.8	-79.9	8
CUBA, Tunas de Zarza	21.63	-79.55	1
Duck Pond Bight	19.3	-81.3	1
George Town Harbour	19.3	-81.38	1
Governor's Harbour	25.17	-76.23	1
Governor's Sound	25.17	-76.23	1
HONDURAS, Bay Islands	16.33	-86.5	1
HONDURAS, Brus Laguna	15.75	-84.48	1
HONDURAS, Iriona Viejo	15.92	-85.22	1
HONDURAS, La Ceiba	15.74	-86.86	1
HONDURAS, Puerto Lempira	15.27	-83.77	1
HONDURAS, Rosalen Bank	16.5	-80.5	1
HONDURAS, Utila	16.08	-86.9	1
Hubbert Bodden's Pond	19.28	-81.24	4
MEXICO, Q.R., X-Calak	18.27	-87.83	1
NICARAGUA, Halfway Cay	12	-83.72	1
NICARAGUA, Man O'War Cay	12.75	-83.32	2
NICARAGUA, Miskito Cays	14.31	-82.77	6

Recapture Site	Latitude	Longitude	Recaptures
NICARAGUA, Plis Raya (?)	14.15	-81.43	1
NICARAGUA, Puerto Cabezas	14.03	-83.38	1
NICARAGUA, Witties Cay	14.3	-82.77	1
North Sound	38.9	-72.6	4
PANAMA, Bocas del Toro	9.33	-82.25	2
Red Bay	19.28	-81.35	1
Seven Mile Beach	19.36	-81.42	1
U.S.A., FLORIDA, Grayton Beach	30.33	-86.17	1
U.S.A., Texas, Galveston	29.3	-94.8	1
USA, FL, Snug Harbor	27.2	-80.23	1
VENEZUELA, Islas Caracas	10.37	-64.43	1

APPENDIX 4. SUBSET OF THE COMPILED GIS DATABASE

Shape	Id	Area_km2	Count	Ave_sst_wi	Count	Ave_sst_sp	Count	Ave_sst_su
Point	364	400	2	26.4	2	28.725	2	29.25
Point	578	400	3	26.4	3	27.75	3	28.85
Point	1084	400						
Point	1086	400	5	26.85	5	28.11	5	28.92
Point	1295	400	3	26.8	3	28.05	3	28.9
Point	2021	400						
Point	2436	400						
Point	2783	400	1	26.4	1	28.2	1	29.85
Point	2831	400	2	27.45	2	27.825	2	29.7
Point	2849	400						
Point	2889	400						
Point	3043	400	4	26.7	4	28.2375	4	28.2
Point	3050	400	4	26.8875	4	28.275	4	28.7625
Point	3196	400	4	26.325	4	27.9	4	29.7
Point	3302	400	3	24.8	2	28.35	3	30.05
Point	3364	400	4	26.7	4	28.05	4	28.2
Point	3403	400	4	26.25	4	27.7875	4	29.625
Point	3411	400						
Point	3612	400	6	26.225	6	27.975	6	29.825
Point	3620	400						
Point	3648	400	1	27.6	1	28.65	1	28.5
Point	3725	400	3	25.95	3	27.35	3	29.7
Point	3825	400	2	24.6	2	28.05	2	29.925
Point	3924	400	6	26.225	6	27.9	6	29.9
Point	3931	400						
Point	4031	400	4	25.575	4	28.2375	4	30.1875
Point	4091	400	4	26.7	4	27.6	4	28.05
Point	4120	400	3	26.55	3	27.9	3	29.3
Point	4131	400	4	26.25	4	27.8625	4	29.8125
Point	4140	400						
Point	4224	400	3	26.65	3	27.95	3	29.35
Point	4341	400	4	26.1375	4	28.0875	4	30.075
Point	4343	400	2	26.1	2	28.2	2	30.075
Point	4344	400						
Point	4624	400	4	26.55	4	27.5625	4	28.2
Point	4758	400	2	26.325	2	28.125	2	29.85
Point	4965	400	2	26.175	2	27.975	2	30.075
Point	5173	400						
Point	5274	400	4	25.9875	4	28.125	4	30.1125
Point	5278	400						
Point	5584	400	2	26.325	2	28.35	2	30.225
Point	5588	400	5	25.08	5	28.23	5	30.12
Point	5687	400	2	26.4	2	28.125	2	29.925
Point	5895	400	5	25.71	5	28.44	5	30.36
Point	5998	400	4	26.025	4	28.5	4	30.375
Point	6107	400						
Point	6730	400						
Point	7063	400	4	23.925	4	26.025	4	29.25
Point	7244	400						
Point	13534	400	2	23.55	2	25.125	2	25.875

Id	Count	Ave_sst_fa	Count	Ave_sst_st	Count	Ave_Hor_gr	Count	Ave_chl_wi
364	2	27.825	2	1.081	2	0.0024	1	1.132
578	3	27.7	3	0.8861	3	0.0045	1	4.677
1084								
1086	5	28.11	3	0.7431	3	0.0013	4	0.3065
1295	3	27.95	2	0.733	2	0.0006	2	0.2095
2021								
2436								
2783	1	27.75	1	1.2324	1	0.0041		
2831	2	27.375	1	1.3306	1	0.012		
2849								
2889								
3043	4	27.825	4	0.6238	4	0.0029	4	0.3433
3050	4	27.4875	3	0.7103	3	0.0037	3	0.665
3196	4	28.1625	3	1.2065	3	0.0018	3	0.1313
3302	3	27.1	2	1.9051	2	0.002	1	3.532
3364	4	27.9375	4	0.5979	4	0.0004	4	0.5423
3403	4	28.05	4	1.1972	4	0.0007	4	0.1295
3411								
3612	6	27.975	4	1.2618	4	0.006	4	0.1433
3620								
3648	1	28.2	1	0.4021	1	0.0017		
3725	3	27.25	2	1.3544	2	0.0026	3	0.1637
3825	2	26.475	2	1.9661	2	0.0036		
3924	6	28.125	4	1.2956	4	0.0021	4	0.1418
3931								
4031	4	27.3	4	1.6664	4	0.0048	2	5.302
4091	4	28.125	4	0.5678	4	0.0005	4	0.1393
4120	3	28.35	3	0.9905	3	0.0008	4	0.1298
4131	4	28.125	4	1.264	4	0.001	4	0.1315
4140								
4224	3	28.4	1	0.9627	2	0.0014	2	0.1215
4341	4	28.0125	4	1.3982	4	0.0033	4	0.311
4343	2	27.825	2	1.4124	2	0.001	1	0.166
4344								
4624	4	28.2	4	0.6753	4	0.0005	4	0.2143
4758	2	27.75	2	1.2563	2	0.0033	2	0.1245
4965	2	28.05	2	1.3878	2	0.003		
5173								
5274	4	27.9	4	1.4671	4	0.0052	2	0.22
5278								
5584	2	28.05	2	1.387	2	0.0042	2	1.288
5588	5	27.27	4	1.8209	4	0.0014	4	1.6312
5687	2	28.35	2	1.2496	2	0.0012	2	0.1195
5895	5	27.75	4	1.6689	4	0.0052	3	0.658
5998	4	27.9	4	1.5621	4	0.0047	4	0.6155
6107								
6730								
7063	4	25.875	2	2.2315	4	0.009	2	0.6195
7244								
13534	1	27	1	1.3722	1	0.0046	2	3.0935

Id	Count	Ave_chl_sp	Count	Ave_chl_su	Count	Ave_chl_fa	Count	Ave_chl_st
364	1	0.858	1	1.684	1	2.328	1	0.5628
578	1	5.099	1	6.209	1	8.024	1	1.2944
1084								
1086	4	0.207	4	0.2528	4	0.4042	3	0.0714
1295	2	0.1455	2	0.147	2	0.221	2	0.0348
2021								
2436								
2783								
2831								
2849								
2889								
3043	4	0.3902	4	0.4617	4	0.7248	4	0.1548
3050	3	0.5537	3	0.8613	3	1.6667	3	0.4512
3196	3	0.0883	3	0.0857	3	0.1287	3	0.0216
3302	1	4.541	1	7.034	1	4.764	1	1.2801
3364	4	0.5197	4	0.558	4	0.646	4	0.0668
3403	4	0.0845	4	0.081	4	0.1205	4	0.0214
3411								
3612	4	0.0958	4	0.0953	4	0.1435	4	0.0241
3620								
3648								
3725	3	0.1127	3	0.0847	3	0.1597	2	0.0333
3825								
3924	4	0.0975	4	0.0922	4	0.1415	4	0.0236
3931								
4031	3	3.8953	3	4.9577	3	5.9007	2	0.7771
4091	4	0.105	4	0.122	4	0.147	4	0.0176
4120	4	0.1028	4	0.081	4	0.1235	4	0.0194
4131	4	0.085	4	0.0803	4	0.1255	4	0.0231
4140								
4224	2	0.0965	2	0.08	2	0.113	1	0.0171
4341	4	0.3478	4	0.3875	4	0.2995	4	0.0463
4343	1	0.142	1	0.151	1	0.193	1	0.0193
4344								
4624	4	0.202	4	0.1992	4	0.2218	4	0.0104
4758	2	0.125	1	0.09	2	0.124	1	0.0155
4965								
5173								
5274	2	0.1325	2	0.1615	2	0.206	2	0.0369
5278								
5584	2	1.489	2	1.141	2	1.1915	2	0.1467
5588	4	1.554	4	2.4612	4	2.6093	4	0.5342
5687	2	0.0985	2	0.089	2	0.1205	2	0.0136
5895	3	0.6257	3	0.707	3	0.9317	2	0.124
5998	4	0.6925	4	0.7682	4	0.7743	4	0.0701
6107								
6730								
7063	3	0.7817	3	0.672	2	0.392	1	0.1124
7244								
13534	2	1.5655	2	0.8045	2	0.7585	2	0.9445

Id	Count	Ave_depth	Count	Ave_score	Recaptures ⁹	Id	X_coord	Y_coord
364	2	-9	2	0	1	364	-1496003	1967346
578	4	-39.5	3	1.2333	1	578	-1456003	2087346
1084			1	0.5	1	1084	-1356003	1807346
1086	4	-99	4	1.975	1	1086	-1356003	1847346
1295	8	-718	3	1.2333	1	1295	-1316003	1867346
2021	2	-1	2	0	1	2021	-1176003	1827346
2436					1	2436	-1096003	1807346
2783	2	-235	3	2.6	1	2783	-1036003	2507346
2831	5	-16.8	1	0	1	2831	-1016003	1387346
2849	2	-10			1	2849	-1016003	1747346
2889					3	2889	-1016003	2547346
3043	4	-15.25	4	0	2	3043	-976003	1467346
3050	3	-9.6667	3	0	1	3050	-976003	1607346
3196	3	-1287.33	3	0.9	1	3196	-956003	2447346
3302	3	-23.6667	2	0.65	1	3302	-936003	2487346
3364	4	-20	4	0	7	3364	-916003	1647346
3403	6	-2572.83	4	2.55	6	3403	-916003	2427346
3411					1	3411	-916003	2587346
3612	4	-529.75	4	3.175	1	3612	-876003	2447346
3620					3	3620	-876003	2607346
3648	6	-146.5	4	1.45	2	3648	-856003	1087346
3725	4	-1014.25	2	0.1	1	3725	-856003	2627346
3825	2	-10	2	0	2	3825	-836003	2547346
3924	4	-963.5	4	4.975	3	3924	-816003	2447346
3931					1	3931	-816003	2587346
4031	4	-16.5	4	0.1	1	4031	-796003	2507346
4091	6	-705.5	4	0	1	4091	-776003	1627346
4120	6	-884	4	2.3	2	4120	-776003	2207346
4131	9	-4113.44	4	4.45	2	4131	-776003	2427346
4140	1	-149	1	0	2	4140	-776003	2607346
4224	3	-549.667	3	2.6	8	4224	-756003	2207346
4341	4	-497.75	4	2.875	1	4341	-736003	2467346
4343	4	-316.25	3	0.0333	2	4343	-736003	2507346
4344	2	-92	1	0	1	4344	-736003	2527346
4624	4	-236.5	4	0	1	4624	-676003	1887346
4758	4	-1234	3	0	3	4758	-656003	2487346
4965	3	-308.333	2	0	8	4965	-616003	2467346
5173	1	-10	1	0	1	5173	-576003	2467346
5274	6	-201.333	4	3.775	2	5274	-556003	2407346
5278					1	5278	-556003	2487346
5584	4	-139	4	4.25	1	5584	-496003	2367346
5588	4	-10	4	0	1	5588	-496003	2447346
5687	6	-492.833	4	4.475	1	5687	-476003	2347346
5895	4	-27	4	2.425	1	5895	-436003	2347346
5998	6	-179.5	4	1.45	74	5998	-416003	2327346
6107					3	6107	-396003	2427346
6730					1	6730	-276003	2407346
7063	5	-113.2	4	3.65	2	7063	-216003	2827346
7244					1	7244	-176003	2287346
13534	4	-436.25	3	0	1	13534	1043997	1207346

⁹ Source of the recaptures data: CTF