Integrating Local Knowledge and Spatial Information Technologies for Marine Species Management: A Case Study in the Turks and Caicos Islands

by

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Abstract

Despite a heavy reliance on scientific knowledge as the primary source of information in resource management, many resources are in decline, especially in fisheries. In this context, the literature suggests that the knowledge of local resource users can supplement scientific knowledge in designing and implementing management strategies. The integration of local knowledge with scientific knowledge for marine species management is problematic stemming primarily from conflicting data types. Local knowledge is inherently qualitative and gathered from local resource users. In this thesis these users have spent a lifetime harvesting aquatic organisms using generational knowledge, intuition, and experience as their fundamental knowledge base. Scientific knowledge, in contrast, is based primarily on a quantitative approach to the study of individual marine species, their preferred habitat, migration routes and spawning behaviours.

The research in this thesis considered the use of spatial information technology as a medium upon which to integrate and visualise spatial distributions of both quantitative scientific data and qualitative local knowledge for the purposes of producing valid and locally relevant fisheries management plans. The case study is a small-scale fishery in the Turks and Caicos Islands. The research takes a common sense, community-based management approach to the development of a multi-knowledge protocol for small-scale fisheries designed to reduce the knowledge gap that currently exists between fisheries researchers who tend to rely on scientific methodologies and knowledge, and local fisherman who use intuition, traditional practices and passed on knowledge.

The results indicate the potential to produce valid and locally relevant fisheries management plans. ArcView GIS is used as a relatively inexpensive medium with which to integrate and visualise spatial distributions of data from quantitative scientific knowledge and qualitative local knowledge. Further, the research protocol, through the Fisheries First management sequence, provides an alternative approach for small, developing countries to assess and keep track of their own fishery in a relatively inexpensive manner.

To Kirsten

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
BTC	Bottom Type Classification
C	Conch
D	Days
DECR	Department of Environmental and Coastal Resources
FK	Fisherss' Knowledge
FMP	Fisheries Management Plan
GIS	Geographical Information Systems
GPS	Global Positioning System
GT	Grand Turk
HAID	Harvester Identification Number
HPZ	High Pressure Zone
IK	Indigenous Knowledge
L	Lobster
LK	Local Knowledge
MB	Multi-Buffer
MSY	Maximum Sustainable Yield
mt	Metric Tonnes
NK	Native Knowledge
OCTS	Ocean Colour and Temperature Sensor
PLA	Participatory Local Appraisal
PR	Providenciales
RRA	Rapid Rural Appraisal
RS	Remote Sensing
SB	Single Buffer
SC	South Caicos
SCL	Species Location Classification
SFS	School for Field Studies
SIT	Spatial Information Technology
SK	Scientific Knowledge
TCI	Turks and Caicos Islands
TEK	Traditional Ecological Knowledge
UEM	Underwater Elevation Model
VFC	Visitation Frequency Classification

Chapter 1

INTRODUCTION

The need for successful resource management has become universally recognized in the last two decades. Human population growth and the resulting demand for space and use of natural resources have depleted non-renewable resources to critical levels. Moreover, many renewable resources, such as the harvest of the sea, are in a state of crisis with species declining to population levels below long-term sustainability. For example, years of over fishing and poor stock management have resulted in the loss of the resource and loss of livelihood for tens of thousands of fishers (and their families) in Canada's Atlantic provinces (especially Newfoundland) and in the United Kingdom's Cod fishing ports. This has been revealed in the second closure of the West Atlantic Cod (*Gadus morhua*) fishery in the past ten years and the threatened closure of the North Sea Cod fishery due to critically low stock levels.

Human dietary desires for animal protein have induced considerable strain on aquatic resources. Each year roughly 51 million fishers, 99 percent of whom are small-scale, harvest 80 percent of the world's fisheries beyond their maximum sustainable yields (maximum level of harvest a fishery can sustain over time while still capable of replenishment)(Berkes et al, 2001; Cochrane, 2000). This equates to roughly 115 million metric tons of fish caught globally each year, approximately 25 percent of which are by-catch, non-targeted organisms killed or injured during commercial harvest operations. Not included in these figures are mortalities due to the illegal harvesting of fish and organisms trapped in lost nets and other fishing equipment (OSB, 1999).

These statistics point to a basic failing in fisheries practice and management that has rendered global fish stocks severely depleted, or actually exhausted in some species. Hence, there is an urgent need to understand more thoroughly the harvest activities of fishers in order to manage these resources better. This observation is equally true of large-scale fisheries, such as the Atlantic and North Sea Cod fisheries, and of smaller scale fisheries, such as those discussed in this thesis.

Cochrane (2000, 3) identifies four main factors that contribute to the failings in global fisheries:

1) High biological uncertainty
2) Conflict between the constraint of sustainability and social and economic priorities
3) Poorly defined objectives
4) Institutional failures related to access rights and participation in management by the users.

These factors contribute to highly complex, fluid systems of processes and patterns of biological as well as human dimensions that occur at multiple temporal and spatial scales. This complexity circumscribes the multifaceted and data inference demands that fisheries managers must deal with in shaping and enforcing species and industry management policies. Perhaps not surprisingly, it is these very complexities that are often blamed for the deficiencies in fisheries management. For example, Neis and Felt (2000; 11) state:

> The crisis in fish populations has created a crisis in confidence in existing management systems for wild fisheries. Major, unanticipated stock collapses in managed fisheries, as has happened with the northern Cod stocks in NFL, point to our limited understanding of the oceans, fishing practices, and their interactions with the physical-chemical environment.

This thesis considers one aspect of the "limited understanding" noted by Neis and Felt, namely the largely untapped knowledge of local fishers. Specifically, this thesis explores the integration of local knowledge and harvest activity into fisheries management planning. It is argued that incorporating local fishers' knowledge and harvest activities into a management framework can work together with current scientific knowledge to improve species sustainability, decrease biological uncertainty (see point 1 above), and improve institutional/user relations (see point 4 above). The proposed approach does not suggest that scientific research on fish stocks is invalid. On the contrary, most knowledge and technological advancements in resource management have been achieved through scientific study and research (Mitchell, 1997). Unfortunately, however, natural resources and their uses are not always measurable, and despite our depth of understanding (or lack of it), resource managers must make decisions with limited information. As Franklin (1997:37) notes:

> When forced to make changes, resource managers and society at large, have always had to operate, to make decisions, with inadequate information. Resource managers have never known as much as we thought, nor as much as we have led the public to believe, about

> our natural resources and how they will respond to a proposed management treatment. But lack of knowledge has never prevented us from moving ahead in making decisions and implementing management programs.

Hence, scientific knowledge alone does not supply adequate information to the resource knowledge base that is required for holistic or integrated resource management. Further, since decisions must be made regardless of the information available for policy development and enforcement, it is necessary to consider other knowledge sources if resource managers are to reduce the level of uncertainty and complexity inherent in fisheries systems.

In recent years, increasing evidence has been assembled to support the view that local fishers' knowledge is fundamental to the management of fish species (Berkes et al, 2001; Neis & Felt, 2000; Johannes, 1989). This knowledge, however, has in the past been neglected in management plans due to the notion that local knowledge is fragmented and subjective, and thus lacking in scientific merit. This view is currently undergoing re-evaluation as the importance of local knowledge is now being recognized, especially in light of the failures of management policies derived solely from the use of scientific knowledge.

Fishers, because they are on the water most days of the week (weather dependent), experience patterns in climate, water currents, migration patterns and species' behaviour that may not be occurring during the time when a scientific study takes place (Johannes, 1989). The most striking example of this concerns the Giant Squid (*Architeuthis dux*) that live off the coasts of Australia, Tasmania and New Zealand. Very little is known about this creature, with less then 50 sightings over the last century. What is known comes largely from fishers' eyewitness accounts, specifically of whales in "fierce battles" with these creatures. These claims went unrecognized by the scientific community until whales where caught with large tentacle marks on their bodies and large squid "beaks" in their stomachs (CNN, 2002; BBC, 2000).

One reason such local knowledge is important as a knowledge source for researchers and fisheries resource managers alike is its inherent spatial component. Fishers tend to perceive the environment as a non-linear representation of space, often orientating themselves based on place, such as how far a fishing spot is from a particular island or where a location is along a riverbank (Brodnig & Mayer-

Schönbergerm, 2000; St. Martin, 1999). These types of spatial data represent features at a finer, or more local scale than other types of information. In effect, fishers possess mental maps of their fishing locations. Thus, local knowledge has the potential to be very effective if integrated successfully with quantitative data on numbers of, for example, total species harvested or total gross weight. In addition, if collected over a multi-year period, this knowledge can illustrate a temporal picture of fish stock health and populations.

Spatial information technologies (SIT), specifically geographical information systems (GIS) and remote sensing (RS), have recently been experimented with by fisheries scientists (Meaden, 2001). SIT in fisheries science has been slow to evolve relative to terrestrial applications of these technologies. This is largely due to the fluid nature of aquatic systems (Nishida et al, 2001). In addition, although there are GIS software packages that can, to a degree, process qualitative data that are common to local knowledge, GIS systems were designed primarily to manage quantitative data (common to scientific knowledge). Hence, there is a challenge in integrating these two knowledge systems since scientists and fishers tend to view the world differently.

Scientists tend to view the world as Cartesian, or humans above and separate from nature, where reality is ordered and explored through a predominantly quantitative scientific method. Local knowledge, in contrast, tends to be a more qualitative, informal world-view of humans existing with, and being an intricate part of, the natural world where respect for nature may more often lead to sustainable relations with nature (Berkes, 1993; Gadgil et al, 1993; Kalland, 2000, Raedeke and Rikoon, 1997). If the use of GIS is successful in integrating local knowledge and scientific knowledge then GIS could serve as the mechanism that finally allows for the bridging of these two knowledge systems.

Recognizing this dichotomy between scientific and informal or local world-views, this thesis seeks to explore and identify common ground where both views converge to produce scientifically valid and locally relevant fisheries management. The objectives of the thesis are stated in the following section.

1.1 RESEARCH OBJECTIVES

The integration of local knowledge with scientific knowledge is in its infancy. While many authors discuss the potential of using local knowledge as a supplementary knowledge source in fisheries management, very few (for example, Calamia, 2001; Rambaldi and Callosa-Tarr, 2000 and 2001; Weiner, et al, 1999; Ward et al, 1999; Tobias, 2000) have attempted to operationalize local knowledge using SIT. This thesis seeks to bridge the gap that currently exists between local knowledge and scientific knowledge, within the specific context of a small-scale artisanal fishery. The general objective is to develop a process-driven operational framework for integrating local knowledge with scientific knowledge within an SIT environment in order to strengthen the ties between government and local fishing communities for the shared goal of sustainable marine ecosystem and fisheries management and income generation. The thesis examines the harvest of two species, namely the Queen Conch (*Strombus gigas*) and the Spiny Lobster (*Panulirus argus*) that inhabit the coastal waters of the Turks and Caicos Islands (TCI) in the northern Caribbean. The specific objectives are:

1) to devise a method for collecting and storing local knowledge in a GIS database for resource management using basic GIS functionality;
2) to explore the feasibility of building an updateable fishery resource database from local and scientific knowledge sources that can be referenced for future resource management planning and decision-making;
3) to compare and contrast local knowledge and scientific knowledge by comparing sea floor types dictated by the fishers to those observable from satellite imagery;
4) to study fishers' decision processes, specifically how they decide which species (if multiple species are harvestable during the same time period) they fish for.

As noted above, the thesis seeks to find a common ground that facilitates the combined use of local and scientific knowledge, in effect bridging information gaps that exist in current resource knowledge bases. In this context, a simple, GIS framework is proposed using modest data. With the advent of any information technology comes the means to acquire and use it. Thus, the research proposes a solution that will work equally well regardless of a country's economic status and extent of modernization. In addition, the research protocol presented in the thesis is applicable independent of the geographic location and type of fishery in which it is used.

1.2 THESIS OUTLINE

The thesis comprises six chapters. Chapter 2 reviews current literature on resource sustainability and management, with a focus on fisheries. A general conceptual model or framework of resource management is introduced and explained. The concepts of local and scientific knowledge are explained in detail and how they affect management decisions is reviewed in the context of the conceptual model. SIT are then identified as a unifying environment for local and scientific knowledge. Chapter 2 concludes by reviewing the suitability of these technologies relative to the objectives of the thesis.

The conceptual model is operationalised as a research model in Chapter 3. This chapter introduces and defines a protocol that combines local and scientific knowledge within a simple GIS framework. This exploratory framework allows local knowledge to be translated into a quantifiable form, in effect bridging the gap that currently exits between the approaches to resource management.

Chapter 4 describes the geographic and economic characteristics of the study area for the thesis as well as providing background information related to the habitat and economic importance of the Queen Conch and Spiny Lobster to the TCI fishery. The specific research approach used in the TCI case study is also discussed.

Chapter 5 presents and discuses the results achieved through use of the general fisheries protocol discussed in Chapter 3. Furthermore, this chapter considers the possible implications of using the protocol in relation to resource management in general and fisheries management in particular. Finally, Chapter 6 concludes the thesis by outlining the contributions that the research in this thesis provides to resource and fisheries management. The significant findings, improvements for the protocol, and directions for further research are also discussed.

Chapter 2

RESOURCE MANAGEMENT AND SUSTAINABILITY

This chapter presents the conceptual framework for the thesis. The relationships between resource management and the main source of information for its knowledge base, namely traditional scientific knowledge, are discussed. Despite the heavy reliance on scientific knowledge as a primary source of information in resource management, many natural resources are in decline. In this context, the literature suggests that the knowledge of local resource users can supplement scientific knowledge in designing and implementing management strategies. Thus, the role of local knowledge is considered to be equally important in resource management planning.

Current literature on resource management, its approaches and sources of knowledge, are reviewed. The discussion argues that current scientific knowledge is not adequate as a solitary knowledge base and that local knowledge can aid in bridging gaps that exist within current resource knowledge bases. The chapter defines resource management and sustainability as well as explains briefly four methods of resource management, namely adaptive management, environmental management, ecosystem-based management and community-based or participatory management. While the central theme of the thesis is resource management, fisheries management and how it relates to fisheries resources is emphasised throughout this chapter. Hence, two new approaches are introduced to fisheries management, namely interdisciplinary and precautionary, that take into consideration social and complexity issues.

Next, the knowledge systems of scientific knowledge and local knowledge are defined and compared. Issues relevant to the integration of the two knowledge systems are presented including limitations to knowledge integration, local knowledge collection techniques, and resource users' knowledge or intellectual property rights. Emphasis is given to illustrating why local knowledge can be used as a supplementary knowledge source in resource management.

Finally, the chapter reviews the role of SIT in natural resource management in general and fisheries management in particular. The chapter concludes with the argument that SIT can offer a common ground within which local knowledge and scientific knowledge can be successfully integrated for more complete resource management decision making.

2.1 Conceptual Framework

Before exploring in further detail the concept of resource management and its goal of resource sustainability, two sub-components within a general resource management framework, specifically resource knowledge bases and resource management decisions, must be considered. Resource management decisions are influenced directly by the quality and quantity of information available in relevant resource knowledge bases and, as such, knowledge and resource decision-making are intrinsically connected. However, scientific knowledge (SK) is at best patchy in many resource areas in terms of lacking both information on species biology and environmental characteristics (Berkes et al, 2001; Neis and Felt, 2000).

Recent failures in a number of resources, specifically fisheries, have prompted not only the investigation of new approaches to management, but also a search for new sources of knowledge that can help fill gaps that currently exist in resource knowledge bases (Berkes 2001; Mitchell, 1999; Maurstad, 2002). To illustrate, an official from the Canadian Fisheries Department commented on the recent collapses of the Cod fisheries in the North Sea and Canada's Atlantic Provinces, by stating that "(We don't) have an understanding of all the dynamics and what buttons to push to create a predictable outcome. That's well beyond the capacity of science to understand" (The Record, 2002; A4). Two implications of this comment are the assembly of more information on the fishery in question and the use of a precautionary type management approach to resource decision-making.

In the context of needing more information on fisheries, scientists have begun to turn their attention to the activities of local resource users who harvest resources on a regular basis. This knowledge source has been gaining increasing prominence in the resource management field and is generally referred to as local knowledge (LK) in this thesis. There are problems, however, when dealing with local resource users, not only in terms of extracting their knowledge, but more importantly, in the construction of their knowledge into a useable format that managers can read and decipher for the purpose of implementation into management decisions.

There are four main factors that impede the extraction and integration of LK into resource management knowledge bases and decision-making. These factors include: 1) the validity of LK and the treatment of local resource users as equals, 2) conflicting and often incomplete data types, specifically qualitative versus quantitative data, 3) differences in world-views, and 4) reasons not to share the data. While each of these impediments contribute to the problem of knowledge integration, the research in this thesis focuses primarily on point 2 – conflicting and incomplete data types. To address this impediment, GIS is proposed and used as a medium to facilitate the integration of qualitative and quantitative data within the resource management framework of a small-scale artisanal fishery.

Relationships between fisheries management, SK, LK and the use of SIT as a unifying and facilitatory mechanism are portrayed in the general conceptual framework shown in Figure 2.1. This framework illustrates the general flows of information into a unified SK-LK resource management knowledge base. Such a knowledge base is multifaceted and multi-sourced and, as such, can be extremely difficult to manage, specifically when it is uncertain or incomplete. Moreover, construction and maintenance of knowledge can be costly and difficult to achieve in the context of fisheries science, particularly with respect to small-scale fisheries (Berkes et al, 2001).

The research in this thesis seeks to visualize the spatial distributions of data from both traditional science and LK perspectives for the purposes of integrated resource management. Thus, the framework presented in Figure 2.1 presents an approach that allows resource managers to exert control over decisions based on both qualitative and quantitative information aggregated within a GIS. Resource managers, in the case of small-scale fisheries, can be government appointed officials or representatives from the local fishing community. It should be noted that in instances where fishermen have formed a collective (where fishermen come together to manage the resource and/or have a significant part in joint management with the local fisheries department), the LK collected though this framework would be available to both the government and the harvester collective.

The framework in Figure 2.1 depicts the principal sources of knowledge that a resource management system can draw upon regardless of the management approach taken within the system. It is important to note that this figure depicts the high level of the knowledge flows through a resource management system and the same pattern and direction can be used to characterise different types of resources (for example, agriculture, fisheries, forestry). Thus, the final outcome of *Resource Management Decisions* illustrates decisions based on data gathered, transformed, and input into the relevant knowledge base. The interpretation of the collected and transformed data is influenced by the resource management approach within a specific resource management system. The solid line from SK to the *Resource Knowledge Base* indicates the current flow of information and its transformation into a relevant knowledge base. The dotted line represents the barriers or impediments, as mentioned above, that presently exist in regards to the integration of LK with SK.

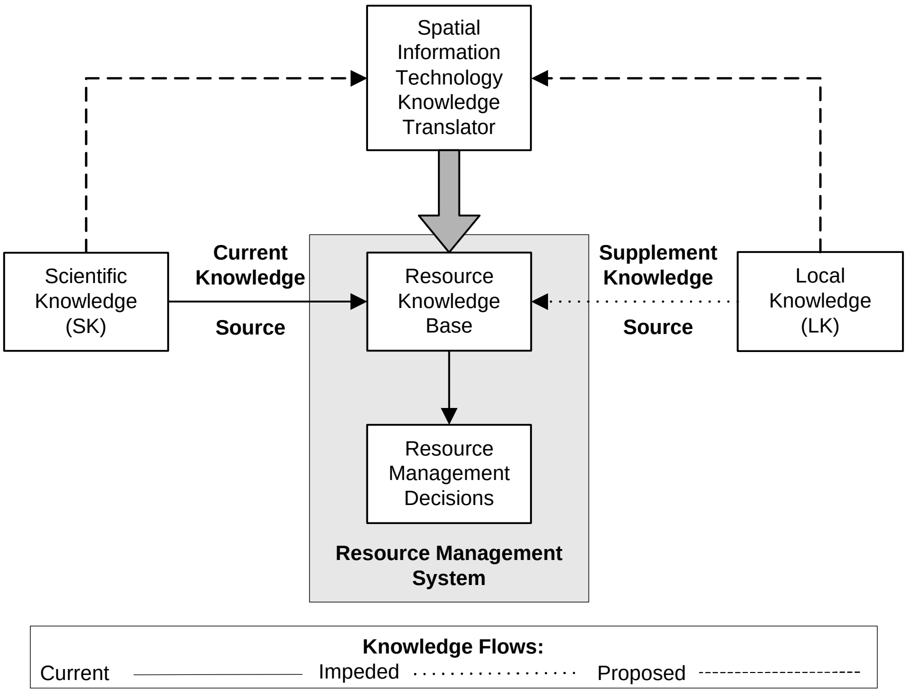


Figure 2.1: General Conceptual Framework for the Integration of Scientific and Local Knowledge into a Resource Management System

Since the *Resource Knowledge Base* acts as a unification of SK and LK, Figure 2.1 proposes that these knowledge sources can be successfully integrated by means of SIT though the translation of data into a common environment. Thus, the dashed lines in Figure 2.1 suggest an alternate means of knowledge input. Instead of knowledge being entered directly into the knowledge base, it is first processed and then transformed prior to analysis and interpretation for resource management decisions. This method of knowledge integration provides a platform from which both qualitative and quantitative data can be viewed and manipulated in tandem, thus constructing a hybrid knowledge source. Once LK and SK have been passed though the SIT translator, resource managers will be better equipped to utilize the untapped knowledge of local resource harvesters in partnership with traditional scientific knowledge for improved management decisions making. For example, a species distribution map derived from SK can be compared with a species distribution surface of the same species constructed from LK. Results can illustrate differences and/or similarities that exist between the two systems of knowledge and inferences may be able to be drawn to ultimately provide a more robust base for decision-making.

Each of the above concepts, starting with resource management and sustainability, is discussed in turn in this chapter. The details of the protocol used to operationalize this model are subsequently discussed in Chapter 3.

2.2 Resource Management

Since the concept of resource management is at the centre of the research in this thesis, it is important to consider issues of resource sustainability as well as the concept of resource management itself. It is not always true that improved knowledge will produce better management decisions. However, in the absence of reliable knowledge, decision-making may be impaired and resources may fall below a replaceable stock level thereby threatening their viability and long-term sustainability. While some resources are not renewable (such as minerals), many are. However this requires management to be based on the concepts of resource sustainability and renewal. Four concepts that are central to resource sustainability and decision-making are common property resources, complexity, uncertainty, and chaos. These concepts are discussed in the following section to provide a foundation for the subsequent examination of four commonly used resource management approaches, namely adaptive management, ecosystem-based management, community-based management, and participatory management. While this discussion is general in nature, the relation of resource sustainability to fisheries management is referred to by way of example given its centrality to the substantive area of interest in this thesis.

2.2.1 Resource Management and Sustainability

The general field of resource management deals with the sustainability of a natural resource for human consumption and/or enjoyment. Sustainability is defined in general by the FAO (1995) as:

> The management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agricultural, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economical viable and socially acceptable.

Within the context of fisheries management, the Committee on Ecosystem Management for Sustainable Marine Fisheries Ocean Studies Board (1999: 2) defines sustainability as "activities that do not cause or lead to undesirable changes in biological and economic productivity, biological diversity, or ecosystem structure and functioning from one generation to the next."

While these definitions are the desired outcome of management practices, often smaller scale fisheries experience "ravishing and pillaging" of their resources with little regard to long-term sustainability as seen in small-scale fisheries in Asia (Gibson, 2003; Berkes et al, 2001). Aside from harvesters catching fish for short term gain, issues of poaching can occur where fishers from other villages or countries infiltrate the waters of another village or country to harvest the resource with little regard to any rules that may be in effect in that country (Day, 2002). While these may be realities in some countries, long-term solutions must be the goal in fisheries management practises if fisheries are to remain a renewable resource.

In this context, the broad definitions of resource sustainability noted above, outline the shared goal of conserving renewable resources. As such, resource managers must deal with a number of issues in their decision-making, including common property resources (or common pool resources), complexity, uncertainty, and chaos. Common property resources are natural resources that are either state controlled in some way or collectively owned by society (anyone can harvest them) (Charles, 2001; Berkes et al, 1989; Berkes, 1985; Baden, 1998; Bish, 1998). State controlled common property resources typically have some form of covenant or restrictions placed on their use such as specifying maximal, seasonable harvestable quantities of a given resource. Use, in this context, often involves payment in the form of yearly licensing fees that are used to offset the costs associated with managing the resource (Bish, 1998). State controlled resources typically occur where the resource in question is scarce.

In contrast, publicly or largely unowned common property resources are collectively owned by society and are not regulated by the state. The commonality associated with collectively owned resources, within a laissez-faire economic context, inevitably leads to three problems:

1) Users of the resource fail to see that their use imposes costs, either indirectly or directly, on others and more importantly, on the health and diversity of the resource (Bish, 1998).
2) Refereeing potential users is problematic, specifically in the case of fisheries (Berkes et al, 1989).
3) There is no incentive for individuals to limit their consumption of the resource.

Property rights within an aquatic context will always be an issue in resource management because natural resources are largely unowned. People harvesting owned resources tend to use them more efficiently, however once ownership is removed, individuals often take care of their own interests, typically taking as much as they can harvest (Bish, 1998). This is explained by Baden (1998; 52) who notes that: “in a situation where there is no agency with the power to coordinate or to ration use, action which is individually rational can be collectively disastrous.” This is nowhere more apparent than in small-scale artisanal fisheries where target species are largely concentrated in relatively small geographical areas and no traditional means of constraint and allocation are in place. Thus, each resource harvester in a community typically has access to the entire fishing ground (with the exception of customary societies where the fishing grounds is divided amoung users), resulting potentially in a more severe cumulative depletion of the fishery in question. The common property reality that often results in short term gains at the expense of long-term sustainability is referred to as the "tragedy of the commons" (Charles, 2001). It should be noted that in instances where common property resources are state regulated, the concept of the "tragedy of the commons" is often avoided (Gibson, 2003).

In addition to dealing with the "tragedy of the commons," resource managers must also confront the issue of resource complexity. A system is considered complex when researchers and managers alike do not fully understand the functioning or structure of the system (Charles, 2001). By definition, a complex system is one that contains many elements and each element interacts with potentially every other element interior and exterior to the system. In the context of species resource management, the more diverse the species are in a given system, the more elaborate and intricate the interactions will be (Charles, 2001). In this way, diversity is directly correlated to complexity; the higher the level of diversity in a system, the higher the complexity in that system. Examples of complexity include multiple and conflicting objectives, multiple species, and the ecological or trophic interactions between them, and multiple users and user conflicts, to name a few (Charles, 2001).

An intrinsic aspect of complexity that must not go unrecognized is scale. In the context of fisheries, for example, a single species fishery system may be viewed as biologically "simple." However, upon closer inspection, this simplicity may contain complexities among different types of users (for example each fisherman wanting to harvest different species within the same fishery), complexity within the spatial interaction of sub-regions within the system, interactions among other aquatic species, and problems associated with poaching (Charles, 2001).

The third issue that the resource managers must deal with is uncertainty. Similar to complexity, uncertainty is caused by lack of complete knowledge about a system, potential effects of intervention, and by the inherent unpredictability of complex systems. Uncertainty can be defined as something that is in doubt of being true (Oxford English Dictionary, 1991). Further Mitchell

(1998; 17) notes that: "[o]ur understanding of biophysical systems, of human societies, or of the interactions between natural and social systems is often incomplete or imperfect. Furthermore, we are aware that conditions and circumstances in the future could well change relative to what they are today." Thus, the view of many resources managers is to maintain a conservative level of stock harvest in order to protect for an unknown future. Conversely, resource users may express the desire to harvest as much as they can in the short-term for the same reason (i.e. an unknown future related to the "tragedy of the commons" noted earlier) (Clark, 1985). This rationale is readily apparent in Southeast Asia where harvesting for immediate gain has devastated fish stocks to critical levels (Berkes et al, 2001). Table 2.1 summarizes types of uncertainty, both natural and human induced, within the context of fisheries.

Underlying the concepts of common pool resources, complexity, and uncertainty is chaos theory or complex dynamics. Chaos is a sub-set of complexity and is essentially an unseen principle that is inherent in all non-linear systems (Lewin, 1999). It implies order within a system where the order is not predictable (Mitchell, 1998; Charles, 2001). Ecosystems are good examples of non-linear systems and, as such, are impossible to simulate mathematically (Lewin, 1999). The most common example of this is the "butterfly effect," which is described by Lewin (1999; 11) as follows:

> In non-linear systems, small inputs can lead to dramatically large consequences. This is often characterised as the so-called butterfly effect: a butterfly flaps its wings over the Amazon rain forest, and sets in motion events that lead to a storm over Chicago. The next time the butterfly flaps its wings, however, nothing of meteorological consequence happens. This is the second feature of non-linear systems: very slight differences in initial conditions produce very different outcomes.

This example illustrates the foundation of a non-linear system, such as a natural resource system, to be inherently unpredictable (Lewin, 1999). Furthermore, it is important to appreciate the relevance of chaos theory in natural resource management as it represents an additional dimension of complexity in an already complex system.

Natural Sources of Uncertainty	Human Sources of Uncertainty
Stock Size and Age Structure	Fish Prices and Market Structure
Natural Mortality	Operating and Opportunity Costs
Spatial Heterogeneity	Discount Rate
Migration	Technological Change
Stock-Recruitment Parameters	Management Objectives
Stock-Recruitment Relationships	Resource Harvester Objectives
Multi-Species Interactions	Resource Harvester Response to Regulations
Fish-Environment Interactions	Perceptions of Stock Status

Table 2.1: Examples of Uncertainty in Fisheries (adapted from Charles, 2001; 204)

In order to address the "tragedy of the commons", complexity, uncertainty and chaos, all of which affect natural resources to some extent, resource managers must devise management strategies that permit resource stocks to be harvested at levels where the resource is able to regenerate itself naturally, without any additional human intervention (Welcomme, 2001). Furthermore, for sustainable resource use and development to be successful, specifically in the context of fisheries, long-term precautionary goals must be set that are relevant to the value systems of the resource harvesters (Berkes et al, 2001; Mitchell, 1998; Charles, 2001). One problematic aspect of using SK for formulating these goals is that: "…the adoption of science-based innovations and technologies by local people has often been stifled by their perceived incompatibly with traditional value systems and cultural practices." (Brodnig, 2002;2)

At an even finer scale of inquiry, the ethnic, cultural and, even, religious backgrounds of fishers will often cause the "value" of their resource and their environment to be viewed differently. This is especially true in the case of small-scale artisanal and subsistence fisheries (Berkes, 1999; Mitchell, 1997). Value in this context refers to human values rather than monetary value, although in some contexts the monetary or economic value of the resource can also be viewed differently. Such differences in resource views are due primarily to the fact that fishers use fish as their main source of subsistence and protein intake. As a result, fishers will often provide self-regulatory or *defacto* management practices of the resource they harvest as their health as well as their livelihood depends on the resource (Maurstad, 2002). More importantly, at any scale of enquiry the management approach taken will greatly influence the successfulness of management planning (WCED, 1987). This is discussed in the following section.

2.2.2 Management Approaches

In an attempt to balance the increasing pressure human population growth and activities place on natural resources, management approaches are shifting away from traditional exploitive short-term models to approaches that focus more on long-term resource security and management of complete ecosystems (Welcomme, 2001; Mitchell, 1997; Berkes et al, 2001; Charles, 2001). This change in approaches is particularly relevant to fisheries due to the dynamic and uncertain nature of aquatic environments. Not only must fisheries resource managers deal with hydrological and oceanic processes, but they must also consider and incorporate the biology of fish and how they relate to changeable environmental conditions (Welcomme, 2001, Valavanis, 2002).

Added to this complexity are the characteristics and goals of the resource users and the government agencies charged with managing the resource. In this context, Pinkerton (1989), Welcomme (2001), Berkes (1999, 2001), Charles (2001) and WCED (1987) suggest that a co-management approach to sustainable resource development can be extremely effective, particularly when resource users are involved in management planning and decision-making. Pinkerton (1989:4) defines co-management as:

> … agreements (between government and fishers) to promote conservation and enhancement of fish stocks, to improve the quality of data and data analysis, to reduce excessive investments by fishers in competitive gear, to make allocation of fishing opportunities more equitable, to promote community economic development, and to reduce conflict between government and fishers, and conflict among fishermen's groups.

Examples of approaches that operate under the general umbrella of co-management include adaptive management, ecosystem-based management, community-based management, and participatory management. Each of these forms of co-management is now described.

Adaptive management is an approach that utilizes the philosophy that environmental conditions are dynamic and that unpredictability and uncertainty are fundamental aspects of all ecosystems. Adaptive resource managers view and interact with resources on the premise that nature cannot be controlled or specie populations calculated accurately (Berkes, 1999). This implies that adaptive management removes the numerical constraints associated with the scientific method, thus allowing a more flexible approach to management to be employed. Adaptive management also emphasises the need for appropriate feedback mechanisms and adaptive design, how processes associated with one variable affect the process of another (chaos theory), and the requirement that management plans be adjusted appropriately in order to accommodate change in resource conditions and uses, in effect "learning by doing" (Berkes, 1999 & 2001).

This approach has the potential to be extremely effective in the context of fisheries management since the knowledge base for fisheries is constantly evolving and expanding due the variability of aquatic environments. Neill (1998:290) emphasises this in stating:

> Environmental factors may directly affect physiological properties of individual growth, survival and reproduction, and assessing these direct effects is a well-established part of modern fisheries science. But environmental variation may also *indirectly* affect productivity by altering the properties of biotic linkages among organisms in a species' food web, sometimes several steps removed from fisheries near the top of the trophic pyramid. While forecasting the occurrence, timing and magnitude of environmental change is at best stochastic, forecasting subsequent indirect effects on stock productivity is much more difficult than forecasting direct physiological effects. The range of possibilities for indirect effects is potentially enormous.

For these reasons, it is imperative to have an open, flexible and evolving forum to allow for the uncertain and complex nature of fish stocks. Such an approach allows managers to change and redirect management plans to suit varying environmental conditions (Charles, 2001).

The second approach, ecosystem-based management, concentrates on the management of the health and rehabilitation of an ecosystem rather than the management of the harvesters of the ecosystem itself (Mitchell, 1997). While ecosystem-based management constitutes a much broader scale in terms of land-based resource management, in the context of aquatic ecosystems, the Committee on Ecosystem Management for Sustainable Marine Fisheries Ocean Studies Board (1999:15) defines the ecosystem approach as one "… that seriously takes all major ecosystem components and services – both structural and functional – into account in managing fisheries and one that is committed to understanding larger ecosystem processes for the goal of achieving sustainability …".

With respect to fisheries management, this approach promotes the regeneration of larger predator-type fish such as Chinook Salmon (*Oncorhynchus tshawytscha*) and Tuna (*Scombridae*), as they tend to be the preferred species for both recreational and commercial fishers (Ross, 1997; Welcomme, 2001; Pitcher and Pauly, 1998). The majority of current management regulations in both marine and terrestrial aquatic ecosystems concentrate on sustaining the younger populations of fish species in an attempt to allow them to breed at least once before harvest (OSB, 1999; Ross, 1997). This has additional secondary beneficial consequences on species dynamics and populations, as larger fish produce larger numbers of eggs, thereby increasing the chances for species procreation (OSB, 1999).

Community-based management is similar to participatory management in principle and in practice, therefore these approaches are discussed together. The main idea behind community-based or participatory management is the decentralisation of management control from managers to users and the local communities supported by the resource (Welcomme, 2001). Brown (1998:187) defines community-based management formally as "a system wherein authority and responsibility over local resources is shared between government and local resource users and/or their communities."

Participatory management is similar to this in that the users of the resource, as well as the broader community, have a say in the management of the resource. This type of management approach has the potential to be very effective, specifically when dealing with integrating LK into the management approach as there is a readily available source of LK input to the management decision process. Given this, there is clear vested interest in good management principles from the local community (Berkes, 1999; Mitchell, 1998). This method of management is widely referenced in the literature as it serves as a focal point for enabling local people to have the opportunity for their voices to be heard and incorporated into management practices (Berkes, 1999 and 2001; Mitchell, 1998; Conway and McCracken, 1990; Chambers, 1994).

These four approaches to resource management have recently undergone changes to fit more directly with the issues inherent in fisheries management. In particular, responses to uncertainty and the "tragedy of the commons" have been incorporated to varying degrees into each approach. However, in general there is consensus in the literature that a new approach to fisheries management must be adopted that works both within *and* outside the conventional scientific realm (Charles, 2001). Thus, the following section concentrates directly on fisheries management and the factors that affect its successes and failures, as well as discussing two new approaches specific to fisheries management, namely the interdisciplinary and precautionary approaches.

2.3 FISHERIES AND FISHERY MANAGEMENT

In the previous section, the majority of the discussion focused on the general principles and approaches to resource management with some reference to fisheries. The discussion now turns to focus specifically on the issue of fisheries resource management using the framework presented in Figure 2.1. The next sub-section provides a brief introduction to fisheries, the different users of fisheries resources and their potentially negative effects on the resource and the aquatic environments they use. This discussion is followed by a review of fisheries management and related management strategies, concluding with a summary of factors that affect success and failure in fisheries management. The section concludes with a discussion of two proposed management approaches specific to fisheries.

2.3.1 Fisheries

A fishery, as defined by Ross (1997), is the interaction between the fishery resource, its environment, and humans. The benefits of a fishery system can be economic, nutrition (food consumption) or sport (nonconsumption) related. Most fisheries are referred to as a common pool resource following the discussion in section 2.2 because the resource can be accessed by anyone at any time (Baden and Noonan, 1998). Similarly, with the exception of aquaculture practices, fish cannot be restricted to specific areas unless these are in containment pools or specific fish ponds. To illustrate this point, Bish (1998; 66) states, "the existence of valuable unowned resources provides an incentive for individuals to try to capture the resource before other potential users can do so. This is likely to lead to premature use of the resource and increase the possibility of its destruction." This is a clear example of the concept of the "tragedy of the commons" and is the fundamental reason why governments place restrictions in the form of quotas, minimum size limits, regeneration zones on fish stock harvesters, and territorial waters based on the law of the sea in order to promote sustainability of the resource. Before discussing these restrictions in more detail, the users of fisheries and their impacts on the environment are reviewed.

2.3.2 Fishery Users

Those who harvest aquatic organisms for monetary or recreational returns are referred to generically hereafter as harvesters (Welcomme, 2001; Ross, 1997; Charles, 2001). Charles (2001) defines four main categories of harvesters, namely subsistence, indigenous, commercial and recreational, (see Figure 2.2). Subsistence harvesters are typically confined to smaller communities where traditional fishing techniques are used. There is some disagreement in the literature on whether subsistence harvesters operate only for themselves or also for profit.

Generally, the literature agrees that the main motivation for subsistence harvesting is to supplement protein intake with no surplus being sold (Charles, 2001; Welcomme, 2001; Berkes et al, 2001). Native, or indigenous harvesters are also motivated by subsistence, tending to rely on inter-generational knowledge transmission, experience, and instinct to guide their fishing practices. Commercial harvesters, in contrast, are those who harvest fish chiefly as a source of net economic gain. There are two levels of commercial fishers, namely small-scale and large-scale, whose characteristics are described in further detail below. Finally, recreational harvesters, also referred to as anglers, are "people who fish for personal, aesthetic experiences rather than solely for income or subsidence" (Ross, 1997:331). Anglers can also fish as a source of income. However, this is practiced primarily in North America through fishing tournaments where prizes are awarded, for example, for the highest total weight in fish caught. Such events draw millions of dollars a year that are injected into local economies during fishing tournament activities.

Since the focus of the research in this thesis deals with commercial fisheries, the remainder of this discussion focuses on the characteristics of large and small-scale commercial fisheries.

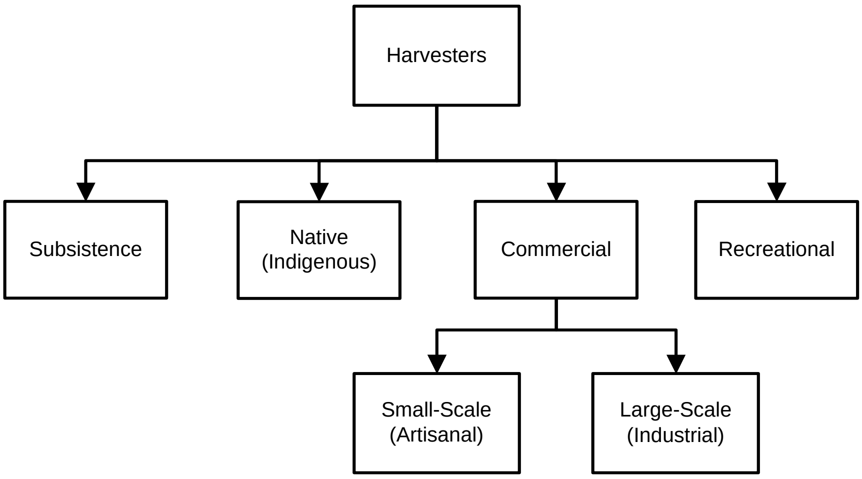


Figure 2.2: Classification of Fisheries Harvesters (Source: Charles 2001; 45)

Of the 51 million fishers worldwide, fewer than one million are large-scale harvesters. Table 2.2 summaries the differences between small and large-scale fisheries. Small-scale harvesters represent 99 percent of the total fishers, harvesting almost 50 percent of the total annual catch. Large-scale harvesters are those who have access to larger fishing grounds, typically in marine environments, and large scale, high volume harvesting technologies. In contrast, small-scale harvesters are those who are typically confined to a small geographic fishing area and are limited to traditional harvest practices inherent to the culture of the community (Charles, 2001).

Large-scale fishers tend to fish far offshore, while small-scale fishers fish close to shore. Large-scale commercial fishers, although far smaller in number, are responsible for the majority of the world's catch (OSB, 1999). They are also subject to closer scrutiny through cater monitoring and regulations, with restrictions put on everything from boat registration to catch quotas (Berkes, 1999). Given this, much more tends to be known about large-scale fisheries and relevant commercial fish stocks than small-scale fisheries. This also has implications for data collection and analysis (Berkes et al, 2001; Mahon, 1997).

Key Features of the Fisheries	Large-Scale Fisheries	Small-Scale Fisheries
Direct Employment in Fishing	500,000 People	50,000,000 People
Fishery-Related Occupations	-	150,000,000 People
Fishing Household Dependants	-	250,000,000 People
Capital Cost per Fishing Job	US$30,000 - $300,000	US$20 - $300
Annual Catch for Food	15 – 40 Million Tonnes	20 – 30 Million Tonnes
Annual Fish Bycatch	5 – 20 Million Tonnes	< 1 Million Tonnes
Annual Fuel Oil Consumption	14 – 19 Million Tonnes	1 – 2.5 Million Tonnes
Catch per Metric Tonne of Oil used	2 – 5 Metric Tonnes	10 – 20 Metric Tonnes

Table 2.2: Small and Large-Scale Fisheries (Source: Berkes et al, 2001; 9)

Specific characteristics of small-scale harvesters as noted by Charles (2001; pg 47) include the following:

1) High level of dependence on the fishery for their livelihood, with few other job opportunities, and often with relatively low net incomes.
2) Utilisation of vessels that are relatively small and individually owned.
3) A tendency towards use of a “share” systems to divide fishing income among boat owner, captain and crew, rather then a wage system (as is common in industrial fisheries).
4) Traditionally being outside the centres of economic and political power, on the periphery of the larger society.
5) Often viewed by analysts in one of two very different ways: as participants in an activity “ripe for modernisation and rationalisation,” or as people (and communities) threatened by external economic forces and in need of protection.

Fishing methods used by both large and small-scale harvesters predominantly involve the use of nets and lines varying in size by the type of fishery. However, these types of fishing practices often lead to by-catch or unwanted species caught in the nets in addition to the target species (Welcomme, 2001; Ross, 1997; Charles, 2001). Another method of harvesting fish is skin diving. This is typically practiced in small-scale artisanal fishing communities, where fishers free dive, unassisted by underwater breathing apparatuses, to retrieve their catch by hand, spear or hook.

Humans typically inflict some type of damage to the resource environments they harvest from, and the aquatic environment is no exception. The next section discusses how fishing practices adversely affect both existing fisheries and their environments, thus reaffirming the need to construct careful management policy for small-scale fisheries.

2.3.3 Repercussions of Fishing

In the context of harvest activities, humans inflict three levels of damage on aquatic ecosystems. Primary damage from harvesting activity alters the populations of various species, disrupts age structures and breeding ratios, as well as affects the influence that species have within the food web (Neill, 1998; Canada's Ocean Strategy, 2002). Secondary damage that occurs from harvesting activities includes the destruction of habitats through species reduction within the food chain or through harvesting procedures that change bottom structures, specifically when that structure is part of a benthic community (organisms that feed and live on the ocean floor) (OSB, 1999; Canada's Ocean Strategy, 2002).

A third level of damage that can result from harvesting activities is the effect of pollution that humans inflict during harvest operations. This includes pollution in the form of chemical and biological agents, as well as discarded or lost gear. Chemical pollution results in the use of fuels, oils, sludge, and other harmful substances that get deposited in the water through leaks or spills from fishing vessels (Canada's Ocean Strategy, 2002). These chemicals eventually make their way through the food chain, resulting in stunted growth and other defects to aquatic organisms. Biological toxins harm aquatic environments through discarded fish innards and other fish related body parts that are typically dumped over the side when fish are processed. Also, lost traps, nets, and other fishing equipment that can entrap and kill a variety of species pose significant problems for future fisheries as a direct result of past fishing activities. Over 100,000 tons of gear are lost each year in the commercial sector (Sumich, 1992).

Ecosystem damage can, to a degree, be controlled in the form of regulations put into place by national local governments depending upon the scale of operation. The next section discusses fisheries management, followed by an overview of the types of management-orientated regulations governments typically use to control the numbers of fish harvested.

2.3.4 Fisheries Management

Thus far this chapter has discussed the need for resource management, the convergence of resource knowledge sources and how resource management relates to fisheries management in general. Common pool resources, complexity, uncertainty, and chaos were explained as issues that both natural resource and fisheries managers alike must deal with in any natural resource setting. Despite the recognition of these issues, current fisheries management approaches seem to be failing (Berkes et al, 2001; Cochrane, 2000). This section focuses on fisheries resources specifically, by defining and describing the need for fisheries management, and discussing the issues that are prevalent within fisheries management. The conservation measures that are outlined below have been devised to take into consideration the issues already mentioned.

In the early 1900s, a theory was in effect called the "inexhaustible nature of the sea" (Gordon, 1998). This theory proposed that the actions of humans on aquatic systems were inconsequential and that regardless of how many fish were harvested from the sea, the marine fishery would never be in doubt and that any attempts to place restrictions on fishing were not constructive (Gordon, 1998). The theory, however, was short lived as studies showed considerable growth in fish populations during the World Wars when fishing in European waters was, in effect, stopped. This proved that management practices were indeed needed to protect fish populations through subsequent enforcement of fishing regulations (Gordon, 1998).

Today, fisheries "…are managed in an arena of uncertainty that includes an incomplete understanding of the ability to predict fish population dynamics, interactions among species, effects of environment factors on fish populations, and effects of human actions" (OSB, 1999:7). Thus, the rationale for management action is to maintain fisheries perpetually to ensure the health of fresh water and marine ecosystems as well to keep recreational and commercial activities in check. If fish stocks are left unmanaged, they run the risk of collapse due to the "tragedy of the commons" noted earlier. This reality is particularly relevant to tropical environments due to the diversity of the small population-sized species that are found there (Berkes 2001).

Fish population or abundance is an important factor in the health of a fishery. As such, there is a close relationship between the effective management practices of fish populations and the ability of researchers and resource managers alike to obtain accurate estimates of fish abundance and distribution (William, 2001). However, it has been proven to be extremely difficult in practice to estimate fish biomass accurately due to the intrinsic characteristics of the aquatic environment, the nature of common property resources, and the uncertainties inherent to human/environment interactions discussed in Section 2.2.1. These issues can, to varying degrees, affect the success of fisheries management. Thus, the following section examines issues that relate to the effectiveness of fisheries management, but first fishing regulations are discussed as an example of methods governments use to control fish stock abundance.

2.3.5 Regulations

There are a number of ways governments can manage and control fish stocks. Examples of government regulations include minimum size limits, fishing licences, open and closed seasons, catch quotas, creel limits, and marine protected areas (fish sanctuaries). These strategies have been developed primarily through the use of scientific research and are defined below. Before defining the strategies, however, the reason for and definition of fishing regulations are discussed.

Fishing regulations or restrictions are put in place to help alleviate pressure created by excessive catches within fisheries and to minimize over-harvest of the breeding population (Welcomme, 2001; Ross, 1997; OSB, 1999). Fishing pressure relates to the amount or number of harvesters an area of water receives at any given moment. Regulations are put in place either by catch limits, including size and number, open and closed seasons, and sanctuaries (areas where there are typically high concentrations of fish populations that are extremely vulnerable to humans or important spawning and/or nurturing grounds). Regulations will differ depending on the environment (either freshwater or marine), watershed (freshwater), or regional boundaries (Ross, 1997). Furthermore, the effectiveness of regulations is dependent on the users. In this context, Ross (1997:181) states that:

> Many recreational users are receptive to regulations if they understand that their future enjoyment will be enhanced by current constraints on their fishing activities. Commercial harvesters are less patient when their fishing activities are restricted, as their current income often is far more critical to them than is any future project of fishing. Commercial harvesters often viewed regulations as a threat to their pursuit of a chosen occupation. Therefore, it is not surprising that commercial harvesters often vigorously oppose restrictive harvest regulations.

While the above regulatory strategies are important, only a few relate specifically to the research in this thesis, namely minimum size limits, open seasons, catch quotas, and marine protected areas (MPAs). These management strategies are now discussed.

Minimum size limits require that a fish be of a certain size before it can be harvested. This ensures that the fish has a chance to breed at least once (Ross, 1997; OSB, 2001). Open and closed seasons are put in place in order to protect concentrations of fish, usually due to spawning behaviours that would typically position the fish in areas highly vulnerable to humans (Ross, 1997; Welcomme, 2001). Catch quotas are applied to commercial fisheries to limit the total weight of fish that commercial harvesters are allowed to catch annually. Commercial quotas are usually based on maximum sustainable yield (MSY) indices, which are typically estimated from historical time series of catch counts. MSY is defined as the "management of a fish stock that allows the maximum yearly harvest that can be sustained through time" (Ross, 1997: 334). Marine Protected Areas (MPAs) are areas where there is absolutely no fishing permitted at any time throughout the year. MPAs typically protect areas that are used for spawning or are considered sensitive for a particular species or habitat.

Regulatory strategies, such as those mentioned above, are in use all over the world but their success is highly variable. This is primarily attributed to incomplete or uncertain knowledge about specific aquatic environments and organisms that reside there and the difficulties in enforcing regulations. Other factors include harvesting outside legal size limits and boundaries and poaching, both of which result in cumulative stock decline. The next section discusses four reasons for the failure of fisheries management.

2.3.6 Fisheries Management Failure

As mentioned earlier in the chapter, common property resources, uncertainty, and complexity are common problems in natural resources management. These problems place significant demands on the amount and types of knowledge that are required to make informed management decisions. They are specifically relevant in fisheries due to the intrinsic characteristics and dynamic nature of the oceans and terrestrial water bodies in which fish live, not to mention the human dimension of resource harvesters (Cochrane, 2000). These considerations relate to issues that affect fisheries management and coincide closely with Cochrane's four reasons for failed fisheries mentioned in Chapter 1. To reiterate, these are:

1) high biological uncertainty,
2) conflict between the constraint of sustainability and social and economic priorities,
3) poorly defined objectives, and
4) institutional failures related to access rights and participation in management by the users.

Each of these points is now discussed. Biological uncertainty is characterized as a lack of complete knowledge about an aquatic species in nature. Berkes (2001) defines five types of error associated with uncertainty, specifically measurement error, process error, model error, estimation error, and implementation error. Measurement errors result in false quantities observed from research carried out on biological and catch considerations. Examples of these include misrepresentation of commercial fleet logbook data and statistical problems attributed to traditional sampling methods. Process error is the natural variability associated with fish population dynamics.

The inability of scientists to predict environmental conditions, and the subsequent fish population response, results in a high degree of uncertainty in terms of predicting total fish biomass for the species of interest. Model error stems from the misuse of model structure, where models produce very different outcomes based on the same dataset. Estimation error can occur from a combination of the above errors. Estimates of fish abundance and mortality are often sketchy and estimation errors increase or decrease exponentially as these values are worked though the system. Finally, implementation error is the direct result of poor management policy implementation. Implementation error occurs mainly from a government's failure to enforce regulations adopted for the control of harvesting activates.

Conflict between social and economic priorities conveys the idea that economic issues often are prioritised above social issues, which in turn conflicts with fisheries management objectives that are in place to promote resource sustainability (Cochrane, 2000). With one third of the world's catch traded internationally, the harvest of commercial fisheries provide livelihoods and food for many local communities, especially in developing countries where it is estimated that 12 million people are employed in small-scale commercial and subsistence fisheries (Pauly, 1997; Garcia and Newton, 1997). Governments tend to place a higher priority on economic interests over sustainability of a resource, typically suggesting that they are managing for sustainability, but in reality, they are managing for short-term gain (Cochrane, 2000).

Poorly defined objectives are often responsible for the failings in fisheries management. With governments struggling to find a balance between economic interests and long-term resource sustainability, fisheries objectives often end up being poorly defined (Cochrane, 1997, Pikitch et al, 1997; Olver et al, 1995; Hilborn et al, 1993). This problem worsens as resource users and species harvested increase (Cochrane, 1999; Jentoft and McCay, 1995). As Cochrane (2000; 8) notes, "[i]n the absence of clear and unambiguous objectives, it is impossible for fisheries managers to know what is expected from them, and the likely response is to make decisions based on immediate crisis and short term, poorly considered objectives." This often results in secondary social problems such as access issues and a lack of resource user participation in management activities.

The final reason for the failure of fisheries as noted by Cochrane (2000) is institutional weakness. Institutional weakness is defined as a problem arising from the processes and rules that preside over fisheries management. Two main areas that lead to managerial problems are access issues and resource user participation (Cochrane, 2000). In the past, fisheries management was characterised as government operated, top-down management of common pooled resources (Symes, 1996; Pearse, 1994). Top-down management approaches, however, often tend to produce poor communication among and between managers and harvesters that can lead to frustration amid the harvesters. This often results in poor compliance with fishery regulations (Cochrane, 2000).

New management approaches must be developed in order to overcome the constraints and problems associated with the issues noted above. Scientists must re-think and reconstruct new resource management approaches that are better suited to the goals of ecological sustainability of the resources, the livelihood of the harvesters of the resource, and the dietary needs of human populations (Berkes et al, 2001). Two such approaches are the interdisciplinary resource management approach and the commonsense precautionary approach.

2.3.7 Fisheries Management Strategies

Previous resource management research produced the approaches of adaptive management, ecosystem management, community based management and participatory management discussed early in the chapter. While these are important in managing natural resources, two relatively new approaches specific to fisheries management are now presented, namely interdisciplinary resource management and the precautionary approach. Both of these approaches fit transparently into the research framework presented in Figure 2.1.

Interdisciplinary natural resource management conveys the idea that a group of researchers from a number of different disciplines form a research team, where each researcher works together to extract a more accurate, complete knowledge base while inflicting minimal damage to the environment and the people whom they are working with. For example, if collecting biological information from a small island fishing community, the research team could be comprised of an oceanographer, a marine biologist, an anthropologist, and if possible, representation from the local community in terms of a government official and/or a representative from the local fishing community. The oceanographer and biologist would ensure that the right types of scientific oceanic processes and species related questions were being asked, while the anthropologist could act as a liaison between the scientists and the local community to ensure that information was extracted in a culturally appropriate manner in addition to translating technical information into a format that the locals could more readily understand. Additionally, the representative body from the local community could further aid in cultural issues and language and terminology translations.

The commonsense precautionary approach is a management approach that exaggerates critical regulatory parameters erring on the side of conservation in developing management decisions (Berkes et al, 2001). For example, if the catch quota for a season was calculated to be 600,000 lbs, then the value would be adjusted downward to 500,000 lbs to compensate for error or lack of knowledge that may have affected the original value. The commonsense precautionary approach was first used by both the FAO and the United Nations in 1995 for the “Code of Conduct for Responsible Fisheries” and “Straddling Fish Stocks and Highly Migratory Fish Stocks Agreement” respectively (Berkes et al, 2001). This approach is now commonplace in most international fisheries agreements and is specifically applicable to decisions that could cause irreversible damage to the resource.

Both of these approaches, as with the four previously mentioned, function within the framework presented in Figure 2.1. To illustrate this, a slightly modified version of Figure 2.1 is presented in Figure 2.3. This modified framework illustrates that a resource management approach, such as any of the six mentioned above, forms an integral part of a resource management system. Knowledge requirements for each management approach differ dependent on its objectives. Therefore, in Figure 2.3 the semi-dashed lines indicate a request for knowledge that is sent out to the respective knowledge sources.

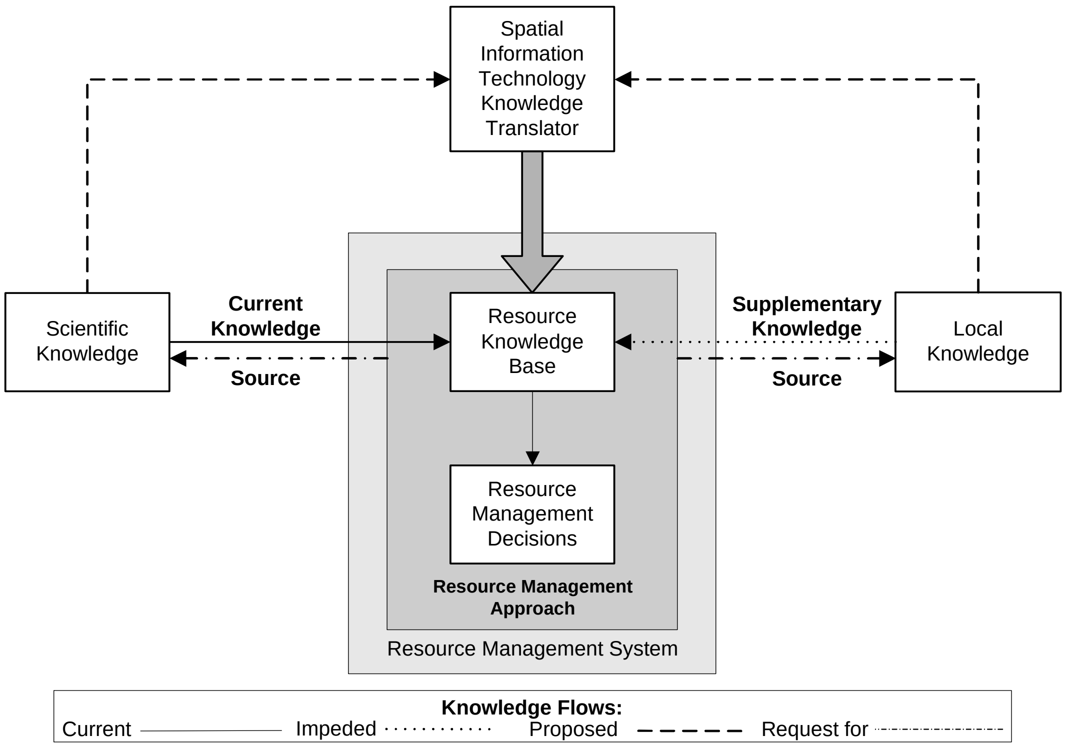


Figure 2.3: Modified Version of the General Conceptual Framework from Figure 2.1 illustrating how Management Approaches Operate within a Resource Management System.

Regardless of the resource management approach used, incorporation of various knowledge sources into a relevant knowledge base cannot occur without some form of objective or meaning attached to the knowledge being collected. In order to accomplish this, it is important to understand fundamental aspects of the systems from which the knowledge is being extracted. Thus, the next section defines and explains the two primary knowledge sources that feed resource management approaches, namely SK and potentially LK, in terms of current and supplementary knowledge required for effective fisheries resource management.

2.4 Knowledge Systems

Prior discussion in this chapter has focused on the issues and approaches inherent in resource management in general and fisheries in particular. Four general resource management approaches were discussed namely adaptive management, ecosystem-based management, community-based management, and participatory management. In addition, two management approaches tailored specifically to fisheries were introduced. Since knowledge sources are required for resource management decision making, and given that the integration of SK and LK is the prime focus of the research in this thesis, this section defines the two knowledge systems central to Figures 2.1 and 2.3 and contrasts the differences between each.

2.4.1 Knowledge Systems Defined

There are two primary systems of knowledge utilized in resource management, namely SK and LK. SK is based primarily on the quantitative analysis of natural resource data (i.e. forestry, fisheries, wildlife) and their resource characteristics, whereas LK draws on local resource users inter-generational knowledge, instinct and experience accumulated during time spent growing crops or fishing on a body of water (Berkes et al, 2001).

Until recently, SK was considered the prime and in some cases the only valid source of information upon which resource management decisions could be based. However, recent research and international interest have demonstrated that LK can influence resource management decisions by providing qualitative information on species and environmental characteristics that are unknown in the scientific domain (Berkes, 1999; Neis & Felt, 2000).

During the United Nations Sustainable Development Agenda 21 Summit (2002), the use of LK in natural resource management planning was one of the main topics of interest. In particular, a central aspect from Agenda 21 was the recommendation that LK should be used more centrally in improving scientific understanding of natural systems. However, it was noted that SK alone could not provide adequate information in resource planning. Given this, two of the objectives of Agenda 21 – Chapter 35 were to "strengthen the scientific basis for sustainable management," and "build up scientific capacity and capability," with both objectives specifically calling for the use of LK in natural resource management. The first objective as stated in Chapter 35.7 (point-h) notes:

> Countries, with the assistance of international organizations, where required, should develop methods to link the findings of the established sciences with the indigenous knowledge of different cultures. The methods should be tested using pilot studies. They should be developed at the local level and should concentrate on the links between the traditional knowledge of indigenous groups and corresponding, current "advanced science," with particular focus on disseminating and applying the results to environmental protection and sustainable development.

The second objective of Agenda 21 as stated in Chapter 35.21 (point-a) adds:

> The primary objective is to improve the scientific capacities of all countries – in particular, those of developing countries – with specific regard to education,` training and facilities for local research and development and human resource development in basic scientific disciplines and in environment-relates sciences, utilizing where appropriate traditional and local knowledge of sustainability.

From these two statements, it is clear that the use of LK is gaining worldwide attention as a plausible knowledge source. This section, therefore, begins by defining knowledge, discusses how knowledge relates to SK and LK, and concludes by considering the characteristics of each knowledge system.

From a management perspective, resource sustainability is dependent upon the amount and quality of knowledge about the resource in question. Without knowledge, no sensible management can take place and resource depletion will occur (Weakness, 1999; Brodnig 2000). In this context, knowledge has many interpretations including, but not limited to:

1) "A mental grasp of a fact(s) of reality, reached either by perceptual observation or by a process of reason based on perceptual observation" (Rand, 1979; 45);

2) An “awareness or familiarity gained by experience” (The Oxford English Dictionary, 1995; 753); or
3) Information “acquired through direct experience, especially visual: its production involves accurate observation” (Johnston, 1999; 40).

Thus, knowledge is comprised of two common components as seen in the above definitions, namely observation and experience. Since local resource users learn predominantly through direct long-term contact and interaction with a resource, experience is typically the main driving factor for their knowledge accumulation. Similarly, knowledge accumulation from the perspective of a researcher or scientist is primarily achieved through observation. Therefore, in order to create a complete knowledge base, resource managers must combine knowledge gained though observation (SK) and knowledge gained through experience (LK). Before this can occur, however, it is important to understand the individual knowledge systems.

SK is based on the western ideology that humans are separate from nature; that humans are above nature and therefore seek control over natural systems (Berkes, 1999; Gadgil and Berkes 1991; Kalland, 2000). This concept is derived from the Cartesian dualism philosophy that suggests mind is more powerful than matter, which pits humans against nature (Berkes, 1999). In addition, SK is based primarily on a reductionist approach, using empirical and analytical techniques in the assembly of knowledge (Maurstad, 2000). In addition, SK is gathered through use of the scientific method, which is centred on a measurable system of numbers and conditions that allow the simplification of events for the purpose of adding control and predictability to otherwise, in the case of natural resources, unpredictable systems (Mitchell, 1997).

Problems associated with the use of SK within natural resource management include scarce or little detailed information about the resource, misuse of available information, and the inability of scientists to accept local peoples’ knowledge as a valid source of information upon with to craft management policies and decision-making.

Inherent to LK is a level of ambiguity in definition of the concept. In the literature on this subject there are many variations in the terminology used including traditional ecological knowledge (TEK), traditional knowledge (TK), indigenous knowledge (IK), native knowledge (NK), and, in the context of fisheries, fishers' knowledge (FK). While some authors see these variations as synonymous (Kloppenburg 1991; Franklin, 1990; Neis and Felt, 2000; Mitchell, 1997; Nakashima, 1999), others see them as separate and meaning different things. A generally accepted definition of TEK is that promoted by Berkes (1999; 4):

> … a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment. Further, TEK is an attribute of societies with historical continuity in resource use practices; by and large, these are non-industrial or less technological advanced societies, many of them indigenous or tribal.

Berkes (2001) further defines LK, IK, and TK as:

LK: Knowledge based on local observation made by resource users; differs from TEK in not being multigenerational or culturally transmitted.

IK: LK held by a group of indigenous people, or LK unique to a given culture or society. TEK is a sub set of IK.

TK: A cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission.

Berkes (1999) also defines NK as an accumulation of concrete, personal experience while Braimoh (2002; 76) defines IK as referring to institutionalized LK that has been built upon from one generation to another. Other researchers (for example Kloppenburg 1991; Franklin, 1990; Neis and Felt, 2000; Mitchell, 1997) define LK as experience derived through first-hand contact with the environment that is specific to place. In this interpretation, indigenous people view themselves as part of nature, as having widespread empirical (experience-based) knowledge of the environment around them and this distinguishes their world-view clearly from the Cartesian view of SK noted earlier (Berkes, 1999; Kalland, 2000). LK is gathered through a holistic approach that is both oral and intuitive (Maurstad, 2000). In this context, Kalland (2000) refers to LK as being practical. She argues (2000; 325), "… rather than studying how plants and animals are constructed and how they evolved (scientific knowledge), local knowledge explores how they can be found, harvested, and used.” For the purposes of this research, the terms LK and TEK are used synonymously according to Berkes’ definition of IK.

A major limitation in the use of LK is the reality that a local harvesters’ knowledge has not traditionally been considered important by the scientific community in management planning and decision making activities (Berkes, 1999; Neis and Felt, 2000). In this context, Brodnig (2002; 2) suggests that, “[w]estern scientists and “experts” have tended to regard LK as methodologically questionable, anecdotal, or – at best – of localized importance.” This localization is highly place-specific and, as such, it clashes with the facets of scientific enquiry and understanding which seeks to establish order and regularities that are generally applicable independent of place.

While the biology of aquatic species can vary independent of place, environmental conditions can often dictate further differences in species biology specifically in a fluid environment such as the sea (Valavanis, 2002). Hence, localised knowledge, in contradiction to scientific thinking, is imperative in management, especially if small geographic areas define management units. Subsequently, interviewing the harvester of resources from those areas will potentially provide a more holistic view of the environment and the biology of the fish within that geographic extent. As a result, it is possible that better informed management decisions can be made about specific geographic locations. Currently, it seems, scientists lend fuel to the problem of resource depletion by tackling too large of an area at once and often generalizing many smaller heterogeneous areas into one assumed uniform management unit.

2.4.2 Knowledge Systems Compared

With a general overview of the knowledge systems now completed, it is important to examine more closely the differences between SK and LK for the purpose of establishing why LK can be useful in devising responsive forms of resource management that encompass all the facets of the resource in question. Table 2.3 illustrates the major differences between the two knowledge systems namely, types of data, length of study time, methods of data collection, type of study, and world-views. These are now discussed.

Traditional Science	Local Knowledge
Primarily Quantitative	Primarily Qualitative
Synchronic Data	Diachronic Data
Data Collected by Researcher	Data Collected by Resource User
Empirical	Hermeneutic
Reductionist	Holistic
World as a Mechanical System	World as an Organic Whole

Table 2.3: Major differences between Traditional Science and Local Knowledge

The fundamental difference between the knowledge systems of LK and SK concerns data types. The method by which scientists and resource harvesters collect their data represents the main difference between these knowledge systems. As previously noted, resource harvesters use a qualitative approach to harvest activity while scientists use a quantitative approach to resource management.

In terms of data collection, researchers collect SK during typically short periods of time (synchronic), for example a few weeks or at most several months. In contrast, LK is knowledge collected continuously by the resource users themselves, over typically longer time periods spanning years to generations. This extended time period (diachronic) during which information about the resource(s) in question is learnt and observed can prove advantageous in that resource users are likely to be part of a hunter-gatherer culture where resource use is closely tied to the need for resource sustainability (St. Martin, 1999; Neis and Felt, 2000; Berkes, 1993; Brodnig and Mayer-Schönbergerm, 2000).

Next, scientists view knowledge as empirical, or the world as independent from the observer. As such, research typically takes on a reductionist model meaning that systems are broken down into individual parts (Johnston, 1986, Berkes, 1999; Hipwell, 2002). Conversely, local resource users view their world as hermeneutic where nothing outside the realm of the observer exits as perception of an empirical event requires interpretation (Johnston, 1999). Similarly, local resource users take a holistic approach to their knowledge of the resource in that they see a system as a whole entity, where humans are an intricate part of the environment (Charles, 2002; Berkes et al, 2001).

Finally, SK and LK differ in terms of how advocates of each form of knowledge view and interpret the world. As noted in the previous section, scientists view the world as a mechanical system that implies a world of rationality, certainty and order. Local resource users, in contrast, view their world as an organic whole focusing on human ingenuity, individuality and identity (Johnston, 1999).

In conclusion, although the knowledge of local resource users is not "scientific" according to the conventional view, the above discussion indicates that LK has the potential to fill in gaps in areas of natural resource knowledge bases where SK may otherwise be lacking. The next section specifically explores the integration of LK with SK, referencing limitations issues to overcome, techniques for collecting LK, and introduces the rights of local resource users in terms of legal and ethical issues involved in extracting their knowledge.

2.4.3 Integration of Knowledge Systems

Most human technological advancements have been accomplished through scientific study, and as such, it is important to recognize that it is not a matter of any one knowledge system being better than the other, but more specifically that SK is proven through facts based on rigorous observation and study (Mitchell, 1998). To a degree, LK also studies the identification and use of facts based on long-term observation, however in this case the objective is more for personal use rather than collective human advancement. Scientists have rejected LK because it cannot be measured and it does not fit comfortably into the realm of scientific methodologies. Thus, can two fundamentally different knowledge systems be integrated into one knowledge base? Before this question can be answered, it is important to consider data collection techniques for LK and the intellectual property rights of the resource users from which knowledge is to be collected.

The collection of LK from resource users represents a critical step in the integration of LK with SK. Mitchell (1998), Chambers (1994) and Conway and McCracken (1990) discuss the effectiveness of using Participatory Local Appraisal (PLA) methods in the collection of LK. PLA is the term given to a collection of systems that empower local people to voice, share and enhance their information concerning resource use and community life. PLA is the latest in an evolution of participatory approaches. Encompassed within PLA are two systems that are of particular relevance to this research. They are rapid rural appraisal (RRA) and participatory rural appraisal (PRA) (Mitchell, 1998; Conway and McCracken, 1990; Chambers, 1994).

Developed in the late 1970s, RRA is characterised as a system of semi-structured informal interview-type activities carried out by a multidisciplinary team of researchers. The methodology is intended to collect primarily qualitative information about rural life in a quick and efficient manner (Conway and McCracken, 1990, Mitchell, 1998; Theis and Grady, 1991). RRA was first developed to help alleviate problems encountered during the collection of LK. Previous attempts at collecting LK resulted in a number of issues including “emergence of better alternatives,” “over-reliance on questionnaire surveys,” and “anti-poverty biases” (Mitchell, 1998; Chambers, 1994). “Emergence of better alternatives,” unlike the other two issues, provided a positive reason to develop RRA. The “emergence of better alternatives” was the “recognition by professionals that local people were often very knowledgeable about matters which affected their lives, including the behaviour and patterns of local systems”(Mitchell, 1998; 182). This recognition eventually led to the emergence of the concept of TEK and consideration of its relevance in resource management.

Over-reliance on questionnaire surveys was a problem that occurred when questionnaires were being designed without any regard to the culture, language and education level of the people who were being interviewed. This caused problems in informant comprehension that often resulted in information being lost in translations during interviews (translation in terms of differing languages, vocabulary discrepancies, etc.).

The final issue that motivated the development of RRA was “anti-poverty biases.” These biases were a direct result of a typically western, urban researcher bias in administering studies in developing countries. Mitchell (1998) describes five types of anti-poverty biases that occurred during LK collection attempts, namely spatial, temporal, people, project and diplomatic biases. Spatial biases occur when study areas are chosen focusing primarily on urban cores and other easily accessible areas. Problems can and do occur outside highly populated areas, however these areas are often ignored due to the problem of accessibility. Temporal biases occur due to research projects being conducted primarily during cool and dry seasons instead of wet and hot seasons, when issues typically arise. The people bias takes place when interviews are conducted. Researchers tend to interview officials instead of the local people, who often know more first-hand realities concerning their life situation. In addition, men have tended to be interviewed more often than women. Project biases occur when researchers take on official projects supported by government-funded agencies instead of local projects that deal with informal programmes. Finally, diplomatic biases occur when questions dealing with sensitive or offensive issues are disregarded for fear of official backlash from the host country.

In order to compensate for the three problems described above ("emergence of better alternatives," "over-reliance on questionnaire surveys," and "anti-poverty biases"), five solutions have been developed. When used in tandem, these solutions can facilitate the extraction of LK in an improved and fair-minded manner. These solutions include "innovative methodologies," "iterative objectives," "informal interviews," "interactive research teams," and "in the field learning" (Mitchell, 1998; Chambers, 1994).

"Innovative methodologies" provide a solution that allows the researcher to take a customized approach to their interviews based on the skill level of the informant. Often information may be lost or lessened because the informant does not understand the terminology used. The second solution, "iterative objectives," is the idea that the objectives of a project should be set loosely. Thus, "iterative objectives" allow researchers to modify their objectives as a situation dictates. Third, "informal interviews" stress the use of casual, informal data gathering using open-ended, semi-structured questions. This method, similar to "innovative methodologies" and "iterative objectives," gives the researcher more control over the questions being asked and allows the researcher the option of intervention from an otherwise strict set of questions and guidelines pertaining to the interview.

Fourth, “interactive research teams” suggest that the research approach should comprise of representative members from a number of disciplines rather than one disciplinary perspective. This enables many perspectives to be taken on the extraction of LK, such as an anthropologist for the social perspective and a geographer for the spatial perspective (Valavanis, 2002).

Finally, “in the field learning” suggests that researchers should learn what they want to know “by doing”. “Learning by doing” is a concept derived from the Jean Piaget School of education research whereby the researcher works with the local people in their daily activities (Hall, 2003). This places the researcher in the reality of the people and their culture, thus immersing the researcher within the local community and culture, allowing him/her to learn as the local user would, by direct hands-on experience.

During the late 1980s, RRA evolved into a new method of collecting LK called participatory rural appraisal (PRA). Although RRA was, and still is, an effective method in collecting LK, very little in terms of knowledge and support were given back to the communities from which the knowledge was taken. In this context, RRA was seen as exploitive, misleading and time intensive for the informants (Mitchell, 1998; Chambers, 1994). Thus, PRA was developed to compensate for these concerns as well as to promote and facilitate the fundamentals of sustainable development, namely equity, social justice and local empowerment (Mitchell, 1998).

The final challenge in the integration of LK into resource management is “intellectual property rights.” In this case, it is important to protect the rights of resource users, such as local harvesters, and their community. As a result Maurstad (2002) discusses the effects of disclosing LK. It is suggested in the literature that LK will no longer be LK once this knowledge is written down and distributed (Maurstad 2002). Hence, harvesters may not want to disclose their resource knowledge for others to take advantage of, especially in a common property resource. Thus, it is imperative that disclosure of any knowledge must be confidential. Data collected are considered sensitive in nature and therefore must be handled with care when producing hardcopy outputs such as maps and reports for public use.

With the issues relevant to the integration of LK and SK now discussed, attention turns to the integration of these two fundamentally different knowledge systems into a computer framework. In this thesis it is argued that this integration can be facilitated through the use of spatial information technologies (SIT), namely geographic information systems (GIS) and remote sensing (RS). These two now well-established computer-based tools can serve to alleviate many of the issues described above, particularly concerning conflicting data types. Thus, the next section discusses GIS and RS with respect to their use in natural resource and fisheries management.

2.5 SPATIAL INFORMATION TECHNOLOGY FOR INTEGRATING KNOWLEDGE SYSTEMS

Discussion in this chapter has focused on the integration of LK with SK mediated by an integrated knowledge base for natural resource management. As illustrated in Figure 2.1 and 2.3, SIT such as GIS and RS can serve as an operational medium through which these two knowledge systems can be integrated specifically for fisheries resource management. Initially, this section provides a general overview of SIT, including GIS and RS, within the context of terrestrial and marine applications. Second, the section discuses marine and fisheries GIS, followed by a discussion of the integration of LK and SK for marine species management.

2.5.1 Spatial Information Technologies

SIT is a term used to encompass tools and methodologies drawn from the fields of RS and GIS that allow the collection and manipulation of spatial digital data concerning the earth, its features and its inhabitants. GIS is defined by Goodchild (2000; pg viii) as “software that is used for handling, displaying, analyzing, and modelling information about the locations of phenomena and features on the Earth’s surface.” Phenomena can be recorded in two data formats, namely vector and raster. Raster images are recorded as a continuous, gridded surface where each cell has an attribute value associated with it. In vector-based data structures, data are discontinuous or discrete and require interpolation for areas lacking recorded data. Thus, raster data require no interpolation, providing a continuous, relatively accurate (dependent on spatial resolutions and interpretive accuracy) surface of values. In vector-based applications, phenomena are represented as zero dimensional points, one dimensional lines, two dimensional polygons, and three dimensional surfaces. Thus, the essence of

GIS is to transform geographical data into information that are consequential to the development of management decisions (Valavanis, 2002).

In the past, primary consideration was given to terrestrial GIS applications where features typically are relatively inert and well defined and are surveyed using geodetic networks that cover the earth's landmasses (Goodchild, 2000). In the context of marine environments, however, GIS applications must deal with features and objects that are almost always in a state of flux (Valavanis, 2002). The closest features that could be considered static are lakes or the ocean floor, but even these can change over relatively short time periods. In addition, water depth and coastlines can also be considered fixed, however these features fluctuate with tides and other environmental factors such as El Niño events, drought, erosion, and melting of the polar ice caps (Kemp and Meaden, 2002). In addition, a marine GIS must deal with characteristics such as fuzzy boundaries, a complete lack of geodetic control, and third and forth dimensional data, the forth dimension being time (Valavanis, 2002; Goodchild, 2000). The data relevant to marine resource management are not limited to GIS sources as a great deal of relevant data can be obtained through RS technologies

Green et al (2000; 25) define RS as the "measurement of electromagnetic radiation reflected or emitted by the Earth's Surface." With this technology, data about features on the earth are acquired through the use of satellites and low altitude aircraft that capture photographic spectral or radiometric images of the earth below. These images are recorded in raster format that can then be used for a number of applications including, for example, location and health of vegetation, feature extraction, change detection over time, or the construction of thematic maps such as vegetation, landforms, or road networks (Goodchild, 2000). In the marine context, RS technologies are used to determine sea surface temperatures (SST), track algae blooms, monitor coral health, construct shallow water bathymetry, and isolate marine habitats (Johannessen et al, 1989; Simpson, 1992; Meaden and Kapetsky, 1991, Knight et al, 1997; Green et al, 2000). While many RS software programs allow the processing and interpretation of remotely sensed imagery, they also provide a valuable source of data inputs for GIS applications. One such data source that is of interest in this thesis is the extraction of sea bottom-type features (for example grass, coral, sand). RS technologies have the ability, given the correction for the effects of water depth, turbidity, and wave action, to record bottom features (Green et al, 2000). These features can then be converted into a two-dimensional polygon map layer suitable for GIS input or used as a raster layer. Given this ability to fuse GIS and RS technologies, the next section explores the use of each data source in the context of marine environments.

2.5.2 Marine GIS

Marine GIS is a term used to encompass the broad field of GIS use in salt-water aquatic environments. Within the field of marine GIS, application niches include fisheries analysis and coastal and oceanographic research, each possessing common characteristics of the other (Valavanis, 2002). Marine GIS, exemplifies a technology originally designed for fixed sets of co-ordinate systems that have had to adjust to function in a fluid environment where the only relatively static features are covered by millions of litres of water (Goodchild, 2000). GIS and the hardware that supports them, must adapt to the vast data requirements that stem from the highly variable spatial and temporal scales and process fluctuations and permutations that exist in a marine environment (Meaden, 2000). Furthermore, data gathering proves difficult in these types of environments due to their size. Further, the lack of any fixed points from which to geo-reference, can make it difficult to enter data with a high degree of accuracy.

One area that has aided in the acquisition of these data is RS technologies. Examples of data inputs for marine GIS acquired through satellite sensors (for example, Sea Viewing Wide Field of View Sensor (SeaWiFS), Advanced Very High Resolution Radiometer (AVHRR), Ocean Colour and Temperature Sensor (OCTS)) in addition to the bottom-types noted above, include SST, chlorophyll, nutrient content, sea surface height, and the presence of ice and ocean currents (Meaden, 2000; Valavanis, 2002). Since many marine applications lack fixed structures from which to reference, RS technologies have two main advantages: 1) RS sensors scan large areas at once and 2) the data that are recorded are raster-based. The advantage of scanning large areas at once, allows for the overlap of landmasses in the image, which enable data geo-referencing. The main disadvantage, however, is the images can require large storage capacity and can be expensive to purchase.

2.5.3 SIT in Fisheries Management

Most issues in fisheries management are inherently spatio-temporal and, as such, are compatible with GIS technologies. Examples of GIS applications in fisheries include determining locations for shrimp farming (Hoque et al, 1998), site section for mariculture (Ross et al, 1993), habitat mapping (Urbanski and Szymelfenig, 2003), the measure of marine productivity (Caddy et al, 1995), locating fishery protection sites (Pollit, 1994), and habitat suitability modeling, (Caddy and Carocci, 1999). In addition, life histories of species, including species biology and ecology are being used with GIS to forecast fish distribution and abundance (Valavanis, 2002).

Despite this recent growth in research, the application of GIS to fisheries management issues has been slow to evolve (Valavanis, 2002; Meaden 2000; Goodchild, 2000). In this context, Meaden (2000) identifies two main areas that are responsible for this, namely increased GIS elements to consider and the resulting complexities associated with combining these elements in a GIS.

Traditional terrestrial-based GIS databases are typically comprised of objects located in time and space (Meaden, 2000). These objects are largely static, where a typical GIS analysis of buffering, overlaying, and reclassification can be performed with a high level of continuity (Valavanis, 2002). However, as mentioned above, the marine environment is highly dynamic. Thus, Meaden (2000) identifies four new elements associated with the dynamics of a marine environment namely, the vertical plane, processes, dynamics of marine objects, and dynamics of marine processes.

The vertical dimension, including depth, location of temperature isosurfaces (temperature slices at different depths) and water currents, is considered a new marine GIS element. Within a digital elevation model (DEM), vertical height refers to a fixed phenomena (for example, topography) occurring at one location within the vertical plane. In contrast, temperature isosurfaces (water currents) are dynamic, meaning they can move or change speed within the water column. Since these processes affect objects in the water column, they must also be considered as a new element to contend with in a GIS.

The third element in a marine GIS is the dynamics of marine objects. Marine objects in this context include features such as species populations, movements of marine harvesters, and fishing vessels. These types of information allow for the correlation of, for example, salinity versus SST to illustrate how these processes affect fish population distributions (Castillo et al, 1996) or the application of how harvest activities can change with distance from fishing ports (Caddy and Carocci 1999).

The last element new to a marine GIS involves the movements of marine processes including for example gyres and upwellings. Gyres are circular currents that are created when opposing currents (driven by wind patterns) come together while upwellings occur when water currents move to the surface either by two currents (typically warm and cold) converging together with the warm water deflecting towards the surface. Harvestable fish species often congregate at these locations to feed on plankton or other fish species that thrive there and, as a result, data on upwellings can be used to locate schools of fish (Valavanis, 2002; Meaden 2000).

The second impediment to the widespread use of GIS in fisheries management is the increased level of complexity associated with acquiring, combining and modelling the above elements into a GIS database. Although recent improvements in GIS software have included the incorporation of new functionality, for example qualitative analysis and customized modelling capabilities, some problems still exist (Booth, 2001). Examples of these problems, as noted by Meaden (2000; p 209) include:

- Functional design of 4-Dimensional databases
- Defining boundaries in a transitory (fuzzy) environments
- The selection of appropriate temporal and spatial scales for mapping
- Allowance for statistical variance in data collected
- The diversity, fragmentation and widely scattered nature of fishery activities
- Various levels of new GIS components associated with marine environments
- Wide range of socio-economic and operational setting attributed to fishery management functions.

Exaggerating these problems is the issue of insufficient data. Data that are available are supplied predominately from commercial, long distance fishing fleets, where fishing vessels use electronic data loggers and global positioning systems (GPS) to record parameters automatically such as vessel location and number or weight of fish harvested (Meaden, 2000;Valvanis, 2002).

One of the underlying aspects of all of the above examples of fisheries-oriented GIS applications and RS analysis of marine environments is that the approaches and models are exclusively scientific in nature. As noted earlier in this chapter, this approach has inherent limitations resulting in incomplete or inaccurate data for resource management planning. Since much of the knowledge of local harvesters is inherently spatial (i.e. harvest locations, bottom-types, water depth and catch amounts), it is possible to produce representational spatial models from LK inputs. These inputs can then be matched against any variety of representational spatial models developed from SK inputs (i.e. species distribution, bottom-types, sea temperature and water depth) to combine the two knowledge paradigms within an SIT environment. This allows the researcher to compare and contrast what science suggests in terms of fish patterns to what local harvesters suggest. The results of such a comparison will confirm or contradict data collected from the two knowledge sources in terms of dealing with management strategies for over fishing of certain areas in an artisanal fishery.

2.5.4 Local knowledge and SIT

Despite recent advances in marine and fisheries GIS, there are few published references in the literature to a SIT approach to incorporating LK into fisheries management. Fishery scientists are beginning to understand their data limitations, and as such, the knowledge of local harvesters is increasingly in demand. As noted earlier, harvesters present a localised, diachronic aspect of fishing and fishing attributes that could be used to verify and expand SK or visa versa. The foundation of a GIS in this context is its utility to integrate data from many different sources and to allow these data to be stored in various formats with a common database as outlined in Figure 2.1 and 2.3. Currently, the data originate largely from SK. As noted in above, this research proposes that, similar to the input of SK within a fisheries GIS, LK can be used as an additional data source for the purpose of constructing a more comprehensive knowledge base. Furthermore, by integrating an additional system of knowledge into a resource knowledge base, it can further validate existing findings or challenge current knowledge in the knowledge base.

2.6 CHAPTER SUMMARY

This chapter has focused on resource management, fisheries management, management approaches commonly used in resource management, and management approaches specific to fisheries. SK was defined as the main, however incomplete, source of information for resource management. Given this, LK was introduced and explained as a potential supplement to SK in resource management planning. Issues relevant to the integration of these two knowledge systems were presented including limitations to knowledge integration, local knowledge collection techniques, and resource users' knowledge or intellectual property rights. Next, the role of SIT in natural resource management in general and fisheries management in particular was reviewed. The chapter concluded with the argument that SIT can offer a common ground within which LK and SK can be successfully integrated for more complete resource management decision making.

Chapter 3

A PROTOCOL FOR LOCAL AND SCIENTIFIC KNOWLEDGE INTEGRATION IN FISHERIES MANAGEMENT

This chapter operationalizes the concepts discussed in Chapter 2 by developing a general protocol for integrating traditional SK and non-traditional LK to yield enhanced information for fisheries resource management. First, background information, focusing specifically on the management of small-scale fisheries, is discussed building upon the conceptual framework presented in Chapter 2. Next, procedures are identified to select and interview key informants, to collect data, and to extract knowledge revealed in harvest activities. The chapter then discusses the two technologies used for traditional SK, namely GIS and RS, and procedures that can be used to manipulate data on fish harvesting activities. The specific procedures used in this thesis are presented in Chapter 4.

3.1 Planning Processes in Fisheries Management

This section furthers the discussion on fishery harvesters (Section 2.3.2) in Chapter 2 by exploring in more detail large and small-scale fisheries and how the relationships between them negatively affect the management practices of small-scale fisheries. Two procedural sequences that are used to manage small and large-scale fisheries are discussed and a third revised procedural sequence is introduced. The aim of this discussion is to illustrate how the use of SIT can aid in combining LK and SK in the planning processes involved in fisheries management.

3.1.1 Managing Small Scale Fisheries

The condition of global fish stocks is represented in Figure 3.1. Small-scale fisheries are defined as fisheries that harvest, on average, between 1,000 and 10,000 metric tons (mt)/year/fishery (Mahon, 1997). In contrast, large-scale fisheries harvest approximately 100,000 mt/year/fishery, representing five percent of the total global fish stocks. Clearly, even though large-scale fisheries harvest more weight of fish per fishery, the bulk of the world's fisheries are small-scale (Mahon, 1997; Berkes et al, 2001).

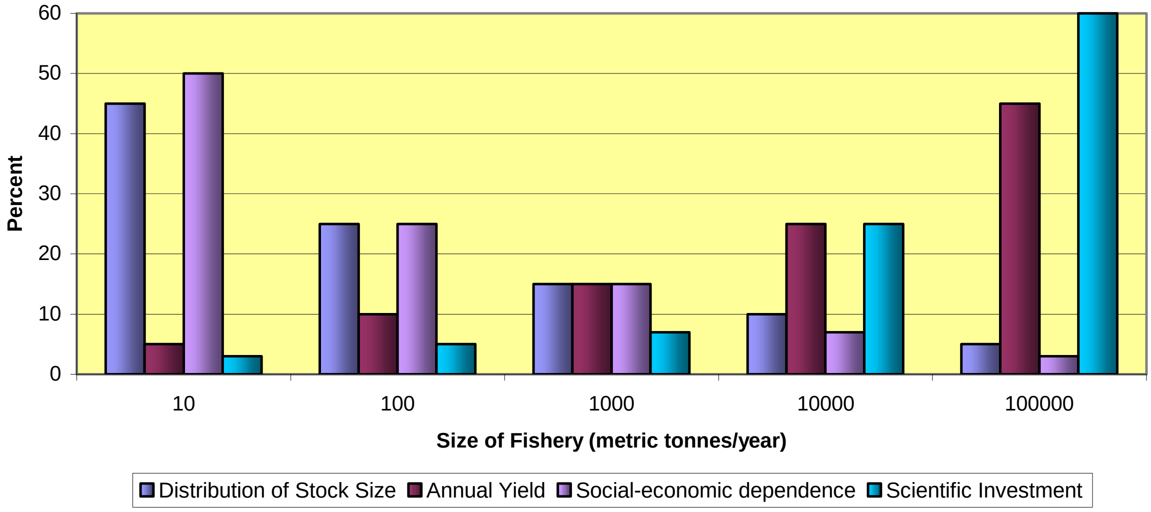


Figure 3.1: Relationships between Global Fisheries (Source: Mahon, 1997)

The majority of small-scale fisheries are located in tropical, underdeveloped countries where species diversity is higher and their associated geographic range smaller than a typical large-scale, single specie harvest operation (Mahon, 1997). This puts small-scale stocks at a higher risk of overexploitation. Berkes et al (2001; pg 40) notes that the failure to manage sufficiently the diversity of a small-scale fishery resource "can have a net or cumulative negative impact that is as high or higher than the collapse of a single large stock fishery." Thus, small-scale fisheries are just as important to manage, if not more so, as large-scale harvest operations (Mahon, 1997; Berkes et al, 2001).

The level of investment that a country is willing to make on fisheries is generally based on the total worth of the fishery (Figure 3.1). Worth, in this case, is defined not just in terms of income, but also in terms of culture, religion, and biodiversity or ecosystem integrity (Berkes et al, 2001; Arnason et al, 2000). However, when monetarized, the value of a small-scale fishery typically does not justify the expenditures needed for data collection and examination used in managing large-scale stocks. Exceptions to this rule include countries that harvest small stocks in tandem with large stocks, or countries that harvest stocks where the unit value is high enough to offset lower yields. Examples of high unit stocks are shrimp (*Penaeus)*, Lobster and Conch fisheries (Berkes et al, 2001). The latter two species are the subject of this thesis.

In the absence of small-scale fisheries management, economic and social ramifications can be devastating, particularly for small-scale artisanal harvesters who use fishing as a main source of protein intake as well as income generation. Examples of the costs associated with a collapsed fishery include:

- Unemployment benefits for those directly involved in the resource i.e. harvesters, processing plant operators and staff, fuel and equipment retailers
- Health care costs associated with malnutrition related to low protein intake
- Law enforcement costs as unemployed may resort to crime
- Loss of culture
- Decrease in foreign exchange
- Loss of tourism dollars from recreational sports (i.e. sport fishing, diving, snorkelling).

In countries where fisheries represent a major source of exports and tourism revenue, the incentive for fisheries management tends to be much higher (Berkes et al, 2001). These countries often resort to large-scale management tactics involving a heavy reliance on biological stock assessments (Figure 3.3). With 60% of the scientific investment going towards large-scale operations (Figure 3.1), small-scale fishery managers tend to implement large-scale management methods, often with little success. The primary reason for this is the sequence of action taken in implementing a fisheries management plan (FMP) (Berkes et al, 2001; Mahon, 1997).

Chapter 2, Figure 2.3 illustrated how resource management approaches corresponded with the overall resource management system. Underlying these management approaches are procedural sequences that guide the direction of resource management planning. Figure 3.2 expands on Figure 2.3 by introducing the underpinnings of the general protocol presented in this chapter. First, Figure 3.2 outlines the general procedures used in defining the types of data requirements for each resource knowledge base. These data can then be collected and used to devise resource management plans. In the context of fisheries management, there are two main management sequences used, namely Management Objective Driven (MOD) and Stock Assessment Driven (SAD) (Berkes et al, 2001; Mahon, 1997). A third, Fishery First (FF) sequence, is a suggested revision to the MOD sequence. Nestled within each sequence is the framework for the development of a FMP and its associated fishery sector review, as illustrated in the figure.

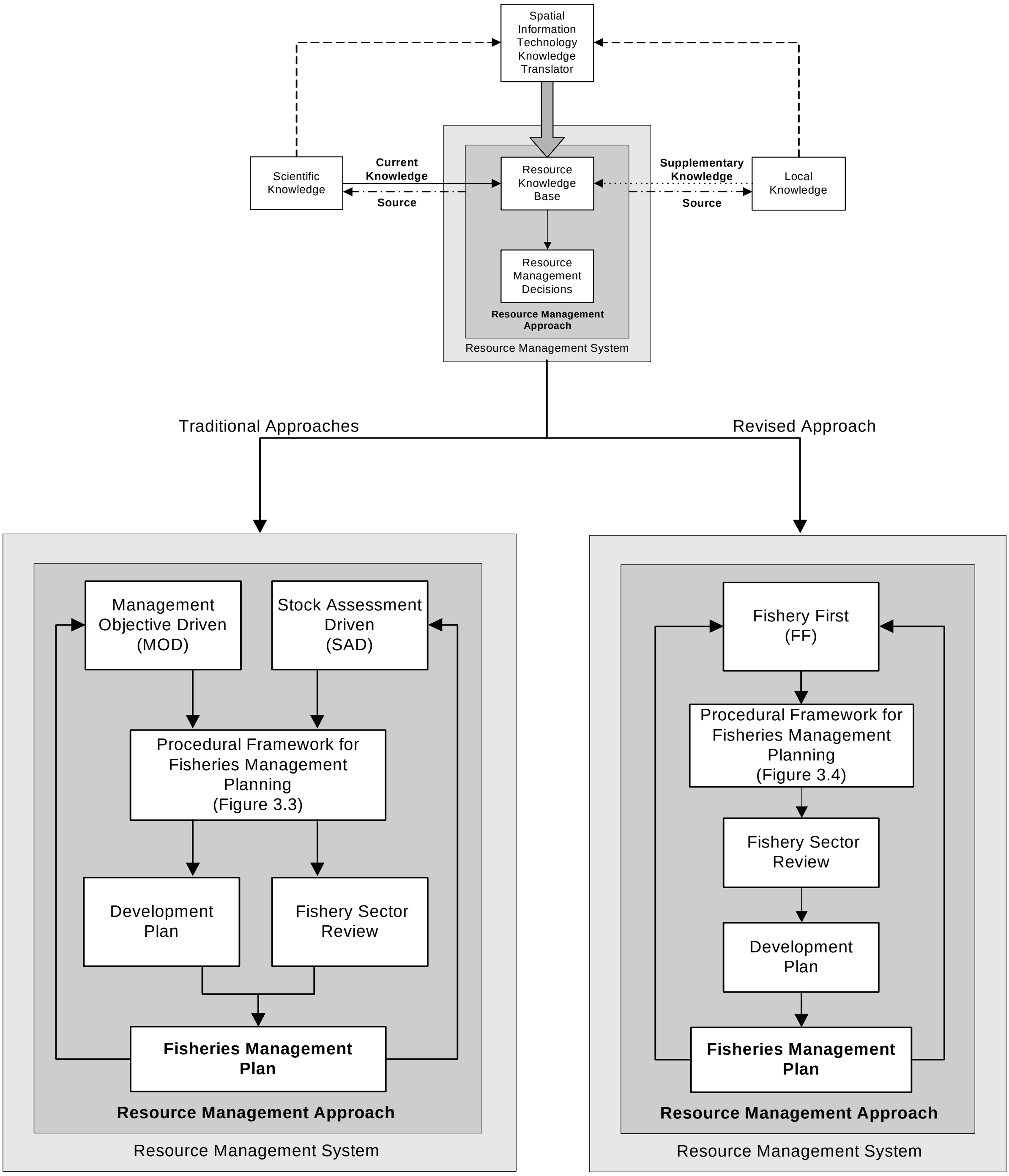


Figure 3.2: Details of a Resource Management Approach from Figure 2.3

The most common contemporary procedural sequence in fisheries management is referred to as Stock Assessment Driven (SAD) as shown in Figure 3.3. The SAD sequence is the management procedure used in larges-scale fisheries. It involves management through ongoing stock assessments where the primary focus is on optimizing and maximising fisheries yields (Berkes et al, 2001). Since most fisheries research is conducted on large-scale commercial fishing operations, fisheries management relies heavily on biological, data-intensive stock assessments prior to the planning of management decisions (Berkes et al, 2001; Mahon, 1997).

While this approach is affordable for large-scale, high-investment fisheries, the amount of time and effort required to assess a stock's biological information is the same regardless of the size of the fishery (Berkes et al, 2001). The majority of small-scale fisheries typically do not have the funds or the human resources available to allow for these types of assessments. However, often in under-funded small-scale fisheries, where a holistic view of management is vital, management is distracted from the holistic approach and instead places emphasis on stock assessment (Mahon, 1997). In this context, Mahon suggests small-scale fisheries should follow a less quantitative, data intensive approach to management, and focus instead on collecting and evaluating data for the purpose of satisfying the objectives set out in accordance with the second procedural sequence, normally the Management Objective Driven (MOD) framework as shown in Figure 3.3.

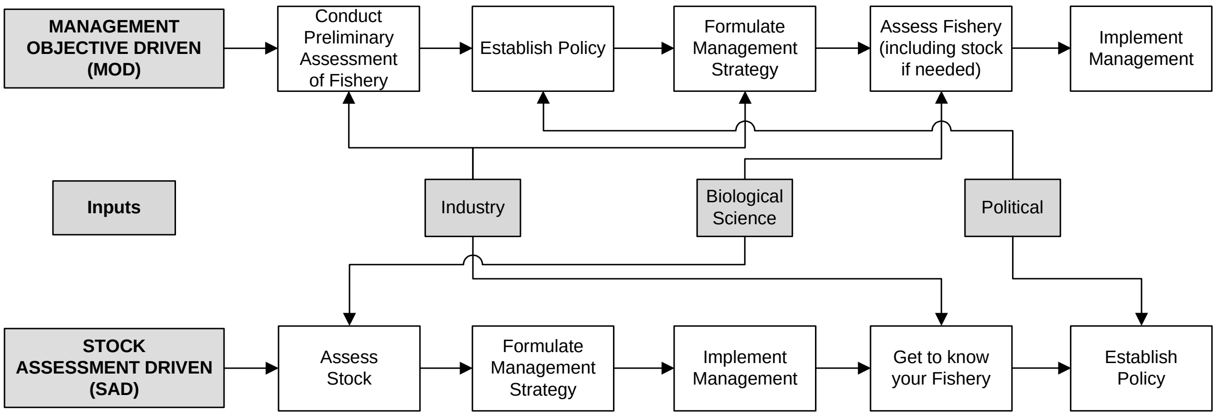


Figure 3.3: Sequence Frameworks for Small (MOD) and Large (SAD) Fisheries (Mahon, 1997:2065)

Consistent with the common sense precautionary approach to management discussed in Chapter 2, Berkes et al (2001) define the MOD sequence as a holistic, process-driven view of the fishery where the needs of the community, harvesters and fishery are considered before a quantitative assessment of the stock is completed. Berkes et al (2001) do not suggest that a quantitative stock assessment is not important, but rather that management planning can proceed regardless of knowing the numeric condition of a stock. Thus, according to Berkes et al (2001: pg 40), the MOD sequence keeps the management process focused on:

1. Management objectives that fit the needs of the community and harvesters,
2. Knowledge and information to identify variables that relate to objectives,
3. Setting target variables for those variables, and
4. Development of control measures and systems to measure success of changes.

The advantage of the MOD sequence is that it ensures that these four criteria are adhered to within the context of the overall fishery management system. The major disadvantage to this approach, however, is the assumption that the fishery stocks are adequate enough to meet the needs of the community (Point 1 above). As the crab fishery on the east coast of Canada illustrated in the spring of 2003, where the government was allowing more fishing boats in an already diminished fishery, if adequate fish stocks are not present or not large enough to support the community, then it is clear that the fishery will not be able to satisfy the needs of the community.

Clearly, the SAD approach is too costly for a small-scale developing state to afford. Hence, there needs to be a revised approach that takes into account the needs of the community (as suggested in the MOD approach) without the expense associated with a large-scale stock assessment (as suggested in the SAD approach). Figure 3.4 suggests a third management sequence, namely the Fishery First (FF) sequence. The FF sequence focuses on assessing and understanding the fishery first using a more qualitative, LK approach, before considering the social and economic needs of the community. The importance of this revised sequence confers upon local fishing communities (both government and the harvester collective if present) the ability to understand more fully the health and condition of their fishery in addition to facilitating the development of a management plan that provides for the community over the long-term.

The key to the success of the FF approach is the construction of a relatively inexpensive method for assessing the fishery by the local community's Fisheries Department. This inexpensive method involves use of a spatial information technologies knowledge translator, such as that introduced in Figure 2.3. This alternative method allows for the integration of qualitative, LK-based input without the expensive quantitative biological assessment used in the SAD approach.

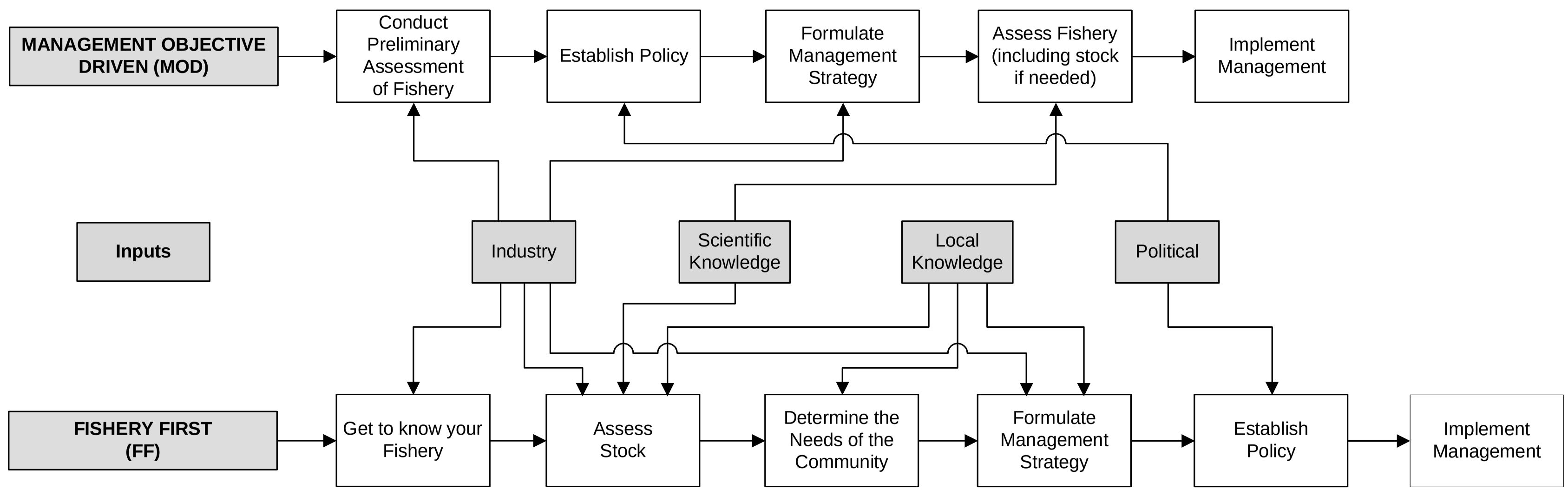


Figure 3.4: Revised Sequence Framework of Fishery First (FF) compared to the MOD Framework

Using the FF sequence, the four points noted above in the MOD sequence could still be used in reference to the FF approach with Point 1 revised to:

> Management objectives that fit the needs of the community and harvesters, given that fish stocks are adequate to support these objectives.

In addition to the knowledge translator, the four criteria noted in the FF sequence (revised MOD sequence) and those used in problem solving by a typical GIS framework, as noted at the end of Chapter 2, are similar. Specifically, use of a GIS involves first establishing a set of criteria or objectives, then required data are collected and analysed to satisfy the criteria. This approach is similar to the sequence in the four points noted above suggesting that, since both the FF and a GIS structure follow similar linkages, a GIS can potentially act as a means of operationalising the FF sequence to enforce the revised four criteria noted above. This operationalisation is discussed in the following sections.

3.2 Spatial Information Technology as a Knowledge Translator

As noted above, the research in this thesis argues that spatial information technologies (SIT) can aid in the addition of LK to a resource knowledge base, as illustrated in Figures 2.1, 2.3 and 3.2, for its use in the development of a FMP. Therefore, this section completes the description of Figures 2.1 and 2.3 and focuses on the procedures within the general small-scale FMP protocol by describing the SIT knowledge translator, specifically the extraction of LK from artisanal harvesters for the purpose of utilization and visualization in a GIS and eventual input into an integrated FMP. The section explains, first, how spatial data related to fisheries activity can be recorded by harvesters on a map (for example fishing locations, bottom-type, water depth and currents). Subsequently, the design and deployment of questionnaires and methods for examining, analysing, and visualizing harvester-generated data are discussed.

3.2.1 Operational Framework

The operational procedures proposed here to facilitate the integration of SK and LK within a small-scale fishery mirror the conceptual framework described in Figures 2.1 and 2.3. Using SIT as a platform to analyse and visualise SK and LK together (referred to in this research as a knowledge translator in Figure 2.1 and 2.3), Figure 3.5 describes the approaches that fisheries managers and planners can use to extract and incorporate LK into their resource knowledge base. This knowledge extraction is achieved primarily through map-based interviews where the informant uses hard copy maps of proximal off-shore marine areas to record their harvest activities. These activities can be in the form of, for example, harvest locations, number and species of fish harvested, bottom-types, and/or depths of water by location. Once these data are integrated into a GIS, they can be combined with scientifically generated analyses of, for example, bottom-types from RS data and depths generated from GIS-based bathymetric mapping, to develop an integrated FMP as discussed in Figure 3.2.

The fisheries literature suggests that a conventional GIS must evolve to fit and model the dynamic elements of marine environments. While the modelling of mobile objects such as currents and fish, in addition to the modelling of time (the 4th dimension), suggest a need for this evolution, this thesis proposes a methodology that utilizes the use of conventional GIS functionality, specifically buffering and overlaying, in tandem with an external word possessor and database management system. Thus, LK is treated equal to any other more conventional forms of spatial data and is input into the GIS, post-collection, in a similar fashion to traditional SK. The key divergence between the two is the nature and source of the respective forms of data. As such, the methodology presented in Figure 3.5 is broken down into four components, namely 1) Interview Preparation and Methods, 2) Geographical Information Systems (GIS) use, 3) Remote Sensing (RS) data analysis, and 4) Data Comparison.

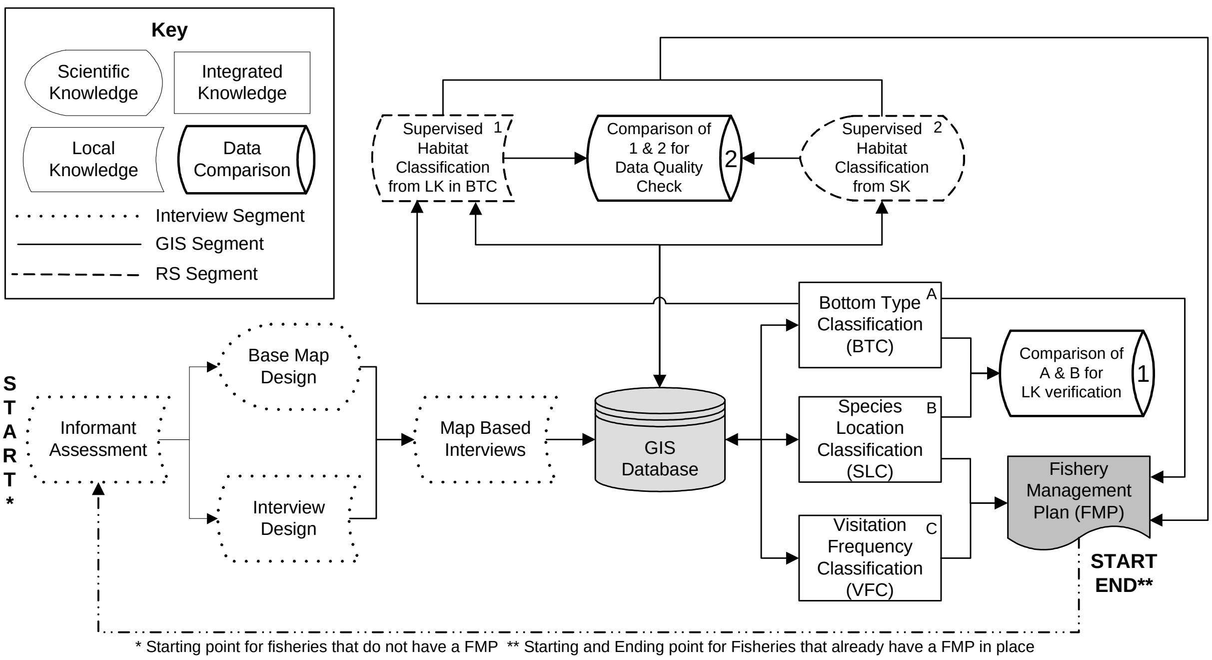


Figure 3.5: Operational Protocol for Small-Scale Fisheries

Figure 3.5 begins with the Interview Preparation procedure (symbolized by dotted outlined shapes) where questionnaires and related interview materials are organized and constructed, in addition to the formulation of tactics to use during the interview process. Next, the GIS component (symbolized by solid outlined shapes in Figure 3.5) allows the researcher to take extracted knowledge, in this case harvest activities (such as bottom-type, location of harvest areas and depth of water) of local harvesters recorded on hardcopy maps, and translate them into a number of choices for data surfaces (e.g. bottom-type (habitat classification), species location, and visitation frequencies (fishing pressure maps)).

The third component of the methodology proposed in Figure 3.5 (symbolized by dashed outlined shapes) utilizes RS technologies. This component is important in analyzing marine-related detail because it can provide images of the study area, showing for example bottom-type, current information and shoreline data. Hence, this component not only provides an additional aspect to the analysis, but is also necessary for LK cross-verification of relevant criteria in addition to the input for the final stage of Figure 3.5 (symbolized by cylindrical shapes), where the correspondence of LK and SK is examined for the study area (satisfying objective 2 of the thesis). In practice, the RS stage and the data comparison stage may not be used in this protocol due to the cost involved in data purchase, required software and operational requirements for RS classification. Thus, in the context of this research, stages three and four are used strictly for an exploratory comparison of the two knowledge types. It should be noted that regardless of the outcome in stage four, neither knowledge source is “incorrect” as accuracy factors affect both knowledge types. This is discussed later in this section.

Each box identified within Figure 3.5 is symbolised depending on the type of knowledge source used. Bullet shapes represent SK, skewed rectangles represent LK, rectangles represent combined SK and LK and cylinders represent the data quality checks. In terms of the knowledge inputs for the framework, LK is extracted from the harvesters that live in the study area and is focused on areas where the harvesters believe the species of interest can be found. SK is based on where the researcher believes the species of interest should be found based on measurable criteria used by traditional science (water temperature data, water depth, etc.). Each of the components of Figure 3.5 are now discussed in detail.

3.2.2 Interview Preparation and Methods Component

The interview preparation and methods component of Figure 3.5 occurs first in the extraction of LK. This component includes the steps necessary for producing questions and maps to be used during interviews with individual harvesters. This component, shown in Figure 3.6, first considers the importance of assessing the harvesters themselves and the culture of the community from which the LK is to be extracted. Next, methods for constructing base maps and formulating specific

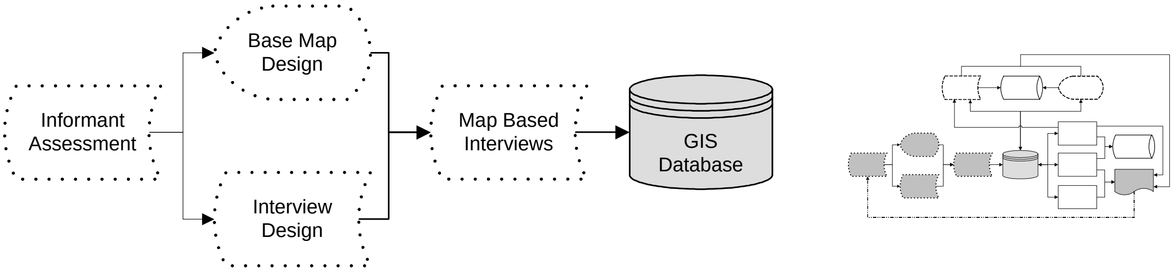


Figure 3.6: Components of the Interview Preparation and Methods Stage from Figure 3.5

questions for harvesters are explored, followed by techniques and tactics for conducting map-based interviews with individual harvesters. The data collected from the combination of these four components provide the input for a GIS database. Before discussing the operational framework in detail, it is important first to explain the characteristics of the informants and how they may respond to map-based data collection.

3.2.2.1 Informant Assessment

The foundation of the research in this thesis lies in the ability to translate fishing areas marked on a map by local harvesters to a GIS database. Working with harvesters, however, involves numerous considerations, most of which relate to the sensitivity of the data to be collected. In many ways, LK can be construed as a form of intellectual property or trade secret, as harvesters are being asked to reveal where they practice their profession. Moreover, researchers/fisheries planners must understand the culture and characteristics of the people they intend to interview and how these characteristics affect the ability of harvesters to interpret information and locations on hard-copy maps. This is of particular importance in small-scale fisheries where the education levels of harvesters can vary substantially. Thus, this section outlines important issues that the researcher/planner must understand before conducting harvester interviews. This information includes considerations such as type of informant, their education level and cognitive abilities, familiarity with using maps, and how this information influences possible map bias, or the accuracy of recording harvest locations on paper map sheets, given the complications of map scale. Issues of data confidentiality must also be considered.

There are two types of informants, namely regular and key. Regular informants are individuals who can provide information about the subject matter in question. Key informants are those "who know a lot about the rules of a culture, are highly articulate, and are, for whatever reason of their own, ready and willing to walk you through their culture and show you the ropes" (Bernard, 2002; 187). These informants will often direct the researcher to specific regular informants who may have pertinent information. It is important to note that when working with informants, there is always the possibility that they will provide false or biased information. If the biased information that they provide is not repeated by other harvesters, then through the protocol methodology discussed in the GIS component below (Section 3.2.3.), this information will not adversely affect the results of the protocol.

The second issue that plays a major part in the interview design and materials stage is the education levels of informants, especially their degree of literacy. Education levels in developing countries are typically low, as noted in section 3.1. Often there is a tendency by researchers, all of whom are likely to be better educated than their informants, to write academic questions, forgetting that not all people can understand academic language (Mitchell, 1998). As such, it is important to write questions in a language that satisfies most education levels, with sensitivity to local culture and customs, and that are written in local languages while leaving room to alter the vernacular of the question in order to fit the context of the informant.

Education levels also affect the abilities of informants to provide written answers. This is particularly important in map-based interviews where the purpose of the exercise is for the informant to draw the location of harvest areas they have used/currently use on paper maps of the area. The researcher should be prepared to translate this information onto the map for the informant and this involves an additional series of considerations related to data accuracy.

Informant spatial cognition or how he/she constructs space should also be considered. By definition, cognition refers to a "mental process of knowing, including aspects such as awareness, perception, reasoning, and judgment"(American Heritage Dictionary, 2000). Thus, an informant's ability to relate to space influences or reflects how they perceive the world around them. This is of particular importance in reference to the disparity in worldviews between local harvesters and the scientific community, as noted in previous chapters. Therefore, in order to understand harvester activities better, this section must consider how their cognition affects the use of maps, specifically distance perception in the context of actual versus perceived locations and spatial references used while on the water. Perhaps the largest problem in the extraction of LK through the use of map-based interviews is the nature of maps themselves. Many small island developing state harvesters have never seen maps, topographic or other, nor do not have any real understanding of the nuances of map scale.

Clearly, the technicalities of map scale are difficult for many, even those who are well-educated, to understand fully. Formally, map scale can be defined as the ratio between the distance in maps units between two points and the distance in ground units between the same two points. At smaller scales, features of significance such as coral heads that break the surface of the water, may not be visible. In fact, at a scale of 1:10000 or smaller, even some very small islands may not be visible. The physical distances that harvesters travel every day in reality is easy for them to comprehend because they experience it regularly (Campbell, 1993). Moreover, distances are often measured by the time taken to get from the dock to specific locations or the time taken in travelling between locations. Hence, travel time may be a more relevant spatial referenent than distance, especially when translated to a base map. Relating times to map units, however, can be difficult, particularly for those who have had little experience with maps. Thus, the researcher must be aware of this issue when interviewing local harvesters and factor this in accordingly. Solutions for dealing with map scale are presented in the procedures discussed below.

The level of generalization in the maps used for the interviews further hinders the translation of harvest activities to hard copy maps. As suggested above, map scale is directly related to the level of map feature generalization. The larger the scale of a map (i.e. 1:10,000 or less), the more detail is present; the smaller the scale (i.e. more than 1:10,000) the more generalized (less detail) the map features become (Campbell, 1993). Generalization of features is of particular importance to local resource users because they use landmarks, islands, island points, shoals, and other shore-based and aquatic features as reference points for locating harvest areas. At a large scale, areas of relevance to a harvester may be obscured because the area covered by the map is too small. These reference points can change slightly depending on the species being harvested. For example, if a species is harvested in shallow water close to shore, weed lines, bottom-types or sand bars could be used as reference. For species harvested in deeper water, islands, coral heads, or reef edges could be used. This is discussed further in Section 3.2.2.3.

The issues discussed above all contribute to potential data errors that are referred to here generically as map bias. Map bias represents the levels of absolute and relative error that can occur through translating harvest locations, as revealed by harvesters, to hard-copy maps. When an informant points to his/her harvest locations, they must draw either a point, line or a polygon on the map that represents their fishing locations (in some cases, the informant may prefer that the interviewer record the locations on the map based on his/her identified locations). If the informant draws the harvest locations, error can occur based on informant interpretation of map scale, generalization, and the map itself. If the interviewer draws the harvest locations, error is potentially greater because the interviewer must estimate locations based on the informant's instructions, which are themselves, affected by the interpretation of scale, generalization and the familiarity with using maps. Map bias is explained in more detail in Section 3.2.3.3.

One other issue to note in the context of informant assessment is information on the species harvested. In this context, it is important for the interviewer to be familiar with the biological characteristics of the species harvested in addition to the fishing technology and techniques used within the fishery being studied. This enables the interviewer and subsequently the analyst to understand better the behaviour and terminology of the resource user. In addition, as noted above, base-map design will differ slightly dependent upon species harvested.

In summary, this section has outlined some of the key issues that need to be explored and understood if LK extraction and integration into a combined knowledge base is to be successful.

These issues should be carefully thought out in advance of any fieldwork. However, room should be left for improvisation in the field. All instruments and interview procedures to be used should be thoroughly pilot-tested and refined accordingly prior to actual use in harvester interviews. These issues are explored further in the following sections.

3.2.2.2 Interview Design

Prior to initiating the interview procedure, the researcher/planner must design a set of questions that will satisfy the data requirements and objectives of his/her research. The data requirements originate directly from previous data collection efforts and plans (as illustrated in Figure 3.5), or from a fishery sector review of the study area and associated fisheries organization(s), as noted in Section 3.1. Since the integration of harvest areas is of primary interest in this research, the use of paper maps is especially important as they provide a common reference framework that harvesters can use to mark out their fishing locations. Other important information that can be collected from harvesters include, number and weight of fish caught on average per day, depth and bottom-type at harvest sites, the estimated current patterns, and weather conditions among other factors. Points to remember when designing questions, in addition to informant literacy levels, include significance and simplicity of questions, and researcher flexibility in the field. These are now discussed.

During an open fishing season, artisanal harvesters typically have relatively little free time, thus questions should be designed to get the required information in as short a time period as possible. Second, in order for an analysis to have merit, there must be a representative sample consisting of complete data sets. If too many peripheral questions are asked, the data sets may not be complete enough in terms of detail and quantity to draw any reasonable conclusions. Hence, questions must be simple, straightforward, and asked in order of most importance to least importance.

A final thought in the design of questionnaires is the flexibility of questions in the field. The interviewer must be able to simplify or change questions depending upon an informant's responses. In instances where it is apparent to the interviewer that informants are losing interest in the interview it is important for the interviewer to ensure that focus is retained. This can be achieved primarily through simplification of questions and/or removing questions that are deemed to be less important or not applicable. Thus, in order to extract the pertinent information, the number of questions asked should be kept to a minimum. In addition, what the interviewer (and researcher if the interviewer is not the same individual) expects prior to arrival can change quickly once a few interviews have been completed. If possible, a visit to the study area and informal discussions with potential informants is a preferred strategy. In these instances the interviewer must be prepared to be flexible with the wording of questions during an interview, especially if informants do not understand the language used or if they associate a different meaning to certain words used during the interview.

A common approach that can serve to alleviate many of the above concerns is to use a combination of the common sense and interdisciplinary approaches as noted in Chapter 2. A multidisciplinary approach brings together researchers from several different disciplines. One critical discipline amoung those relevant to the collection of LK is anthropology. An anthropologist seeks to understand characteristics such as language, culture, and relationships of local people, thus acting as a translator between scientific terms and concepts and local dialogue. Hence, an interdisciplinary approach, where social and spatial researchers work together, can benefit all involved by extracting LK in a fair-minded and efficient manner.

3.2.2.3 Base Map Design

The third stage in the interview preparation process is base map design. To facilitate this, researchers/planners and fisheries managers need to create base maps of the study area(s) or find maps at appropriate scales suitable for interviews that relate to aquatic environments relevant to the harvesters in question. In particular, this requires maps that show large areas of water that include shore-based referents. Harvesters can use these maps either to sketch or point out their fishing locations. Elements to consider in base map design are map detail (small islands, and in the tropics, coral heads must be visible), scale, and grid overlay reference system.

The rationale for maintaining map detail is that harvesters use details as either reference points for locating their harvest areas or these details can represent actual fishing areas. Local resource users see their surroundings at a much finer scale than most GIS represent. Unlike terrestrial environments, there are very few landmarks on the water (with the exception of using landmarks on land as reference points when harvesters are on the water) to distinguish where fishing locations are found. For example, harvesters may use submerged structures in the water that can be seen from the surface as reference points (for example coral, plant growth, etc). However, these structures typically will not be illustrated on a paper map.

Figure 3.7 illustrates examples of errors that can occur through generalization. The black line depicts a generalized extracted shoreline from a Landsat Thematic Mapper satellite image that has a spatial resolution of 30 meters. The green shaded area represents a more detailed version of the

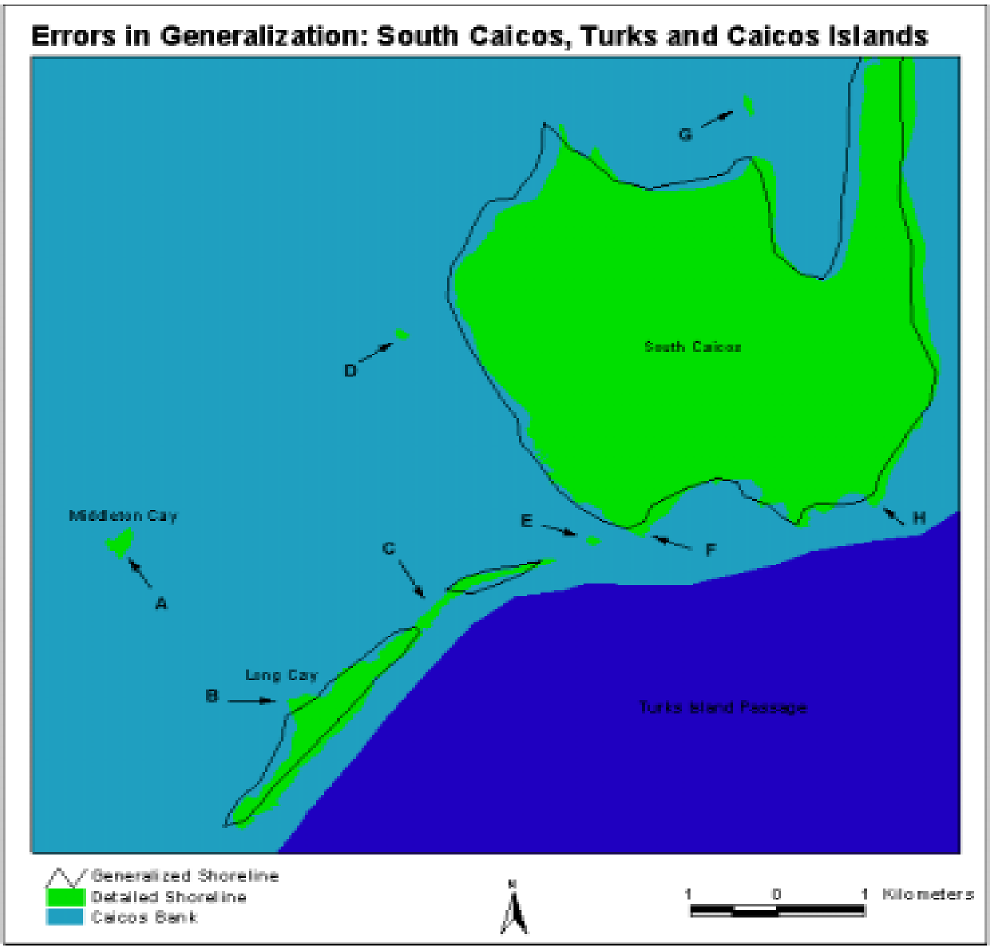


Figure 3.7: Difference between a Detailed and Generalized Shoreline

shoreline and surrounding Cays in the Turks and Caicos Islands. This shoreline was extracted from digital orthophotos of the same area through head-up tracing of the islands. Letters A, D, E, and G represent examples of small islands that were lost during generalization of the Landsat image. These islands are of particular importance when dealing with harvesters who use them as reference points in locating their fishing areas. Removing these islands from paper maps could result in harvesters becoming confused and disorientated during an interview that can lead to inaccurate locations (if located at all) of fishing areas. Letters B, F, and H illustrate the removal or misrepresentation of island points, that again may be used as reference markers by the harvesters. Finally, letter C represents a section of land that has been removed during generalization.

Since water cannot provide ground control points from which to orientate aircraft-based photography equipment, most topographic maps only show areas of water extending to a maximum of 1.5-2 kilometres from land areas as illustrated in the index map series of the Turks and Caicos Islands in Figure 3.8. Indeed, the inclusion of these water areas on topographic maps is only co-incidental as the subject of conventional mapping interest is the land. The essence of areas of water at suitable scales may prove to be important if a harvester fishes outside this zone. For this reason, a smaller scale map must be used. This then presents the problem of "unreferenced areas" on a map, where there will be spans of open water and map edges with no land-based reference points.

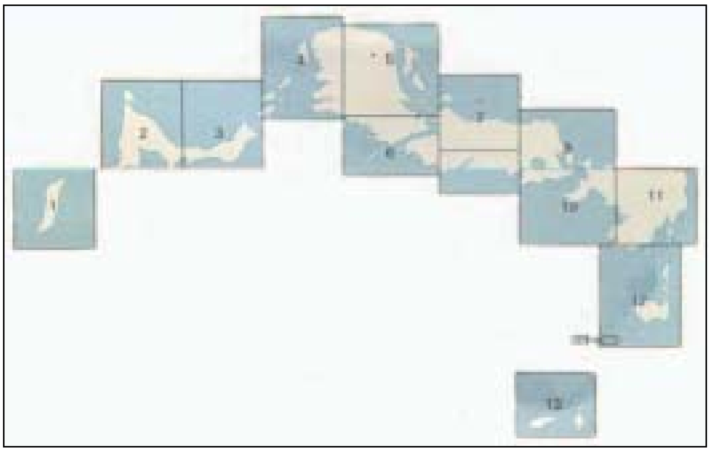


Figure 3.8: Map index for the Topographic Map Series of the Turks and Caicos Islands illustrating the water extent around each island

To compensate for these "unreferenced areas," a good technique to use is the application of a map grid or map tiles for the study area. These provide a referencing system for both the informant and for the researcher when he/she inputs the data into the GIS. This approach not only compensates for "unreferenced areas" on the map borders, it also allows the harvesters to reference larger areas of interest during the interview and the researcher to use these during data input.

3.2.2.4 Map-Based Interviews: LK collection Techniques and Interview Tactics

The final component in the interview procedure involves the map-based interviews themselves. This section reviews tactics on informant selection, discusses interview procedures for the collection of LK, and concludes with guidelines for performing map-based interviews for collection of LK in a small-scale fishery. The discussion is largely an extension of the approaches to data collection presented in Chapter 2.

The success of LK extraction will largely depend on the support the researcher has from the host community. Getting the support of the local or national government Department of Fisheries may increase the likelihood of getting the cooperation of harvesters, especially in countries that have had previous studies undertaken by researchers without them returning with improvements for the harvesters and the community. In should be noted, however, that this can act as a double edged sword as there may be high suspicion of government motives by local harvesters, resulting in the researcher receiving misleading information or no information at all. In terms of creating a meaningful GIS database, the more data that are collected, the more representative the data become when aggregated in the database. Thus, the approach taken to interviewing informants also plays a part in the success of extracting LK.

The approaches of RRA and PRA for data collection were explained in Chapter 2 Section 2.4.3. Hence, this section defines RRA and PRA tactics that can be used in the extraction of information from informants. Even though RRA and PRA are separate and fundamentally different approaches to the collection of LK, methods from each can be used in tandem. Chambers (1994; 959-961) lists characteristics that are common to each method, namely the use of secondary sources, semi-structured interviews, key informants, participatory mapping and modelling, and presentation and analysis.

Independent of, but related to, data collection in the general protocol for LK extraction is the presentation of results and specific forms of approaches to data analysis. The procedures used to operationalise this aspect of the protocol are explained in the following sections.

3.2.3 GIS Component

This section presents the second stage of the LK collection and integration with SK in the general protocol. Figure 3.9 isolates the GIS stage in relation to the general process flow diagram shown in

Figure 3.5. The purpose of this section is to outline elements in the design of a GIS database and to provide methods for the input and output of LK into and from the database. After the data have been input and organized in the database, they can be used to create a number of classification

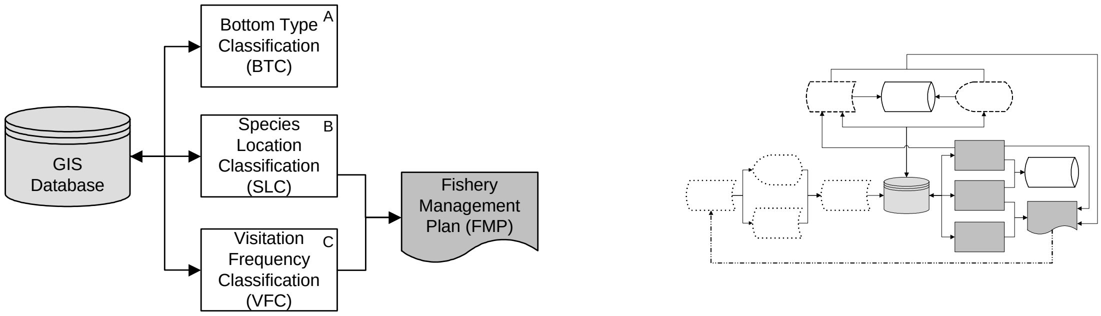


Figure 3.9: Components of the GIS Stage of the Protocol presented in Figure 3.5.

surfaces including, but not limited to, species location, visitation frequency, bottom-type, and surface comparisons. Each of these classifications can be used to determine areas that receive high fishing pressure and that, in turn, can be flagged for management or further research. These different types of surfaces, in addition to an explanation on GIS databases, are discussed below. It is important to note that the general protocol and procedures presented in this section function equally well with single or multi-species fisheries.

3.2.3.1 GIS Databases

A GIS database can be defined as an integrated set of data concerning a specific object or set of objects (Longley et al, 2001), in this case harvest location characteristics. The level of detail and size of a GIS database is determined by the requirements of the application. While all GIS have some form of database management system (DBMS), external DBMS are often used in cases where the number of data layers is large or when the application requires faster query times than the GIS on its own, can provide. Figure 3.10 illustrates a GIS system with and without an external DBMS. The solid line indicates data flow using an external DBMS while the dashed line indicates the flow of data without an external DBMS. In the context of LK extraction and storage, the design of the database is equivalent to a conventional GIS.

Even although it is possible to use either a vector or raster-based GIS for the development of a fisheries management plan, a vector-based GIS is the approach used here with supplemental data and analysis coming from raster-based RS imagery. The primary reasons for this are: (i) the type of data storage structure used by each GIS model, (ii) the similarity between vector data and

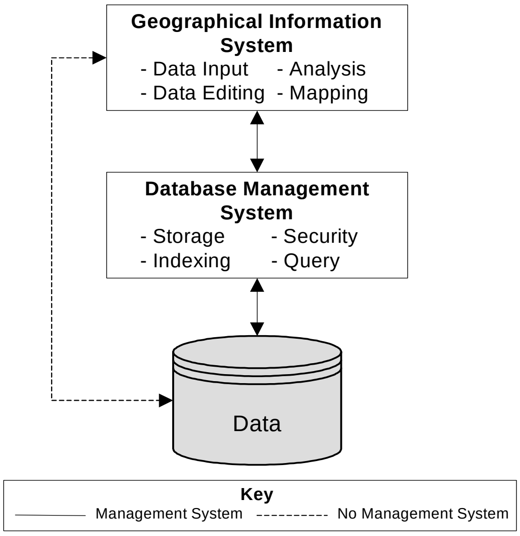


Figure 3.10: Standard GIS System Framework (Source: Longley et al, 2001)

conventional topographic map features, and (iii) the use of attribute tables in the vector data model. The vector model stores data as a series of x, y coordinates, that, depending on their purpose, can form points, lines or polygons, which define the boundaries of objects. This information, along with any additional data pertaining to an object, are stored in tables.

Conversely, in the raster data model, the entire area of interest has data values associated with it. Thus, cells depicting both relevant and non-relevant features have recorded values within the area of interest. Due to the number of interviews typically undertaken when gathering LK, the storage space required for the raster data layers would be large, not to mention the processing time required to analyse all of the data layers. For example, depending on the study area, one raster layer could equal 10 to 20 megabytes. If this is multiplied by the number of harvesters interviewed times the number of feature types used by each harvester, the data storage required would be enormous. In the vector data model, under the same parameters, file sizes would range from a few kilobytes to a few hundred kilobytes. Further, within the context of a small-scale developing state, where funds can be limited and power outages can be a common occurrence, the files sizes and computational time associated with the vector data model are much more manageable. While a raster model can visualise LK, it cannot store additional attribute information concerning harvest areas, a feature that is required for the integration of qualitative data.

Figure 3.11 summarizes the data layers that are input into the GIS database. Regardless of the map type used for the map-based interviews, “heads-up” digitizing is the preferred method of data input because it is difficult to extract precise coordinates from the paper maps that the harvesters draw on. Heads-up digitizing is the process of using a mouse and keyboard instead of the traditional puck and digitizing tablet to input relevant data. This type of digitizing method can be performed manually, where points are input by user estimation or by tracing using a background image. In the context of this research, heads-up digitizing is the preferred method due to the presence of potential map bias noted in section 3.2.2.1.

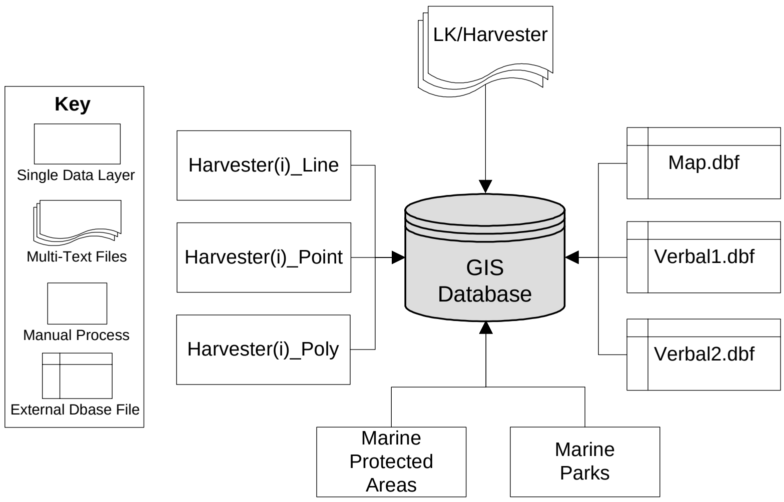


Figure 3.11: Data Input Layers for the GIS Database

Data collected based on questions asked without the use of a map in harvester interviews are input into an external database file while map-based spatial data are input directly into a the GIS database. Additional data layers include, using generic file names such as “verbal1.dbf”, “verbal2.dbf,” etc., LK documents and marine park information. The verbal database files referred to above are reserved for data collected without the use of the hardcopy maps, for example number of years the harvester has fished, weight of fish harvested on a good day, or general comments on conditions of the fishery. The LK documents contain species-specific information volunteered over and above the information requested from the harvester.

Since there are large numbers of harvesters who could potentially fish in the same areas, the overlap of information can be significant. This overlap is vitally important in determining the classification surfaces listed in Figure 3.5 and Figure 3.9. Thus, it is important to associate each harvester with a data layer unique to his/her fishing locations. In addition, it is generally important to have one data layer each for point, line and polygon features to allow for the differentiation and the number of visits by harvesters per location. Line and point features types (and associated data layers) represent specific fishing locations, whereas polygon features represent generalized areas.

3.2.3.2 GIS Functionality

The two GIS analysis functions proposed in the general research protocol are buffer and union. The concept of buffering involves the GIS program building a new polygon feature around the original input feature (be it point, line or polygon) according to a set distance (Longley, 2001). There are two main types of buffers in a vector GIS, namely single-ringed buffers and multi-ringed buffers. Figure 3.12 illustrates the results of a single ringed buffer when applied to a point, line and polygon feature. The black areas in the middle represent the original feature while the lighter area around each feature represents the buffered distance. Similarly, Figure 3.13 illustrates the results of a three-ringed buffer. In cases where multi-ringed buffers are used, the GIS program builds a new polygon feature for each ring specified starting with the original feature.

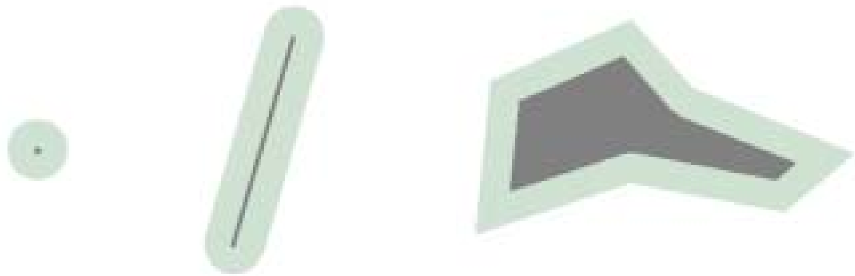


Figure 3.12: Single-Ringed Buffer in a Typical GIS (Modified from Longley et al, 2001: 291)

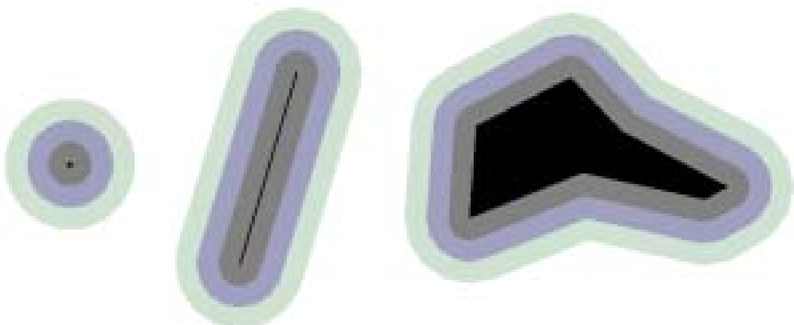


Figure 3.13: Multi-Ringed Buffer in a Typical GIS (Modified from Longley et al, 2001: 291)

The second GIS analysis function proposed is union. The union function is an overlay procedure that merges two or more data layers into one. During a union, all features from two input data layers are preserved in the output layer. Where two features overlap, the intersections between them are calculated and recorded, resulting in additional features being constructed in the output layer (ESRI, 1996). Only two input layers can be unioned at any given time, thus if more than two data layers are to be unioned in the analysis, the output of the first union is used as one of the inputs to the second union. Figure 3.14 illustrates the graphical results of a three data layer union. Input layers 1 and 2 form output layer 1 which doubles as the third input data layer for the second union.

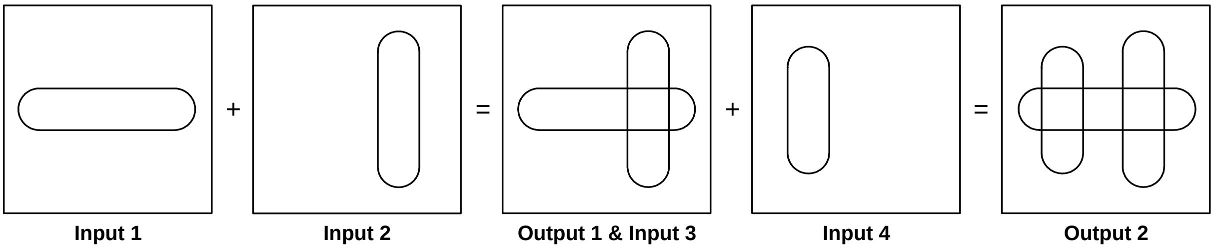
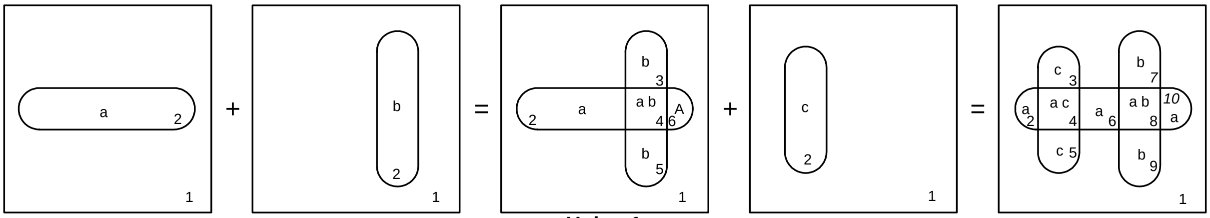


Figure 3.14: Graphical Illustration of Input and Output Layers for a Three-layer Union

In a typical vector GIS database, each data layer has two parts, the graphical view (as shown in Figure 3.14) and an attribute (database) table. Each record (row of data) within the attribute table represents a feature in the graphical view. Columns in the table represent specific attributes associated with each feature. Thus, if an attribute table were associated with each of the three input layers in Figure 3.14, where the letters "a," "b" and "c" represent each of the features in input layers 1, 2, and 3 respectfully, the attribute tables for these data layers would look like those shown in Figure 3.15. The numerical values in each data layer represent the record number in the associated attribute table below each data layer (recorded under the ID field in the tables). The letter that represents each feature is recorded in the associated table based on the record ID number for that feature. For example, the letter "a" represents the feature in data layer 1 (Input 1). Since the corresponding ID number is 2, the letter "a" is recorded in the second record. This holds true for each of the three input layers. The attribute tables for each input and union shown in Figure 3.14 are illustrated in Figure 3.15. Where two features overlap, intersections are constructed resulting in additional records as shown in Union 1 and 2 in Figure 3.15. Similarly, attribute data tables from each of the input layers are joined in the output layer based on a common field, in this case the ID field.



Input 1	Input 2	Union 1 (Output 1 & Input 3)	Input 3	Union 2

Table 1: Input 1

ID	Input1
1	
2	a

Table 2: Input 2

ID	Input2
1	
2	b

Table 3: Union 1

ID	Input1	Input2
1		
2	a	
3		b
4	a	b
5		b
6	a	

Table 4: Input 3

ID	Input3
1	
2	c

Table 4: Union 2

ID	Input1	Input2	Input3
1			
2	a		
3			c
4	a		c
5			c
6	a		
7		b	
8	a	b	
9		b	
10	a		

Figure 3.15: Input and Output for Three-Layer Union with Attribute Tables.

With the union and buffering commands explained, the next section discusses the classifications that can be derived using the LK and the conventional GIS functionality described above.

3.2.3.3 GIS Classification Surfaces

This section describes examples of different types of classifications that can be produced using LK-based data collected from local resource harvesters. As illustrated in Figure 3.5 and Figure 3.9, these surfaces include species location classification, visitation frequency classification, and bottom-type classification. These classifications are determined by LK input on two types of data, namely harvest locations and sea floor or bottom-types. Classifications are devised using a combination of unions and buffers.

The initial preparation steps associated with the species location classification analysis can also be used with the visitation frequency classification, thus the two are explained together. The purpose of the species location classification surface is to illustrate the range of fish species in the study area as indicated by harvesters' data on the locations of fishing areas. The purpose of the visitation frequency classification is to determine the sites in the study area that receive a high degree of fishing pressure, illustrated by the number of harvesters fishing in the same area in a specific period of time. Since each harvester has his/her own data layer associated with each species, a method to combine all of the harvesters into one cumulative data surface is required. One method that satisfies this need is a multiple binary union.

Before considering the overlay procedure, some preliminary data layer preparation is required. As noted above, one of the issues in working with LK in a GIS environment is map bias. When a harvester draws a line to indicate a fishing location (a harvest site regardless of shape (i.e., point, line or polygon)), the line is discrete and more than likely inexact. However, in reality the line is actually representing a generalised stretch of fishing activity as revealed by the harvester. This idea is illustrated in Figure 3.16. The grey areas represent landmasses and the white area within the box represents water. Figure 3.16A shows a fishing area as indicated by a harvester. Figure 3.16B illustrates the same fishing area as interpreted by the interviewer. In cases where harvesters sketch their own fishing areas, only Figure 3.16B applies. Regardless of who draws the harvest area, the accuracy is still generalised due to the effects of map bias.

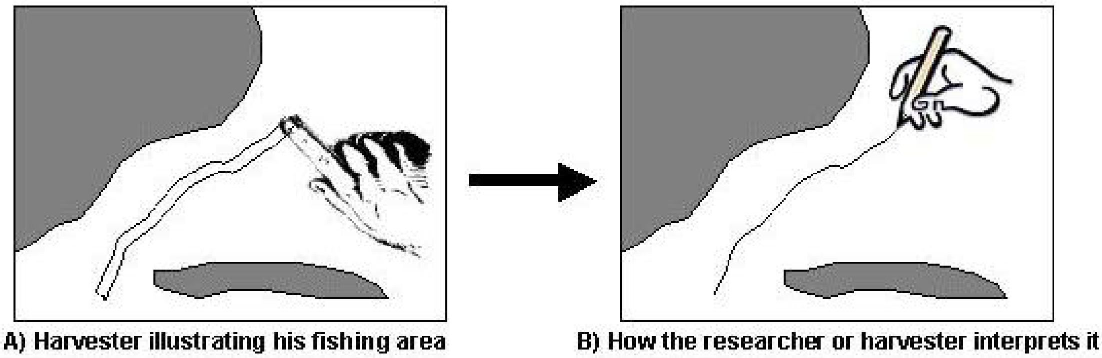


Figure 3.16: Fishing Area as Illustrated by the Harvester and Interpreted by the Researcher

While the issues noted earlier contribute to map bias and affect the interpretation of fishing areas on a two-dimensional map, the two most prominent issues are scale of map and fish movement. Map scale affects the harvester’s interpretation of fishing areas and fish do not follow discrete lines. In essence, the locations marked by the harvester’s finger are merely a representation of reality, while the drawn line is a generalization of reality. To put this into perspective, if a harvester’s finger width is one centimetre, this equates to approximately 10 km on a 1:10000 scale map, 25 km on a 1:25000 scale map, and 50km on a 1:50000 scale map. Similarly, if the width of a drawn line is approximately

0.5 mm, this equates to roughly 5m on a 1:10000 scale map, 12.5m on a 1:25000, and 25m on a 1:50000 scale map.

Since neither the drawn line nor the harvester's finger are true representations of reality, a method is required to accommodate these two sources of potential error. Two solutions are suggested to combat this problem, namely single and multi-ringed buffers. The single-ringed buffer approach provides a general idea of harvest activities while the use of a multi-ringed buffer, acting as a transitional zone, provides the researcher/planner with a more realistic idea of harvest activities within the study area. It should be noted that these solutions are used for line and point features only. Polygon features represent, by definition, a generalized fishing area, thus they are less likely to be affected by the same sources of potential error.

The harvester's drawn line (or researcher/planner's approximation of a harvester's fishing area) is taken to represent the centre or location of highest likelihood of a fish being at a particular location. The likelihood of fish being caught decreases with distance from the centreline. Thus, the drawn line represents the location where the fish are most likely to be found and caught. Since fish move and are unlikely to be at the exact location of the discrete line, the idea behind the buffer is to simulate a realistic harvest area.

Utilizing the above approach, the single-ringed buffer exaggerates the line drawn by a harvester (or drawn by the interviewer under the direction of a harvester) to include a more representative area fished without going to the extreme generalization dictated by the width of the harvester's finger. The distance used to buffer the original line (x) will differ based on the study area, scale of the map used, weather conditions, size of fishing vessel and species harvested. For example, in a small-scale fishery, using a small 14ft boat, and where weather conditions are fairly calm, a buffer distance of x=50m (on either side of the fished line - for a total of 100m in diameter) would be a realistic representation of a harvest area. Furthermore, the 100m total distance would allow for such things as adjusting for map bias, boat drift, and fish movement. Distances will ultimately be up to the discretion of the researcher/planner or fisheries manager, based on the above parameters.

The central idea behind the binary union methodology illustrated in Figure 3.17 is to record a value of "1" (true) each time a species is harvested at a particular location whether the feature type is a point, line or polygon. All other instances receive a value of “0” (False). Since each harvester has a separate data layer for each type of harvest activity (point, line, polygon), a new column is added to the associated table and a value of “1” assigned to all areas fished. If working with a multi-species fishery, where harvesters fish for more than one species within the fishery, each species must be dealt with independently as shown in Figure 3.18. In this approach, each species within the fishery can be examined on an individual basis with the option of being aggregated with other species types at a later date. Once each table (per harvester and object type) has been coded with the values of “1” or “0”, the data layers are unioned one by one, as outlined in Figure 3.15, until all harvester data layers are aggregated into one layer (S(i)_SB_PL = (Species (i), single buffer approach, point and line features) in Figure 3.18). When the overlays are complete, the associated overlay attribute table will have one column for every species in the fishery and the associated value of “1” for areas where each species is found (harvested).

Depending on the classification being constructed (species location classification or visitation frequency classification) the methodology differs. Both the species location classification and the visitation frequency classification have values of “1” recorded in the overlay attribute table for fish presence. The difference between these two classifications is the use of the binary values. For the visitation frequency classification, a “total” column is added to the overlay attribute table and all the columns within the overlay table are summed for each species caught. The end result is a layer where the number of occurrences of species harvested is a numeric value corresponding to the number of harvesters that fish in any given area per day within the study area.

For the species location classification, the binary values with the overlay attribute table are used to calculate the range of species caught over the study area using the formula:

$$\text{if } a > 0 \ \text{ then } i = 1 \qquad (3\text{-}1)$$

where a equals the species frequency from the total column in the visitation frequency classification above and i represents species harvested. If analysing a multi-species fishery then the above formula changes to:

$$\text{if } a > 0 \ \text{ then } i = i' + 1 \qquad (3\text{-}2)$$

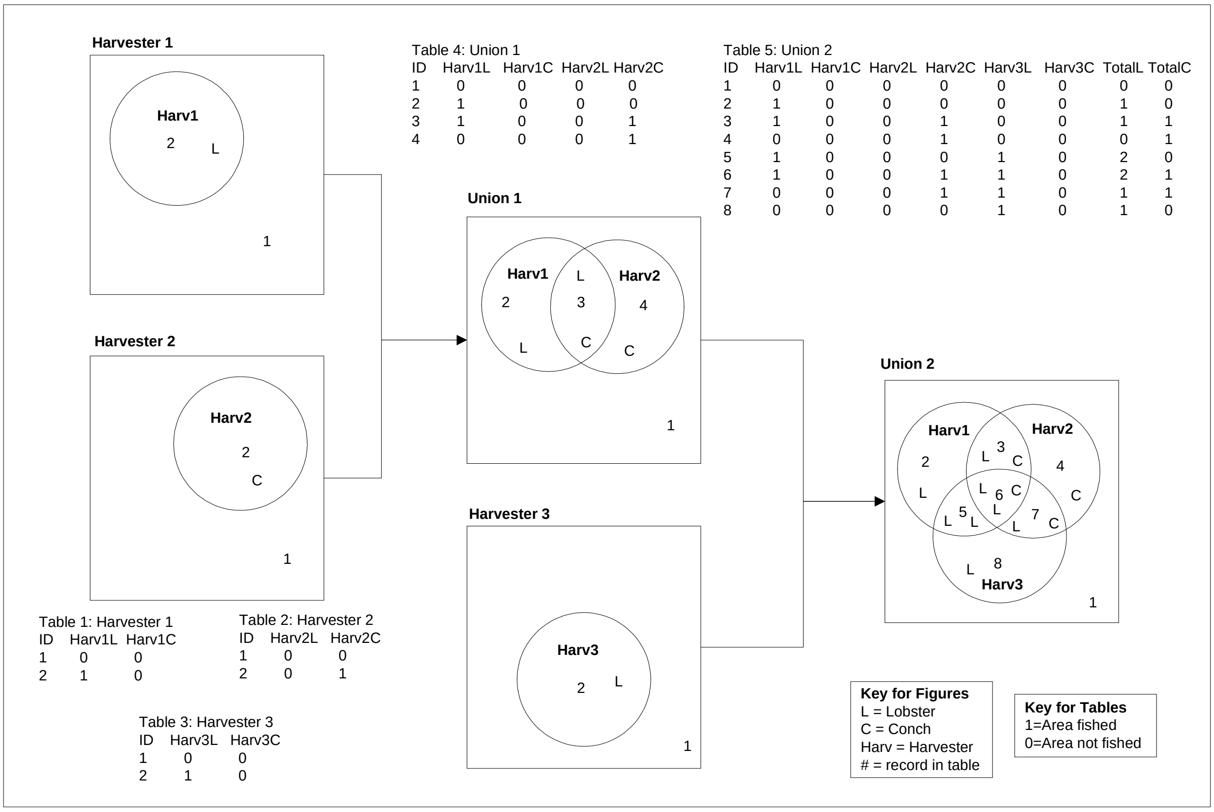


Figure 3.17: Example of a Binary Union

The result produces a unique value that represents each species in the analysis. For example, if Conch, Lobster, and fish are the three species being studied then *i* would equal {1,2,3} with each value representing each species type.

The resulting visitation and species classifications from the above analysis could be broken down by feature type where one surface would represent polygon features (represented as SLC_Poly and VFC_Poly in Figure 3.18) and another surface would represent the combination of line and point features (represented by SLC_PL and VFC_PL in Figure 3.18 (PL = point and line features). These surfaces could then be used to contrast the actual fishing locations and frequencies of harvesters fishing at a location relative to species distributions derived from quantitative stock models and distributions of fish derived from SK.

While the single-buffer approach provides a representative visualization of where harvest activities are occurring in the study area, it does not fully integrate the reality of the aquatic system. Like many natural phenomena, fish species distributions do not conform to exclusive boundaries drawn

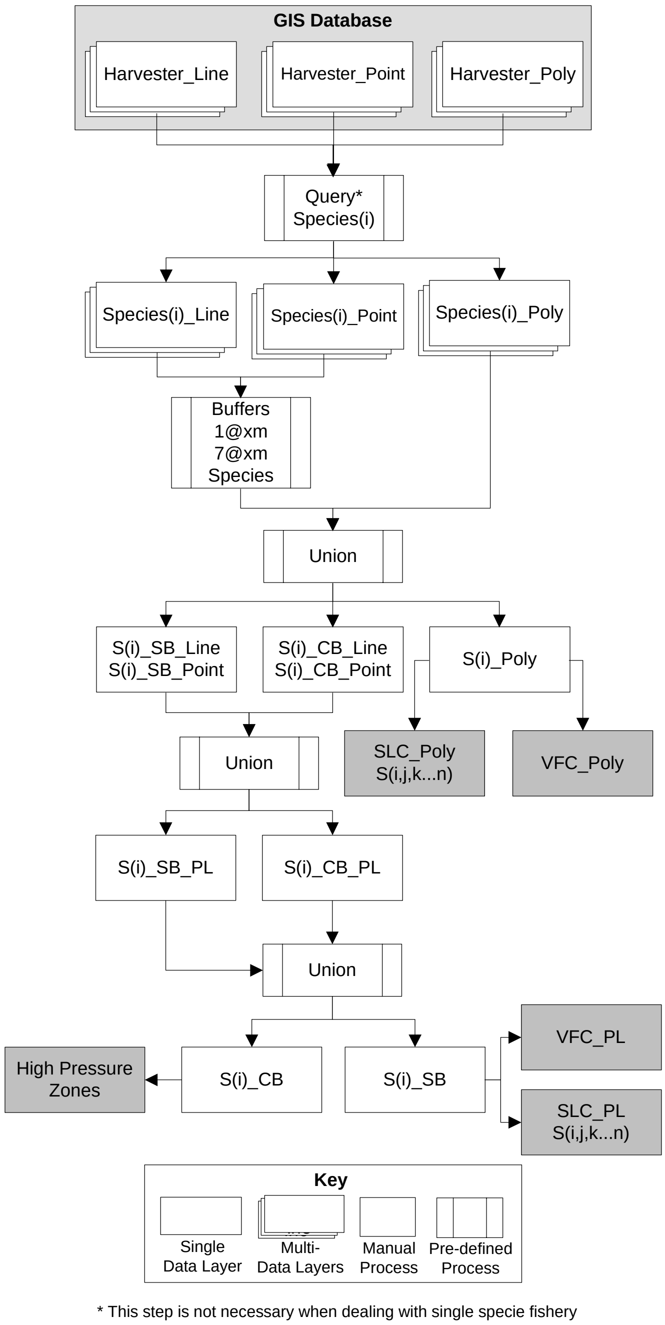


Figure 3.18: Analysis Sequence for Species Location, Visitation Frequency, and Bottom-Type Classification

on a map. Thus, following the rationale of the single-ringed buffer noted above, where the likelihood of a fish occurring decreases with distance from the centreline, the multi-ringed buffer provides a more realistic view of harvest sites in the study area by representing the likelihood of finding fish relative to the fishing spot or track. In this context, the buffer rings are used to represent transitional zones where the likelihood of finding spots decreases with increasing distance.

In the context of this research, the rings of the multi-buffer are collectively used to approximate a likelihood surface at each harvest area or location. Figure 3.19 illustrates the relationship between the buffer rings and the likelihood of fish occurring in each ring. The likelihood of fish occurring is strongest at the centreline (the centreline being the line that represents the area fished as described in Figure 3.16) and decreases with each successive ring. Even though the buffer rings themselves are still Boolean (i.e. hard or crisp in nature), the coding of the rings based on distance from the centreline allows them to represent a form of likelihood of occurrence. In this context, the number of rings dictates the score value of each ring, with the first or inner most buffer ring coded with the highest value and the last or most outer buffer ring coded the lowest value (which will be 1 in all cases). Thus, the range of the integers 1 through 5, with 5 representing the highest likelihood of fish occurring and 1 representing the lowest likelihood of fish occurring, is used. While this form of value assignment is somewhat arbitrary, it is argued that in the absence of other information, it is defensible based on the fluid dynamics involved within a marine environment outlined in Chapter 2.

Figure 3.20 illustrates a three-layer union of a five-ringed multi-buffer using a score range of [1,5] as shown in Table 3.1. The score value and buffer distance have an inverse relationship where the likelihood value is highest closest to the centreline with a value of 5 representing the highest likelihood of a fish occurring in the first ring of the multi-buffer. Once the likelihood values are calculated for each harvester's data layer and the layers unioned into one cumulative layer, the likelihood values of overlapping buffer zones are added together. The resulting effect of combining the multi-buffer likelihood values means that the areas of highest likelihood (values 10-13 in Figure 3.20) occur at the intersections of the three centrelines, decreasing in a radius outwards from these intersections.

For management purposes, a threshold likelihood value is required in order to determine a cut off value for identifying management areas. The method used for this purpose is:

$$\sigma(x)\ 2\ 1\omega, \qquad (3\text{-}3)$$

where μ is the mean, x equals the range of likelihood values and [illegible] is the standard deviation.

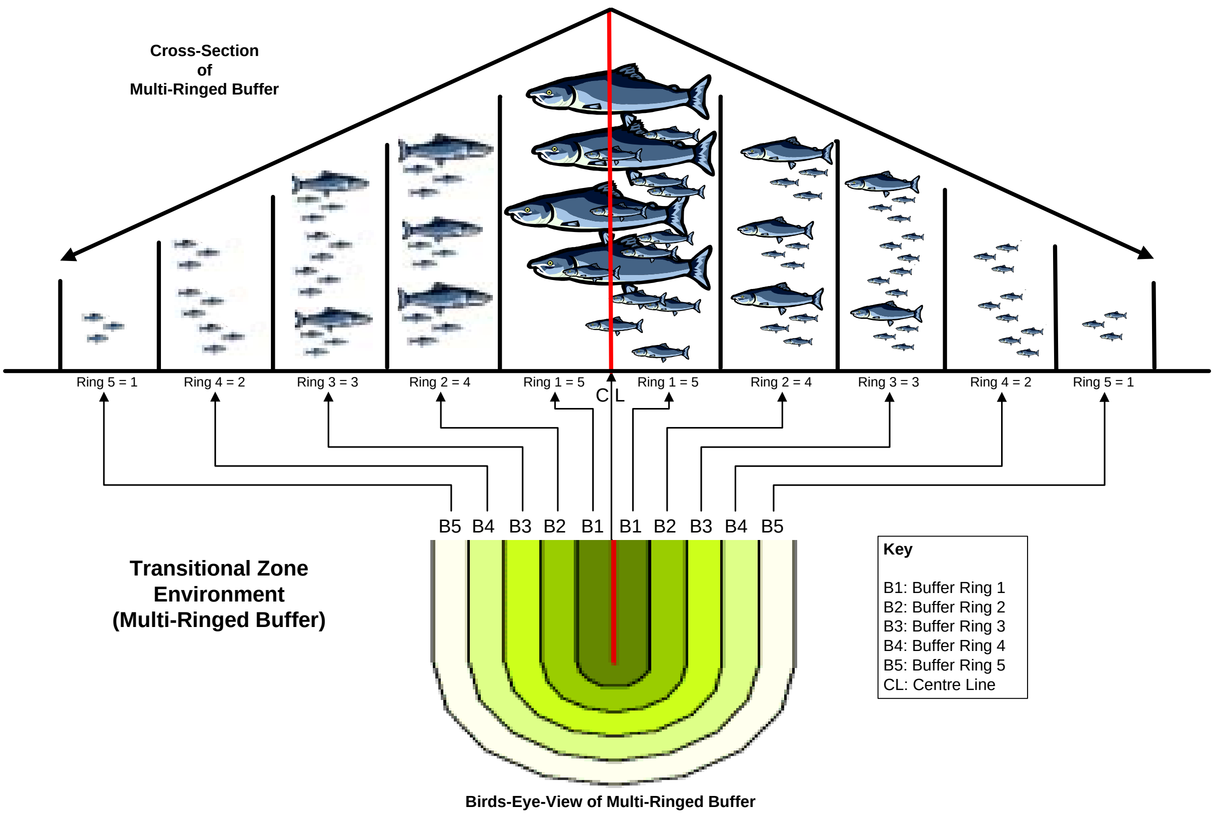


Figure 3.19: Illustration of the Coding of the Buffer Rings to Act as a Transitional Zone

Buffer Distance (from Centreline)	Likelihood Value
50 m	5
100 m	4
150 m	3
200 m	2
250 m	1

Table 3.1: Likelihood Values for Example in Figure 3.20 and 3.21

In addition to the likelihood values, the area (in m^2) of each polygon that met the likelihood threshold criteria noted above is calculated to filter out those polygons that are potentially too small to be deemed viable for further study. For example, if the likelihood threshold value of fish presence for a polygon is 10 or greater, and a polygon from that selection exhibits an area of only 10 square meters, then that polygon is probably too small to be of interest (dependent on species) and thus, not worth managing. If, however, a polygon has a likelihood value of 13 and exhibits an area of 10 square meters, then that particular polygon may be of interest for further research because the chances are that that area exhibits some bottom-type and/or water-based characteristics that make the area productive, thus warranting further study. In this context, area and likelihood have an inverse relationship, as illustrated in 3.21, where the higher the likelihood, the more probable the area would be relevant for management. It should be noted that the threshold values for both area and likelihood vary depending on the species of fish being examined.

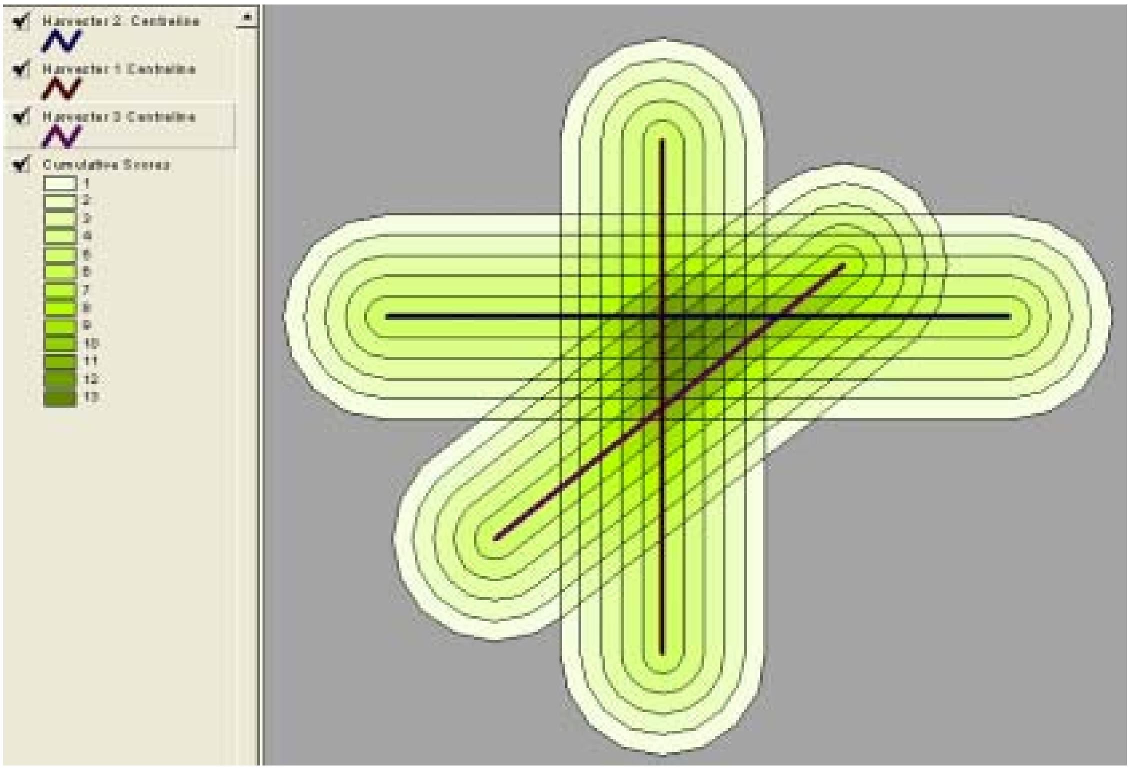


Figure 3.20: Illustration of a Multi-Buffer Overlay

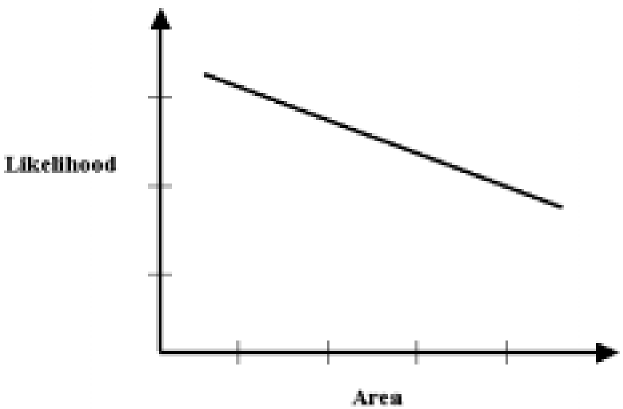


Figure 3.21: Threshold Relationship between Probability of Fish Presence and Area

Thus, based on predetermined area and likelihood threshold values, and biological data of the species being studied, these values are extracted from the final cumulative layer (S(i)_CB) to leave a surface that represents areas of the highest likelihood of fishing activity (Referred to as High Pressure Zone in Figure 3.17). These areas of highest likelihood can be retained for either management or further research.

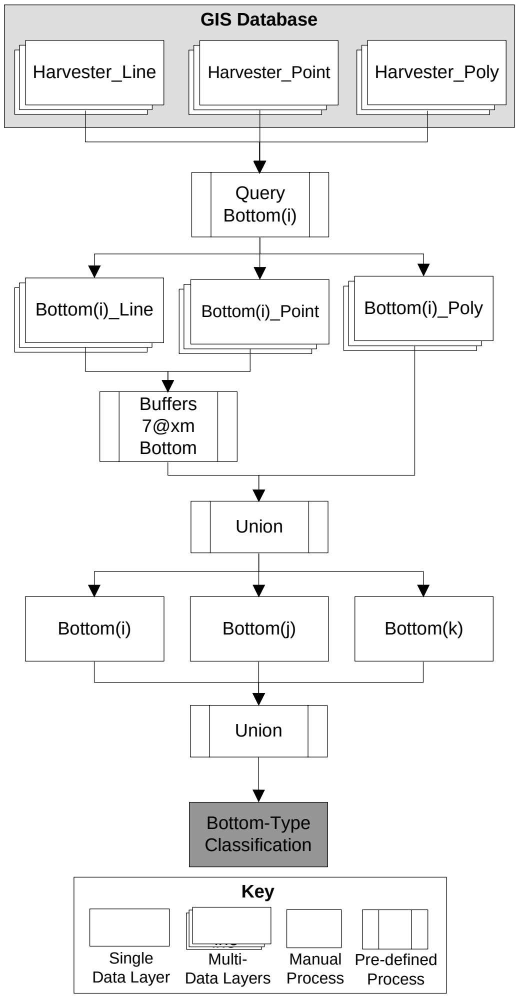


Figure 3.22: Process Flow for determining Bottom-Type Classifications.

The third and final GIS surface presented in Figures 3.5 and 3.9 is referred to as bottom-type classification. The purpose of the bottom-type classification is to determine a habitat classification of the study area. In order to aggregate bottom-types from a number of interviews there is a problem with the same areas potentially being categorized differently by two or more harvesters. For example, an area of water could be classified as having a sand bottom by one harvester, a rocky bottom by another harvester and a coral bottom by yet another. Since two different bottom-types cannot occupy the same geographic location at the same time unless they are clearly mixed, a methodology had to be devised to compensate for this problem. The methodology used involves two steps.

First, a combination of the multi-ringed likelihood buffer described earlier for harvest locations is implemented to determine likelihood surfaces for each bottom-type (Figure 3.22). Second, each bottom-type likelihood surface is unioned together to form one bottom surface (Figure 3.22). Prior to the overlays, each bottom-type attribute table must have a unique field identifying the bottom-type in question with the total likelihood for each record in this field. This will ensure that the bottom-types are distinguishable once aggregated into one surface. From here, the final bottom-type surface is classified, based on the bottom-type with the maximum likelihood for each overlapping polygon. The final LK bottom-type classification can then be used for comparison with bottom-type surfaces extracted from RS imagery.

3.2.3.4 GIS Section Summary

Three types of features are used to analyse harvest locations and their associated characteristics (such as bottom-type, species type, and depth), namely points, lines and polygons. In order to compensate for map bias pertaining to point and line features, the GIS function of buffering is proposed to exaggerate these areas in order to illustrate a more representative harvest area. Both single ringed and multi-ringed buffers were explained as possible solutions to simulate a more realistic representation of harvester activity within the study area.

In order to determine the number of harvesters fishing in the same areas, a form of aggregation is required to overlap each individual harvest layer into one cumulative map layer. The GIS function described in this thesis to accomplish this is union. Using the union function, aggregated map layers of bottom-type, visitation frequencies across the study area, and species location maps were described.

The next section examine the use of RS as a complementary SK-based method for determining bottom-types across the entire study area

3.2.4 Remote Sensing Component

This section represents the third component of the general research protocol. Figure 3.23 segregates the RS sequence from Figure 3.5. The purpose of using RS data is to extract aquatic bottom-types within the entire study area. These data represent a component of SK in addition to being used to cross-verify LK-derived bottom-types for the same area. This section, therefore, defines the image classification method that can be used for this component, namely unsupervised and supervised classifications (multi-spectral). Since this stage in the protocol is only of general interest, specific methodologies for the classifications are not given.

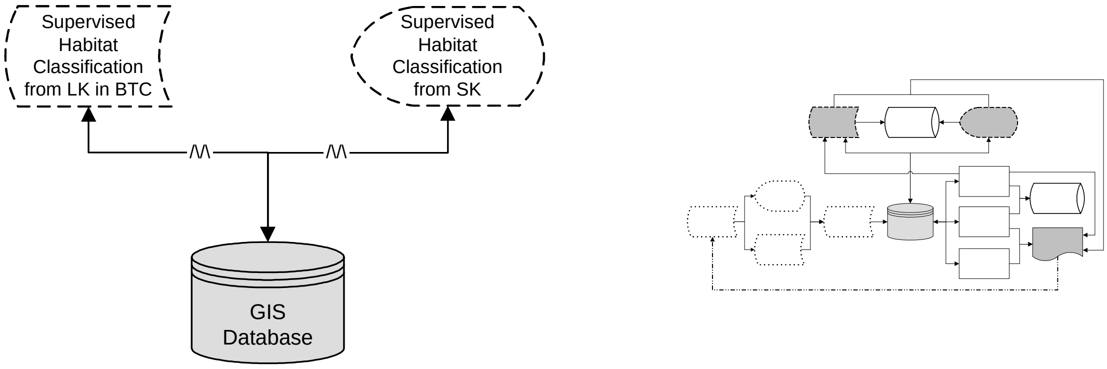


Figure 3.23: Components of the RS Stage of the Protocol presented in Figure 3.5

3.2.4.1 Remote Sensing Functionality

There are two types of multi-spectral classifications commonly used to classify RS imagery, namely supervised and unsupervised. A supervised classification is the process of using samples of pixels of known feature types whose exact locations are known within the image to construct "training areas" that are used by the computer to classify pixels of unknown features over the entire image or study area based on the known feature type values (Lillesand and Kiefer, 2000). In the context of the protocol proposed here, the purpose of a supervised classification would be to use bottom-type information collected from the harvesters to construct training areas that can be used to classify bottom-types for the remainder of the image. The bottom-type data are taken from the bottom-type classification in the GIS segment of the research protocol and used as the training sites.

An unsupervised classification involves the use of pre-existing algorithms to determine natural spectral groupings or classes found in the image based on a feature's spectral reflectance (Lillesand and Kiefer, 2000). These feature classes are then used to classify the remainder of the image. While both these methods are derived from SK, the supervised classification can be derived strictly from LK input.

With both of these classification methods there are residual questions of accuracy, specifically in the application of marine environments. Accuracy in terms of RS, involves the percentage of pixels that have been correctly classified. Errors occur when features possessing similar spectral reflectance values are classified as the same feature. This can occur when not enough classes have been specified in an unsupervised classification or not enough pixels (or correct pixels) are used to classify the image. Green et al (2000) reported an overall accuracy of 50% for an unsupervised classification of the Caicos Bank in the Turks and Caicos Islands using Landsat TM imagery. This accuracy went up to 70% for a supervised classification of the same area. Green et al (2000) also reported a 6-17% increase in accuracy after utilizing water column correction techniques in addition to contextual editing using visual interpretation.

3.2.5 Local Knowledge Data Validity and Quality Checks

Two knowledge comparisons are proposed in Figure 3.5 and 3.24. The purpose of the first comparison is to verify that the local harvesters provide accurate information on harvest activities. To accomplish this, a comparison between aggregated bottom-types from the map portion of the interviews, and bottom-types per species from the verbal portion of the interview, are compared. The verbal portion of the interview is portrayed through the species location classification surface. If, for example, 75% of the harvesters state that Conch are found on a sandy bottom, then sand will be coded wherever Conch are located on the species location classification map. The results of this comparison illustrate the accuracy of information that has been divulged by the harvester. If the accuracy is low, then LK in the area could be misleading due to the trust issue noted earlier in the chapter, or to problems related to the use of maps by the harvesters, lack of land marks from which to reference themselves, or issues with map bias.

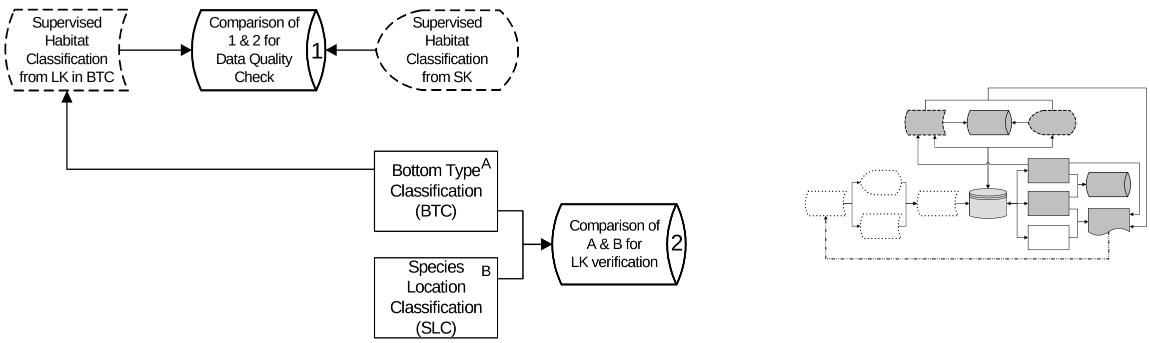


Figure 3.24: Components of Knowledge Comparison Section of the Protocol presented in Figure 3.5

The purpose of the last data comparison is to compare an image classified using SK to define training sites (i.e. sites identified by the researcher using technologies such as global position systems in a boat) for supervised image analysis against an image of the same area that is classified using information provided through LK. Depending on the correspondence of the two images, a number of conclusions can be drawn. For example:

- The data from each knowledge source could reinforce each other. The implication of this is an enhanced ability of a local fisheries department to assess its own fishery in the absence of SK using LK.
- SK could be inaccurate due to accuracy issues in the imagery.
- LK could be inaccurate due to misleading or incorrect information.

Both comparisons can be performed on bottom-type classifications, as this is the only feature that can be objectively used as a benchmark for all knowledge sources including SK.

The inclusion of RS data and analysis concludes the procedures for the general research protocol that is proposed in this thesis. In the following chapter the specific study area examined is described and, consistent with the protocol that has been explained, data sources and the specific procedures employed in the field are detailed.

3.3 Chapter Summary

This chapter has explained a general protocol and procedures that can facilitate the integration of LK with traditional SK into fisheries management. The chapter discussed the differences between small and large-scale fisheries. Management techniques were also reviewed and their ramifications in the absence of management in small-scale fisheries were discussed. Procedural frameworks for developing a FMP were outlined including the SAD and MOD sequences in addition to a third revised sequence introduced, namely FF. Operational procedures were then explained for collecting, storing, analysing and visualizing LK with the aim of empowering local resource users, researchers/planners and fisheries managers to assess their own fishery using relatively cheap and effective procedures. Background information on GIS and RS techniques were outlined. Obstacles encountered included issues with map bias and interview design. Finally, RS techniques for comparing knowledge sources were reviewed.

Chapter 4

CASE STUDY AND METHODOLOGY

This chapter describes the case study used to operationalise the conceptual model of local and scientific knowledge integration presented in Chapter 2 and the subsequent general protocol and techniques for field data collection, processing and integration presented in Chapter 3. First, Chapter 4 provides background information on the case study setting, namely the Turks and Caicos Islands (TCI), their people, and culture. Next, the chapter describes the specific primary and secondary data sources and field methods used for the research. Primary data collection includes the design of the questionnaires and other instruments used in the field, subject contact and interview protocol, as well as the actual analysis procedures used in Chapter 5. Secondary data are also described including digital aerial orthoimagery of the immediate coastal zone and more extensive digital remotely sensed satellite imagery.

The chapter then describes how the primary and secondary data sources were used to construct GIS and RS classifications. Furthermore the soundness of both SK and LK are compared through validity checks between a bottom-type GIS classification derived from LK and bottom-type RS classification derived from SK. The chapter lays the precise groundwork for discussion in Chapter 5 of the results of the protocol used in the TCI.

4.1 Description of Case Study Setting

The Turks and Caicos Islands (TCI) are a British overseas dependent territory. The formal head of state is Her Royal Highness Queen Elizabeth II. The country is run by an elected Legislative Assembly (Executive Council), a Chief Minister appointed by the governing party and an expatriate Governor appointed directly by Her Royal Highness as her representative. The Governor has the legislative power to dissolve the Executive Council and assume direct control of Government, as is the case currently due to nullification of two electoral district votes in the recent national election, which created a stalemate requiring a run-off in the affected districts. Civil law and constitutional law are both British with modifications to suit local conditions. The ultimate court of appeal is the Privy Council of the United Kingdom (Hall, 2003).

The country is located 800 km southeast of Florida on the southern end of the Bahamas chain (Figure 4.1). The islands are comprised of eight inhabited islands and 41 cays divided into two general island groups, namely the Caicos Islands and the Turks Islands (Figure 4.2). The Caicos Islands form the main group, comprised of North Caicos, West Caicos, Middle Caicos, East Caicos, South Caicos, and Providenciales. The Turks Islands are made of Grand Turk, Salt Cay, and a number of smaller cays. TCI has a population of approximately 25,000 and a total land area of 310 km^2 (Baker, 2001). Primary exports include the Spiny Lobster and Queen Conch, totalling approximately $4,000,000.00 US annually (U.S. Census Bureau, 2003). Imported items include mainly food and drink, furniture, automotive parts, and tobacco (U.S. Census Bureau, 2003).

Figure 4.1: Geographic Location of TCI (Source: http://www.turksandcaicos.tc/turks)

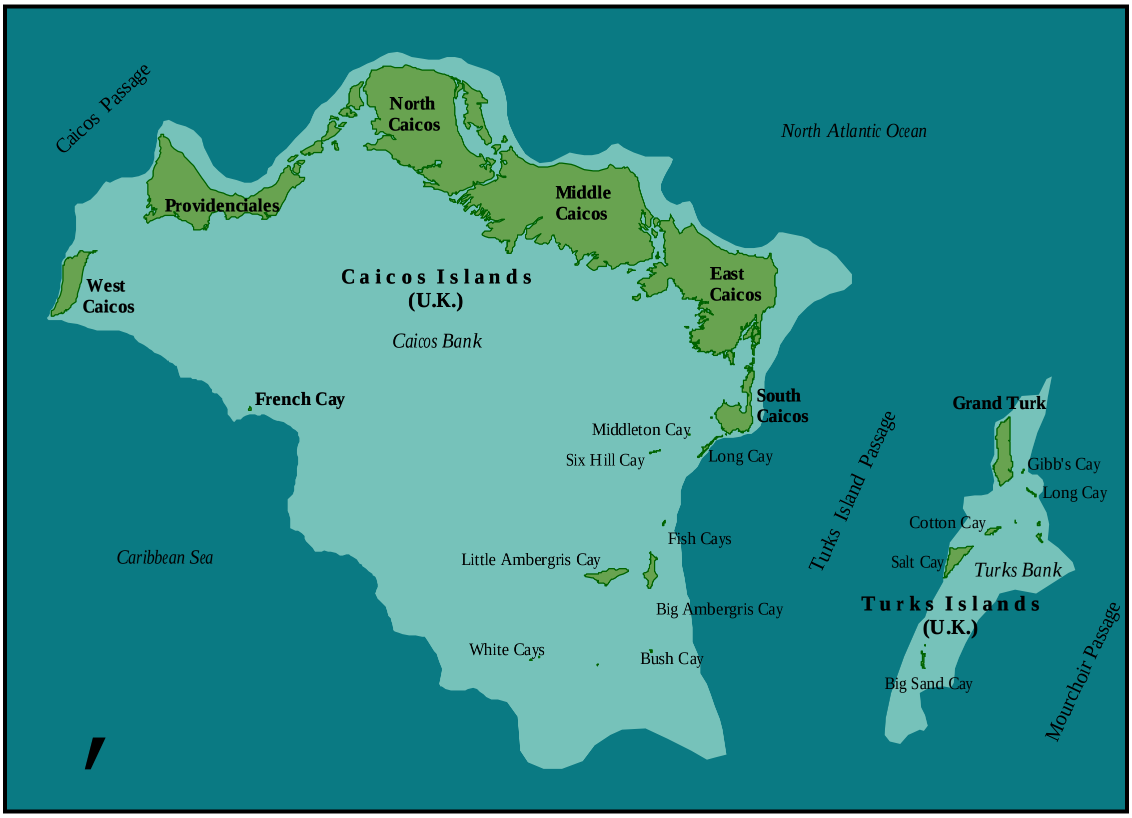


Figure 4.2: The Main Islands and Cays of TCI (Source: Christopher Close)

4.1.1 A Brief History of TCI

Recent artefacts found on the island of Grand Turk suggest that the early history of the TCI parallels that of the Bahamas (Baker, 2001). During the colonial era, ownership of the islands alternated between the Spanish, French, and the British, with power finally settling in favour of Britain. Up until the late 1600s, TCI was largely uninhabited because the islands provided little in terms of natural resources or protected anchorage for the ships of that era, and the islands were located upwind of the main shipping lanes (Baker, 2001). In 1678, a group of Bermudians settled on the islands and began to extract salt from salinas (large shallow water flats used to dry out sea water) that they constructed over much of the larger islands. Remnants of these salinas can still be found on South Caicos and Grand Turk (Figure 4.3), with a fully intact and functional salina located on Salt Cay. Efforts were under way in 2001 to establish this as an historic site (Clerveaux, 2002).

Figure 4.3: Remnants of a Salina on Grand Turk, TCI (Source: Kirsten Baillie)

The Bermudians lived in relative peace until a Spanish fleet captured the islands in 1710. For the next 40 years, TCI became a refuge for pirates, until the French removed them in 1753. After the American Revolution, colonial loyalists brought slaves and settled along side the Bermudians. The Colonialists set up a cotton trade that prospered until 1820, at which time they moved on leaving their slaves behind. Whaling took a brief spotlight in the mid 19^{th} century working from a base in the Ambergris Cays, which lie adjacent to the Turks Island Passage, a 7000 ft deep channel that not only separates the two island groups of TCI but also serves as a yearly migratory route for the North Atlantic Humpback Whale (*Megaptera novaeangliae*) (Baker, 2001)

From 1848 to 1872, the islands were under the supervision of Jamaica. During the early 1940s, the US military brought short-lived prosperity to both South Caicos and Grand Turk by constructing a missile tracking site on South Caicos and a submarine tracking site on Grand Turk in addition to auxiliary naval and air bases on Grand Turk. All of these facilities have since been abandoned. Remnants of the airbase is now used by the TCI Government as the local airport in addition to housing Government departments such as the Department of Environment and Coastal Resources, the Planning and Valuation Departments, and the Lands and Survey Department (Morgan, 2001; Baker 2000).

In 1962, the islands became the focus of international attention as American astronaut John Glenn splashed down off the shore of Grand Turk. During that same year, a number of millionaires leased land on Providenciales in the Chalk Sound area where they built a runway and deep-water anchorage in which to moor their yachts. In 1973, TCI became an overseas dependent territory (Crown Colony) of the United Kingdom of Great Britain.

4.1.2 TCI's Economy

Until the 1950s, the prime revenues were collected through salt and cotton exports. Today, TCI relies heavily on the tourism, financial, and fishing industries to support its economy. Tourism is a booming industry in TCI primarily due to the pristine white sand beaches (Figure 4.4), clear blue water, and thriving coral reef environments. TCI is considered to be one of the best places in the world to dive.

Figure 4.4: White sand beach on Providenciales (Source: Christopher Close)

Tourism generates large revenues in the form of a mandatory Government departure tax collected when visitors leave the island on commercial flights. Providenciales manages the bulk of the tourism trade with American Airlines flying three flights daily into Providenciales, Air Canada and British Airways weekly, and local airlines flying upwards of a dozen flights a day between the islands (TCI Investment Agency, 2003). With the construction of a new 250 room high-end resort on the north end of South Caicos that is currently underway and an airstrip that was recently modified to accommodate commercial airliners, South Caicos is set to emerge in TCI's tourism market (Clerveaux, 2002; Vaughan, 2002).

Financial investment is also a prime source of revenue for the islands due to TCI's tax-free status. The government offers financial services such as banking, offshore insurance and company formation (Baker, 2001). Finally, TCI's most significant exports come from the commercial fishing industry in the form of Lobster, Conch, and Finfish meat. The fishery sector peaked in 1990 accounting for 5.1% of TCI total GDP. This value slowly declined to 2.6% in 1998 due over-fishing and the availability of other more appealing employment opportunities (TCI Investment Agency, 2003). As of 2001, approximately 341 metric tonnes of Conch and Lobster are harvested for export each year (Baker, 2001). Beyond the exports, the harvesting of Conch and Lobster has been an important source of protein and income generation for the people of the TCI (Bennett et al, 2001).

4.1.3 Geographic Context

While the general research setting for this research is the Turks and Caicos Islands, only three of the eight inhabited islands in the group have significant artisanal fishing activities. Hence, these islands were the focus of LK data collection activities, namely Grand Turk, Providenciales, and South Caicos (Figure 4.5). Each of these islands represents a unique landscape and culture. In the summer of 2002, the approximate numbers of harvesters were fewer than 50 for Grand Turk, and 100 to 150 harvesters for each Providenciales and South Caicos. Typically, there are three harvesters per boat (a captain and two divers) with each boat powered by a 70-90 horsepower outboard engine.

Grand Turk is home to Cockburn Town, the capital of TCI. Approximately 3500 people reside on this small 2.5 x 10 km island (Baker, 2001). The population of the island is comprised largely of public servants, their dependents and associated government workers, with additional sizeable communities originating from Haiti and the Dominican Republic. The main industry in Grand Turk, other than government, is tourism with diving featuring prominently as the principal tourist activity. In terms of fisheries, Grand Turk has one local fish market, no fish processing plants and, at the time of data collection, the smallest population of artisanal harvesters of the three islands sampled (n=45 and of these 15 are captains) (Day, 2002).

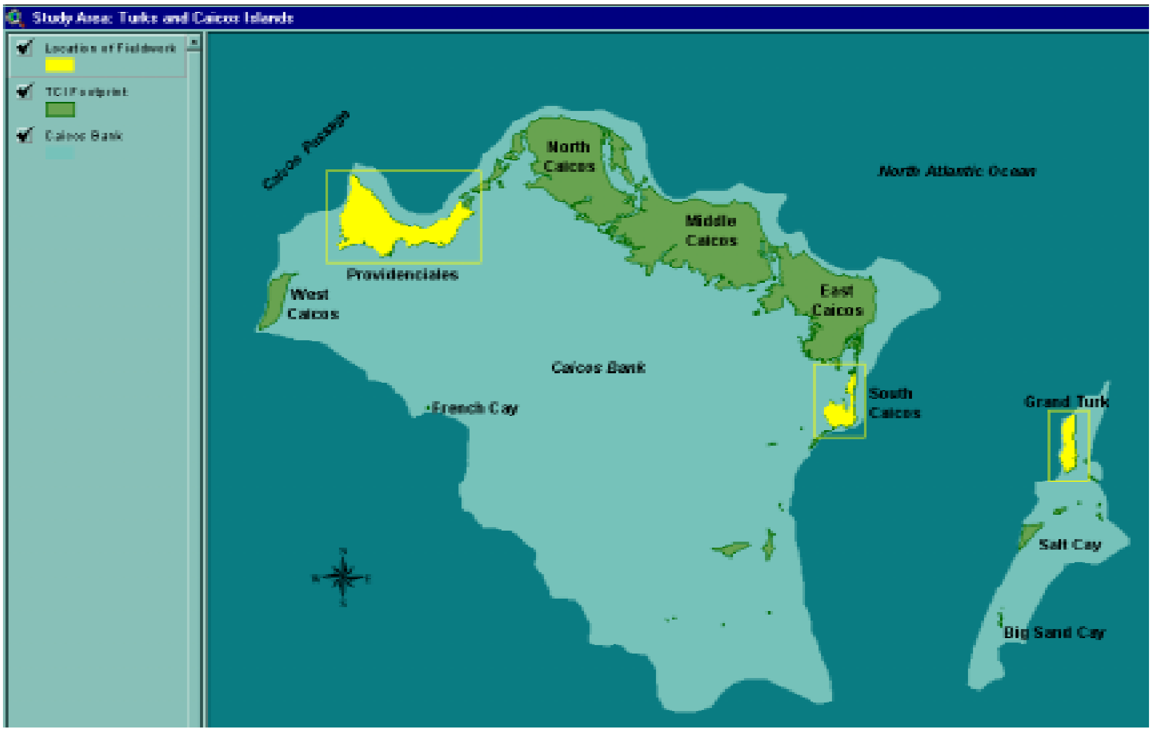


Figure 4.5: Location of the three Study Islands (Source: Christopher Close)

Providenciales is the largest of the three islands in area, population and degree of economic development. It is also the most developed island in the group with tourism and offshore banking being the main forms of economic activity. Providenciales houses the majority of the package hotels in TCI, located primarily along the 12.5 km stretch of Grace Bay on the north shore of the island. The population on Providenciales is approximately 12000 and the island supports three commercial fish processing plants for local consumption but primarily for export. The harvesters (n=150 at the time of the research) comprise of Haitians, Dominicans and “Belongers” (native Turks and Caicos Islanders), with the majority fishing as a secondary source of income. During the Lobster season, many harvesters from Providenciales travel to South Caicos for what is locally called the “big grab,” as the first two weeks of the Lobster season is the most profitable, bringing in 30% of the annual catch (Rudd, 2000; Bennett and Clerveaux, 2001; Bennett et al, 2001).

The third island, South Caicos, is considered the fishing capital of the country with the entire population living directly or indirectly off the revenues of fishing (Bennett et al, 2001; Clerveaux, 2002). The population on South Caicos is made up of a mix of Haitians and Belongers. The male to female ratio in South Caicos is very high (19:1) as the majority of the males stay and carry out the traditional trade of fishing while the females tend to relocate to Providenciales or Grand Turk for employment opportunities or to reside with other family members who have also relocated. The culture in South Caicos is very traditional with the males providing financially for the family, while the females perform domestic and child rearing responsibilities. The climate in South Caicos is desert-like as it is very hot with little wind or precipitation. The ground vegetation is mainly scrub brush. Roughly 150 harvesters participated in the fishing industry at the time of the research.

Figure 4.6 shows fishing boats docked in Cockburn Harbour, South Caicos. The shack in the left photo is where some of the fishers clean their catch, while the photo on the right shows the leftover Conch shells piled on the shore.

Figure 4.6: Fishing Boats in Cockburn Harbour (left) and Piles of Empty Conch Shells on the Shore in Cockburn Harbour (right) (Source: Christopher Close)

4.1.4 Fisheries Management in TCI

At the time of the research, the TCI Government's Department of Environmental and Coastal Research (DECR) under the jurisdiction of the Ministry of Natural Resources, was generally responsible for the protection of the coastal, marine, and physical environments (SnapSHOT, Feb 2003). Examples of recent initiatives carried out by the DECR include coastal resource management projects, restructuring of the National Parks Environmental Advisory Committee, and workshops with beach vendors to help minimize their impact of the beach environment (SnapSHOT, Feb

2003). Specific fisheries responsibilities include the management and monitoring of fishery-related issues.

While the development of a fisheries management plan is of interest to the DECR, no such plan exists. However, the DECR does impose and attempt to enforce catch restrictions including seasonal catch restrictions, minimum length requirements per species caught, prohibition of harvesting egg bearing females, fish catch licensing and export quotas, equipment restrictions, and prohibition of SCUBA gear and use of chemicals in harvest activities (Rudd, in press). In addition to these restrictions, the TCI Government has established 33 Marine Protected Areas and Marine Parks where harvest activities are prohibited at all times.

The main DECR office is located on Grand Turk with offices on Providenciales and South Caicos. Also located on South Caicos is the School for Field Studies (SFS): The Centre for Marine Resource Studies. The SFS is one of six schools located worldwide that offer semestered programs for up to 30 students. The SFS has an ongoing partnership with the DECR in helping them to manage and develop the fisheries resource in the islands including the management of marine parks and reserves (SFS, 2003). Examples of SFS contributions include Lobster, Conch, and Finfish stock assessment levels, educating government officials concerning marine habitats and animals, and on-going development of a standardised protocol for the monitoring of coral reef health (SFS, 2003).

Other research carried out by SFS students included attempts to collect LK from marine fishery harvesters however these efforts have been met with little success to date (Rudd, 2001). In one case, harvesters were criticised because they were reporting to the students on fish caught under the required size limits. Since that time harvesters have been hesitant to talk to researchers for fear of reprimand or other repercussions (Rudd, 2001). Other fishery research conducted in the TCI includes the modelling of Conch and Bonefish movement and breeding patterns (Rudd, 2001; Rudd et al, in press, Danylchuk & Clark, 2001).

Despite having easy access to all the harvesters all the time, the amount of fisheries data that have been collected by the DECR is minimal. Instead, the DECR spends much of its time monitoring illegal fishing activity and little time doing research or collecting information that can be integrated into a management planning exercise such as what is proposed in this thesis. The data that are collected are often done so by outside researchers who take the data away from the islands, as resources there do not allow for on-site data analysis. The end result of this leaves little, if any data that can revert back into the development of a management plan.

4.1.5 Species Profile

The species that are caught commercially by the artisanal harvesters in TCI are Finfish, Spiny Lobster (*Panulirus argus*), and the Queen Conch (*Strombus gigas*), the latter two of which are the focus of this research. Hence, this section focuses on a general description of the Spiny Lobster and Queen Conch, followed by their preferred habitat, lifecycles, and daily movement patterns.

The Spiny Lobster is considered one of the largest members of the crustacean family, measuring in lengths up to 60 cm (Cobb & Phillips, 1980; Lipcius and Eggleston, 2000). The Spiny Lobster is found primarily in shallow, tropical waters of the Caribbean, the southeast coast of the Atlantic Ocean, and the Gulf of Mexico (Dive Sports Scuba, 2003; Lipcius and Eggleston, 2000). Unlike the more common American Lobster (*Homarus americanus*), the Spiny Lobster does not have front claws. Instead, this crustacean is equipped with sharp spines over most of its body in addition to two long antennae located at the front of their heads for protection (Figure 4.7) (Dive Sports Scuba, 2003; Cobb & Phillips, 1980). The preferred habitats of the Spiny Lobster are rocky crevices, coral heads, grass beds, and sand and mud bottoms. The Lobsters come out of their hiding places mainly at night to feed (Lipcius and Eggleston, 2000; Cobb & Phillips, 1980).

The lifecycle of the Spiny Lobster involves three main phases, larval, juvenile, and adult. Typically, female adults release larva in deeper water where the larva can be picked up and transported by ocean currents. During the post-larval phase, the Lobster settle into shallow water algae beds where they remain as juveniles. After approximately two years, the now adult Lobsters move into 10 to 25m of water where they remain until mating season or the seasonal migration begins (Cobb & Phillips, 1980; Lipcius and Eggleston, 2000). Recent studies by Kelly (2001) on tracking Spiny Lobster movement through radio telemetry, show that the Spiny Lobster moves, on average, between 29 to 1000 m per day in the adult stage.

Figure 4.7: Spiny Lobster (Source: Left image unknown; Right image John White)

In the TCI, the Spiny Lobster is harvested for its tail meat by artisanal fishers mainly for commercial sale to processing plants in the area. The open season for the Spiny Lobster in TCI is from August 1st to March 31st with 30% of the annual catch taken in the first two weeks of the season (Bennett and Clerveaux, 2001). Often part-time harvesters will only fish for the these early weeks in order to take advantage of what is locally referred to as the "big grab," as noted earlier in this chapter. Under the current fishing regulation ordinance in TCI, before Lobster can be harvested, they must have a carapace length of three inches or more as shown in Figure 4.8. This ensures that each Lobster spawns at least once. Additionally, any females carrying eggs must be released.

The second species of interest in this thesis is the Queen Conch. The Queen Conch is an endangered shelled gastropod that is protected under the Convention on International Trade in Endangered Species list (CITES) and is found in the tropical waters of the western Atlantic and the Caribbean (Caribbean Fisheries Management Council, 2003). The Queen Conch's habitat is primarily sandy or grassy bottoms with occasional occurrences on coral and gravel bottoms (Randall, 1964).

The lifecycle of the Queen Conch, like that of the Spiny Lobster, involves three main phases, larval, juvenile, and adult. Adult females lay gelatinous egg masses in the sand during the summer months. The eggs hatch as larva and remain in the water column for up to 40 days before settling into the substrate where the young juveniles bury themselves a few inches into the sand (Caribbean Fisheries Management Council, 2003). The gastropod is a slow grower reaching sexual maturity at approximately 3.5 years (Appeldoorn, 1988a). According to Hesse, (1979) adult Queen Conch move, on average, between 50 to 100 m/day.

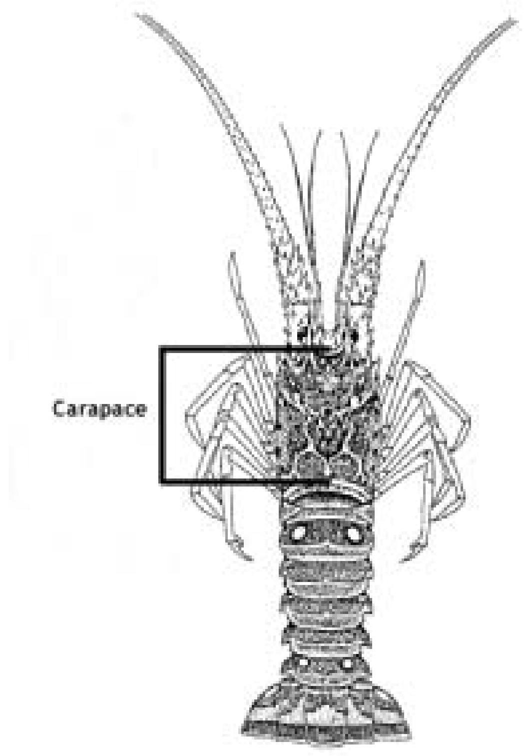


Figure 4.8: Illustration of a Spiny Lobster's Carapace Length (Source: http://marinefisheries.org/)

The Queen Conch is predominantly used for both its meat and shell, however, in the TCI only the meat is used with the shells discarded or sold to tourists for decorative purposes. Figure 4.9 illustrates an intact Queen Conch in the left image and unprocessed Conch meat in the right image. Even though the Queen Conch are endangered in many parts of the world, they are abundant in the Turks and Caicos Banks (Vaughan, 2002).

In the TCI, the Queen Conch has seasonal quota and size restrictions. Open season for the Conch is from October to mid July where a maximum limit of 600,000 lbs of processed Conch meat is collectively allowed for all the harvesters, per season (Vaughan, 2002). This is controlled through weigh-in stations at the processing plants located in Providenciales and South Caicos. At the time of the study, each island was allowed 300,000lbs of processed Conch meat each. Furthermore, a minimum shell length of seven inches or 17.8 cm is required before a specimen can be harvested, a length that is reached only after 2.5 years of age. Thus, unlike the Spiny Lobster, the Queen Conch may not spawn before being harvested.

Figure 4.9: Images of the Queen Conch. Left: Whole specimen; Right: Unprocessed Conch Meat

In TCI, the Spiny Lobster is considered a much more valuable resource as it is worth (to the harvesters), depending on the market, roughly $3.50 US dollars per pound including the carapace, whereas the Queen Conch is worth approximately $0.80 per pound of meat (Figure 4.9).

4.2 Data Collection

This section takes the general interview preparation component of the fisheries protocol detailed in Chapter 3 and operationalises it for the research undertaken in the TCI. The two data sources for this research include primary field data collected from harvesters in TCI and secondary data in the form of digital orthophotography and remotely sensed Landsat Thematic Mapper images of the study area. Each of these data sources is now described according to the general research protocol presented in Figure 3.5.

Since the general protocol is aimed at the management of small-scale fisheries in developing countries, the cost of computer software and hardware required for data analysis were a prime consideration in its development. Given this, the GIS software used for this research was ArcView 3.2. In addition to providing core GIS functionality, ArcView has a proprietary scripting language (Avenue), for automating tedious processes and building custom applications that permit novice users to navigate through complex applications with a simple graphical user interface.

4.2.1 Interview Preparation Component

As noted in the previous chapter, the interview preparation component of the research design included the steps required to produce questions and maps for use during field interviews. Thus, this section outlines the steps that were taken to obtain harvester data in accordance with the TCI case study detailed above, including collecting background information on harvesters, interview questions and base map design and, in accordance with the general protocol outlined in Chapter 3, the procedure used during the map-based harvester interviews.

4.2.1.1 Informant Assessment

Prior to undertaking the fieldwork in the TCI, background information was collected on the people and culture within the study area. This was achieved through Internet searching and the use of published and some unpublished references obtained from contacts from within the DECR in addition to other researchers that had previously completed fisheries and other research projects in the TCI. This information included, for example, establishing the approximate number of harvesters on each of the islands, previous issues that had arisen from LK work in the general area, what types of information that the harvesters were likely to provide, and general field conditions. In addition, the researcher was accompanied in the field by an anthropologist to assist with initial conversations with informants, to help with appropriate word usage, and to help with general informant interaction techniques.

Due to financial constraints, it was impossible to visit TCI prior to undertaking the field interviews. In addition, the questions and primary data collection methodology to be used in this research had to pass formal ethical evaluation and approval at the University of Waterloo. Thus, a surfeit of questions were purposefully devised and tabled with the intention, consistent with points made in Chapter 3, of providing as much flexibility as possible while in the field. Furthermore, questions were constructed using simple language and grammar and as few technical terms as possible in order to be comprehensible to informants with varying education levels.

4.2.1.2 Interview Design

The minimum requirements to achieve the thesis objectives include a spatial data component and an attribute data component. The spatial data are composed of graphical entities that can be recorded in a GIS, while the attribute data contains associated information that pertains to each entity. The identification and location of harvest areas satisfies the spatial data component, while the information pertaining to the characteristics of each harvest area, such as depth and species caught, satisfies the attribute component. The initial list of 31 pre-fieldwork interview questions designed to obtain these data is provided in Appendix A, Table 1.

The original goal of the interview component was to extract LK that would help formulate a 2-dimensional picture of the fishery including locations of Lobster and Conch, bottom-types at each harvest location, and general marine and weather conditions. In this context, the questions were broken down into four main sections. The first section of questions was designed to be easy to answer, to allow the harvester and interviewer to settle into the interview dialogue, and to gather base data about the fishery. Examples of information requested in this section included number of years the harvester had fished for, which species generates more income (Lobster or Conch), and how many times a week did the harvester go fishing (at the time the research took place).

The second section of the questionnaire involved general questions of the fishery and comprised the bulk of the data gathering questions. Unlike the questions discussed above, many of them in the second section included explicit or implicit spatial elements, such as where on the map the harvester would typically catch Lobster and Conch and in what quantities. This section also included questions that were devised to extract information on harvester decision processes (objective 4 of this thesis). More specific data requested on harvest sites included:

- Locations of catch from the previous year

- ∉# Locations of catch for the current year
- ∉# Information on revisited sites
- ∉# Numbers (or weight) of fish caught at each location, and
- ∉# General conditions at each harvest site (for example, weather conditions, depth, bottom-type, and tidal affects).
- ∉# Do you ever fish for both Lobster and Conch during the same trip?

The final two sections involved data that were specific to Lobster and Conch respectively. Examples of data asked in this section included the location of the different age ranges and sex of Lobster and Conch (for example, juvenile, adult, and egg bearing females) in addition to the depth of water, bottom-type and vegetation type at each location. If age-specific sites could be identified, then these areas could be managed more effectively. For example, if the majority of young Lobsters congregated in a certain area, then this could potentially be marked as a marine park or a longer closed season could be imposed there. For the most part, these questions were structured as closed-ended questions.

The 31 questions listed in Appendix A, Table 1, were initially field tested on a sub-sample of harvesters in Grand Turk. After this test, it was clear that, even with its limited scope, the initial questionnaire design and content was too complex and had to be simplified. A subset of 10 questions, listed in Table 4.1, was the result. Furthermore, the interview approach was modified such that the interview process became open-ended and free dialogue-oriented with the interviewer taking notes. The reasons for this rather substantial change in strategy and in content were:

1) Generally, the initial question sequence was too long to retain interest and attention of informants,
2) Some of the questions were repetitive and provided minimal response from informants,
3) Harvesters could not remember (or would not divulge) information on previous years catches, and
4) Harvesters did not understand what was being asked even after numerous attempts at rephrasing the question.

The revised questions still satisfied the minimum requirement of a GIS database noted above, but were much more streamlined. The revised list of 10 questions was broken down into two parts, namely verbal questions (1 to 8 and 10) and map-based questions (9). The verbal portion of the interview involved general questions about the fishery (for example, what type of bottom do you find Conch on, and what do you primarily fish for), while question 9 was devised to extract information on harvest locations for input as spatial data in the GIS. The specific answers to these questions and how they were structured in the GIS database are discussed in Section 4.3. Question 10 was optional, asked only if the informant seemed comfortable and willing to answer more questions.

Revised Interview Questions

1. How many years have you been fishing for?
2. What do you primarily fish for? Lobster/Conch/Both?
3. If you fish for both, which one do you make more money from?
4. How many days a week on average would you go out fishing? In good weather? Bad?
5. What type of bottom do you normally find Lobster? Conch?
6. What do you use to catch Lobster? Conch?
7. What is an average good day of fishing for you in terms of lbs caught for Lobster/Conch?
8. In the last ten years, has the fishing gotten better/worse/same for Lobster? Conch? Why?
9. (Pointing to the map) Each day you went out, where would you catch Lobster/Conch? Depth there? Bottom-type?
10. How do you feel the Lobster and Conch fishery could best be managed?

Table 4.1: Revised Interview Questions

A total of 38 interviews were conducted largely with the captains of each boat, seven on Grand Turk (including the test interviews), seven on Providenciales, and 24 on South Caicos. Of these 38, 15 individuals drew both polygon and linear harvest areas. The others provided either polygon or linear feature types, but not both.

4.2.1.3 Base Map Design

Since no prior exploratory fieldwork was conducted, little was known in terms of what kind of experience the harvesters had with using topographic or other maps. For this reason, four sets of map designs were taken to the field. These included standard hard copy topographic maps of the area produced by the Ordnance Survey of the United Kingdom from aerial photography (at scales of

1:10000 and 1:25000), index maps designed specifically for this research and generated from secondary GIS and remotely sensed imagery, tiled smaller scale maps (individual map sheets generated from the GIS-based index maps), and tourist maps produced by the TCI Government showing each of the main islands and key sites of interest. The Ordnance Survey topographic maps proved to be problematic with informants during pre-testing as they violated many of the issues noted in Chapter 3, such as not enough water extent shown to include fishing locations, little to no visible bottom depth or structure, and generalization of relevant features at the scales of mapping. Despite these problems, however, these maps were still useful as a general orientation and locational reference.

The data sources used for the construction of the vector-based index maps were a 1986 Landsat Thematic Mapper 30 metre resolution image of TCI and a set of 27cm resolution digital orthophotographs flown in 2000 that included most of the islands and cays in TCI (while a more recent Landsat image of TCI was available - 1999, cloud cover obstructed much of the Caicos Bank thus it was not used). As noted in Chapter 3, the coarse resolution of the Landsat image removed many of the small (< $30m^2$) cays and significant shoreline features due to generalization. Thus, the 27cm resolution orthophotographs were used to trace island footprints for the islands around South Caicos and Grand Turk using heads-up digitizing in ArcView GIS. Figure 4.10 illustrates the difference in resolution between the Landsat image and the orthophotos. The images are of Fish Cay, located approximately 15km SSW of South Caicos. The image on the left is the 30m resolution Landsat Thematic Mapper image while the image on the right has a superimposed 27cm resolution orthophotograph overtop of the Landsat image of the same area.

Initially, fieldwork was planned to be conducted on South Caicos and Grand Turk only, thus a Providenciales coastline map was not prepared prior to the fieldwork. Because the orthoimagery was not accessible in the field, the index maps were used for the Providenciales interviews. The intent was to re-digitize the Providenciales footprint, like those of Grand Turk and South Caicos upon returning from the field, however, after the interviews were completed on Providenciales, it was clear that the harvesters did not fish near Providenciales shoreline (where detail of the island would have been required), but rather fished farther out on the Bank, typically in the area of French

Cay (approximately 28 km south of Providenciales) or West Caicos (roughly 21 km southwest of Providenciales). Thus, no re-digitizing was done. Instead, a previous Providenciales footprint was taken from a vector data layer that had been constructed from the 1986 Landsat Thematic Mapper Image using heads-up digitizing.

Re-digitizing the outlines of the islands was a tedious, but necessary process in order to generate hard copy outlines of the islands within a consistent referential framework comprising the individual index maps. Furthermore, since the majority of the harvest activities occur on the Turks and Caicos Banks, a consistent representation of the spatial extent of the Turks and Caicos Banks was required. Even though the resolution was poor in comparison to the orthophotos, the Landsat image represented a continuous view of the entire Caicos Bank, thus it was used to trace the general spatial extent of the Bank (see Figure 4.11). With respect to the Turks Bank, the tourist map was used as a reference since the spatial extent of the 1986 Landsat image does not include this Bank.

Figure 4.10: Resolution difference between the Landsat TM image (left) and Digital Orthophotograph (right) Fish Cay

The index map sheets and the individual map tiles were prepared in accordance with the map design protocols discussed in Chapter 3. ArcView GIS and the auto-tile extension (available at http://www.esri.com) was used to construct the index maps and corresponding map tiles using the TCI and Turks and Caicos Bank vector data layer. The auto-tile extension provided a breakdown of indexed, spatially consistent and printable tiles to use as a separate hard copy (and digital) base map source for use during harvester interviews. Initially, it was thought that only the tiles that were located immediately adjacent to the islands and cays of interest would be required. However, the individual map tiles did not work as expected in the field and were abandoned in favour of the indexed map sheet shown in Figure 4.11.

In addition to being used for the interviews, the index map sheets solved the problem of the potential "unreferenced areas" noted in the Chapter 3 by covering the study area in a consistent tiled grid, as illustrated in Figure 4.11. The intent of the grid was to allow a measurable and spatially consistent reference that could be used to record where, in relation to the Turks and Caicos Banks, harvesters focused their harvest activities.

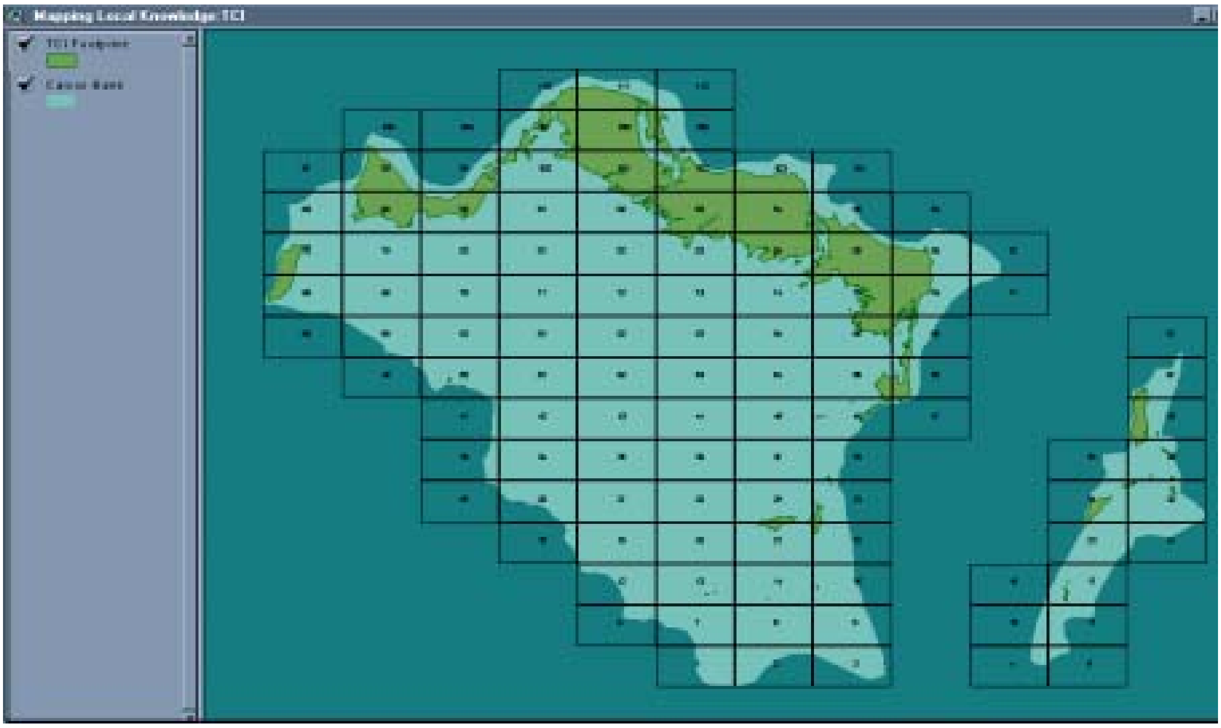


Figure 4.11: Representation of the Index Map and Grid for the Base Maps

Additionally, a few tourist maps were taken into the field as an alternate and backup method if the previous map designs failed. The TCI tourist maps have all of the islands and cays in the country shown, as well as both the Turks and Caicos Banks, and thus could be used to record fishing areas on all parts of the Banks.

4.2.2 Map-based Interviews

As mentioned above, the fieldwork was divided between the three main islands in the country. Since the majority of the government agencies, including the DECR are located on Grand Turk, the fieldwork began there. Initially, the second and third week of the research was planned to be located on South Caicos. However, upon request of the DECR during the first week of the fieldwork, the main island of Providenciales was added to the list of islands to be studied. Furthermore, although a two-week field period was planned for interviews on South Caicos, only four days were required to complete the interviews. Thus, the order of fieldwork locations was: 1st week Grand Turk, 2nd week Providenciales, and the 3rd week in South Caicos.

Contacts were set up a year in advance to the actual fieldwork, thus support for the research from the DECR was very strong. Due to the above noted issues that arose from previous LK research in the area, the DECR officers accompanied the researchers on the majority of the interviews on Grand Turk and South Caicos. Because of distance and time limitations on Providenciales, all harvester interviews were completed without the presence of staff from the DECR.

As discussed in Chapter 3 - Section 3.2.2.4, each of the methods described by Chambers (1994; pg 959-961), namely secondary sources, semi-structured interviews, key informants, participatory mapping and modelling, and presentation and analysis were employed in the research. Secondary sources of study area imagery were used as noted above and semi-structured interviews were employed in the field as officers from the DECR pointed out both key and regular informants. Additionally, four of the five solutions for extracting LK as discussed in Chapter 2 section 2.4.3 were employed. These included innovative methodologies, iterative objectives, informal interviews and interactive research teams.

As noted above, interviews were broken up into two parts, namely verbal and map-based. During the verbal portion of the interview the researchers (author plus anthropologist) would often chat with the informant in an attempt to relax the informant. The interview questions were either asked as part of the dialogue of the conversation or as direct questions. Once the verbal questions were complete, the paper map was introduced and the questions switched to finding out where on the map the informant fished, species caught, bottom-type, and depth of water at each harvest location. In addition to the answers to these questions, some informants provided additional information on the fishery. This information was stored as extra LK and made accessible through ArcView as outlined at the end of the GIS section below.

The next section discusses how the answers from the revised interview questions were input into the GIS and the specific analysis methods that were used to aggregate the extracted data into meaningful maps. The results are discussed in Chapter 5.

4.3 Analysis Methods

This section focuses on the latter three components of the fisheries protocol detailed in Chapter 3, namely the GIS component, RS component, and data comparison component. The GIS component took the data layers described above and applied the protocol from Chapter 3 to construct LK classifications that detail the Conch and Lobster fisheries on the Turks and Caicos Banks. Second, the RS component outlines a supervised and an unsupervised classification of bottom-types derived from LK and SK input respectively. Finally, the data comparison component uses a bottom-type classification constructed from LK in the GIS component and compares it against the unsupervised bottom-type classification constructed through the use of RS technology. Since the RS and data comparison sections of the protocol are largely for scientific comparison purposes, this section focuses more on the GIS component.

4.3.1 GIS Component

The GIS component of the research protocol took the data collected during the informant interviews and transformed them, using the conceptual model presented in Chapter 2 as a guiding framework, into meaningful outputs that feed into fisheries management/planning. The aquatic environment and harvest activity classifications compiled from the research include bottom-type classification (BTC), species location classification (SLC), and visitation frequency classification. While the general procedural protocols were explained in Chapter 3, the specific methods used to construct the LK database in addition to the above surfaces for the case study of TCI, are now described.

4.3.1.1 GIS Database

The main objective of this research is to devise a framework for the input of LK into a GIS database. This section focuses specifically on operationalising the framework presented in Chapter 2 using the primary data collected from the interview questions described above. The section first discusses the organisation of these data for their input into the LK database, the specific structure of the LK database within the GIS and the input of these data into the GIS. Through this discussion, the first two objectives of the thesis are satisfied, namely the incorporation of LK into fisheries management using basic GIS functionality, and the feasibility of building an updatable LK database for future resource management planning.

The first step in the GIS process is the organisation of the data for their use within the GIS database framework. The results from the interview questions were organised into two main groups of attribute and spatial data, namely Harvest Area Data and Harvester Information Data (summarized in Tables 4.2 and 4.3). The Harvester Area dataset contains the map portion of the interviews or the specific spatial and attribute information on harvest areas, while the Harvester Information dataset contains attribute data from the verbal portion of the interviews including general information on the harvester and the fishery.

The Harvester Area dataset is further broken down into two parts, namely the graphical shapes of the harvest areas (lines and polygons to be input in the GIS) and the attributes of those shapes (species, depth, and bottom-type at each harvest area) referred to as Harv_Area1 and Harv_Area2 respectively in the database. A Harvester Area Identification Number or HAID links these data tables together in the GIS, and the Harvester Area dataset and Harvester Information dataset are linked by a Harvester ID field (Harvester_ID in the database). Responses to question 10 and any additional information provided to the researcher outside of the interview questions were stored in documentation files (referred to as Extra_LK in the relational diagram). The specific process to access these Extra_LK files within the GIS is described at the end of this section. Furthermore, these relationships are illustrated in the entity relationship diagram shown in Figure 4.12.

Attribute	Description	Question Ref
Shape	Harvest Area in ArcView (Line or Polygon)	9
HAID	Harvest Area Identification Number	n/a
Harvester_ID	Harvester Identification Number i.e.SC05	n/a
Harvester_ID.txt	Hot Link Field to open Extra_LK text files	n/a
Species I	Species caught at each Harvest Area	9
Map Type	Map used to conduct the interview (Topo, Index, Tiled, Tourist)	n/a
Depth	Depth at each Harvest Area	9
Bottom	Bottom-type at each Harvest Area	9

Table 4.2: Harvest Area Data including Interview Question Reference

Attribute	Description	Question Ref
Harvester_ID	Harvester Identification number i.e. SC05	n/a
Yrs Fishing	The number of years the harvester has been fishing for	1
Species II	Species most often caught by each harvester	2
Most $	Which species brings in the most money for each harvester	3
D/wk Good	Number of days/week the harvester would fish in good weather	4
D/wk Bad	Number of days/week the harvester would fish in bad weather	4
C Method	Tool used to capture the Conch	6
L Method	Tool used to capture the Lobster	6
C Bottom	Bottom-type that the harvester most often finds Conch	5
L Bottom	Bottom-type that the harvester most often finds Lobster	5
C Last 10 yrs	Degree Conch fishing has changed in the last 10 years	8
L Last 10 yrs	Degree Lobster fishing has changed in the last 10 years	8
~ C Good Day	Ave_lbs of Conch caught on a good day (Meat only)	7
~ L Good Day	Ave_lbs of Lobster caught on a good day (Whole Lobster)	7

Table 4.3: Harvester Information including Interview Question Reference

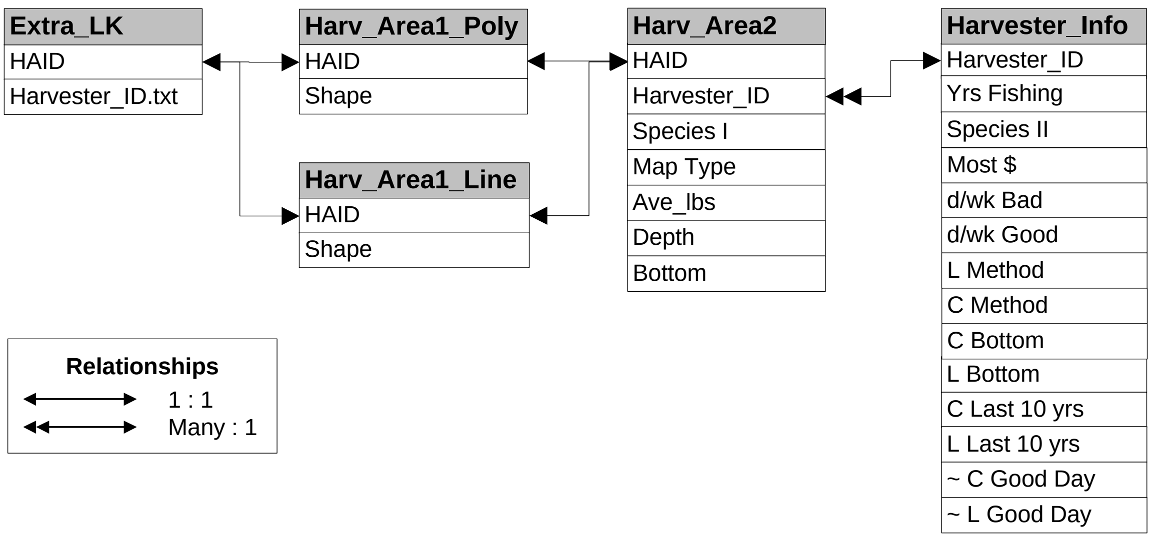


Figure 4.12: Relational Diagram for the LK Database

The purpose of Figure 4.12 is to list the tabular data within the database and the linkages between each table. The types of relationships that can be used are one to one, many to one, and many to many. For the purposes of this research, only the first two are relevant. Thus, in the context of ArcView, each record within a database table represents the attribute data that corresponds to one shape or graphical entity in the database. This type of relationship is referred to as a one to one relationship and is linked together based on a unique alphanumeric combination. As noted above, Harv_Area1 and Harv_Area2 from Figure 4.12 are linked based on a common field called HAID. Thus, one shape in Harv_Area1 equals one record of attribute information in Harv_Area2. In a many to one relationship, one or more records in one table can be associated with a single record in another table. Since one harvester can have multiple harvest areas (shapes) in the Harv_Area2 table, but only record of information in the Harvest_Info table, the relationship between these two tables is many to one.

In terms of data entry, each harvester's areas were input from the hardcopy maps as ArcView GIS shapefiles using heads-up digitizing as described in Chapter 3. Each harvest area received a unique three-digit HAID number within ArcView under the Harv_Area1 attribute table. This HAID number was also recorded on the corresponding shape on the hardcopy map for entry into the Harv_Area2 database table. Additionally, it was noted in Chapter 3 that point, line and polygon feature types could potentially be collected. However, in the case of TCI only lines and polygons were required, as harvesters did not use points to represent any of their harvest locations. In this context, Harv_Area1 was partitioned, if applicable (not all harvesters provided both polygon and linear harvest areas), into two groups of shapefiles for each harvester, namely polygons and lines (referred to as Harv_Area1_Line and Harv_Area1_Poly as shown in Figure 4.12). This was a necessary step since the feature types represent two different forms of harvest areas. Linear fishing areas were typically characterized as adjacent to an island, where the harvester would start fishing from one end of the island and work their way to the other end in a linear fashion, while polygon areas represented a more generalized area of harvest activity. Moreover, the analysis sequence for each feature type is different as discussed in Chapter 3 and reviewed in the next section. Figure 4.13

illustrates the raw (unanalysed) harvest areas (both line and polygon) within the GIS framework as indicated by the harvesters.

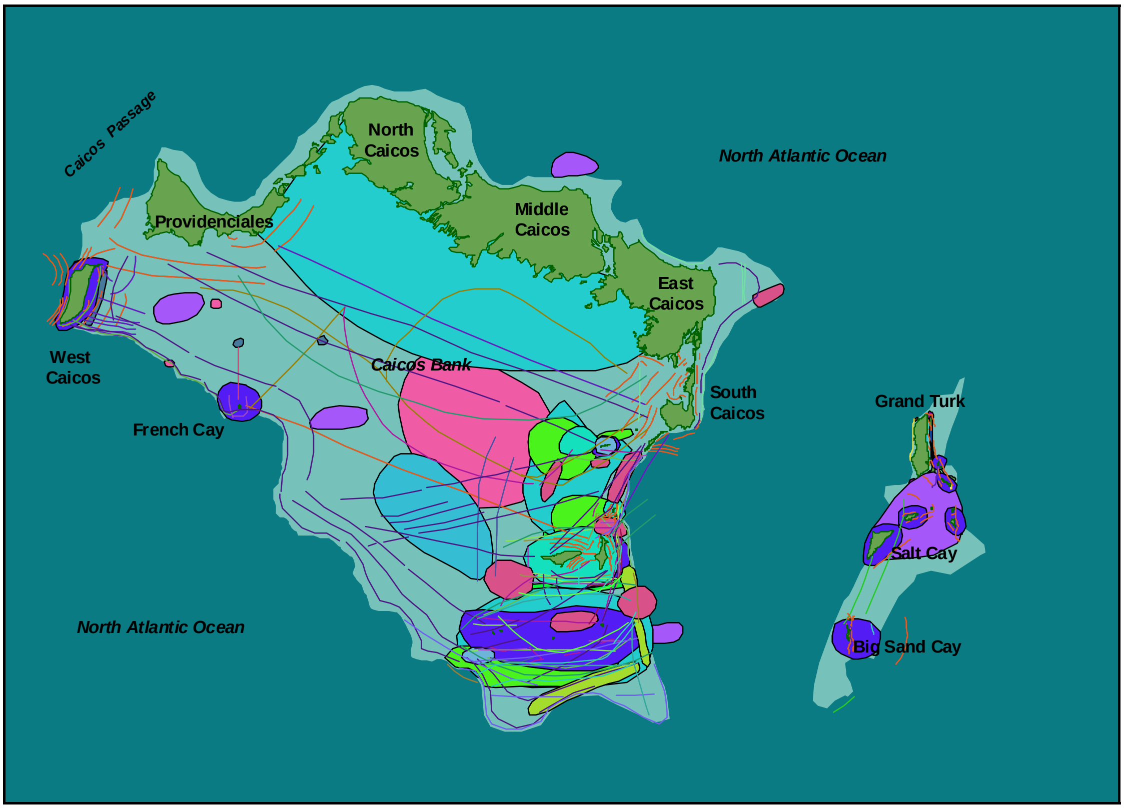


Figure 4.13: Illustration of Raw Harvester Fishing Locations

In terms of attribute entry, ArcView's abilities to input and manipulate tabular data can be cumbersome, thus the attribute data for Harv_Area2 and Harvester_Info were recorded using Microsoft Access. The functionality of Access allows for easy input of data though customized forms, as well as, direct database access through ArcView GIS. Figure 4.14 illustrates a form designed specifically for the TCI case study for the input and update of data into the Harvester_Info database table. The combined functionality of Access and ArcView GIS has the potential to satisfy the second objective of this thesis, namely the feasibility of building an updatable LK database. This is explored in more detail in Chapter 5.

As noted above, in order to maintain the relational linkages between the Harv_Area1 attribute table from ArcView and the external Harv_Area2 database table from Access, the HAID number was used. Similarly, to maintain the relational linkages between Harv_Area2 and Harvester_Info, a Harvester_ID field was used (Figure 4.12). To populate the Harvester_ID field, each harvester was given a unique alphanumeric combination. This was achieved by separating the harvesters by the island they were interviewed on, namely Providenciales, Grand Turk and South Caicos followed by a two-digit number representing the actual individual harvester interviewed (no names of harvesters were recorded in order to maintain harvester confidentiality). Within the database, the corresponding codes given for these islands are PR, GT, and SC respectively. Thus, a Harvester_ID of SC18 equates to harvester number 18 from South Caicos.

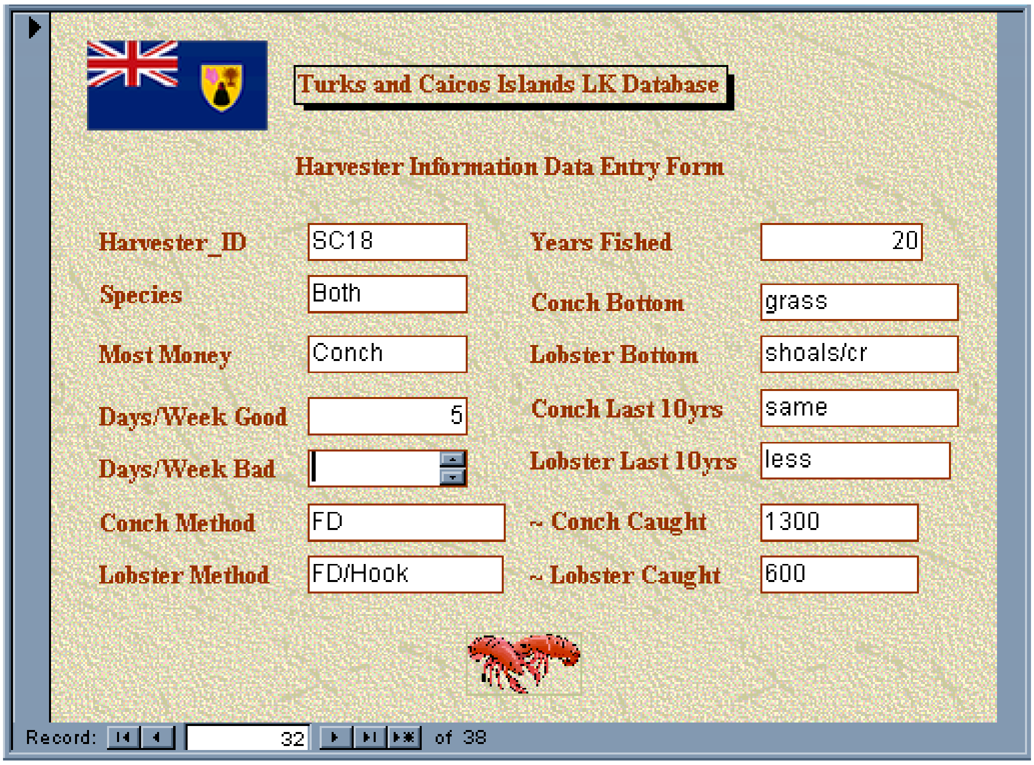


Figure 4.14: Sample Form for Harvester Information Data Input

The combined primary and secondary data sources described in this and previous sections form the basis for the LK GIS database framework presented in Figure 3.10. These specific data sources were organised into eight GIS map layers as summarized in Table 4.4 and were used for the construction and visualization of classification surfaces in the next section.

Data Description	Feature Type
TCI Island outlines	Polygon
Turks and Caicos Bank Area	Polygon
Fishing Ports	Point
Harv_Area2	External Database
Harvester_Info	External Database
Extra_LK	Text
Harv_Area1_Poly	Polygon
Harv_Area1_Line	Line

Table 4.4: Description of data inputs for LK GIS Database

4.3.1.2 GIS Classification Surfaces

The purpose of the classification surfaces described in Chapter 3 (Section 3.2.3.3) is to take the raw data shown in Figure 4.13, in addition to Tables 4.2 and 4.3, and convert them into a more meaningful form that fisheries managers and planners can use for fisheries management planning. To achieve this, the classification protocols described in Chapter 3 were applied, using the data layers described in the previous section, to construct the 10 classifications summarized in Table 4.5. Aggregated classifications of Conch and Lobster were not examined in this research, as outlined in Chapter 3, because harvesters in TCI did not fish for both species in the same trip (objective 4). Furthermore, classifications discussed below that represent the number of harvesters that fish in the study area on average, per day, are only applicable during the open season fishing dates for each species.

The analysis sequence of the classifications outlined in Table 4.5 is broken down into two sections. The first section is comprised of eight classifications that analyze species location data for the construction of the species location classifications, visitation frequency classifications, and subsequent high-pressure zone classifications. The second section consists of two classifications that focus specifically on bottom-type data; one based on specific bottom-type locations as outlined by each harvester (e.g. BTC_Map) and one based on bottom-type information given during the verbal portion of the interview (e.g. BTC_Verbal). Regarding classification construction, only the primary data layers of Harv_Area1_Poly, Harv_Area1_Line, Harv_Area2, and Harvester_Info from Table 4.4 were used. The remaining secondary data layers were used for visualization purposes only.

#	Classification	Description	Theme of Map	Feature Type
1	SLC_CL_P	Species Location Classification	Conch&Lobster	Polygon
2	VFC_C_P	Visitation Frequency Classification	Conch	Polygon
3	VFC_L_P	Visitation Frequency Classification	Lobster	Polygon
4	SLC_CL_L	Species Location Classification	Conch&Lobster	Line
5	VFC_C_L	Visitation Frequency Classification	Conch	Line
6	VFC_L_L	Visitation Frequency Classification	Lobster	Line
7	HPZ_C	High Pressure Zone Classification	Conch	Line
8	HPZ_L	High Pressure Zone Classification	Lobster	Line
9	BTC_Map	Bottom-type Classification	Bottom-types	Line/Polygon
10	BTC_Verbal	Bottom-type Classification	Bottom-types	Line/Polygon

Table 4.5: Description of the Data Layers Constructed using Data Collected from Local Harvesters

For the construction of the polygon harvest area visitation frequency classifications (2_FC_C_P, and 3_VFC_L_P from Table 4.5) and the species location classification (1_SLC_CL_P), the Harv_Area1_Poly shapefiles and the Harv_Area2 database were used. Figure 4.15 illustrates the analysis sequence for the species-based classifications. For both classifications, the Harv_Area2 database was joined to the attribute tables from the Harv_Area1_Poly shapefiles using the common field HAID. The purpose of this join was to reunite the species information for each shape (harvest area) in each Harv_Area1_Poly shapefile (one shapefile equals one harvesters knowledge).

It should be noted that in terms of locations of species harvested, there were instances where harvesters would point to areas where they had seen young Lobster or Conch that were not of legal harvest size. For the visitation frequency surfaces, these areas were removed from the attribute tables leaving only market-sized Conch and Lobster in the final visitation frequency classifications. These areas could be included in the species location classification, but would need to be classified as a separate data layer in order to allow for distinction in instances where areas of young Lobster or Conch coincided with areas of market sized Lobster and Conch. Similarly, occasionally a harvester would indicate areas where large Lobster could be found. These areas were not illustrated in any of the maps in this thesis due to confidentiality issues noted in Chapter 2. These areas, however, would be available for fisheries managers for further research as these are the areas that may exhibit environmental characteristics that support the growth of adult Lobsters.

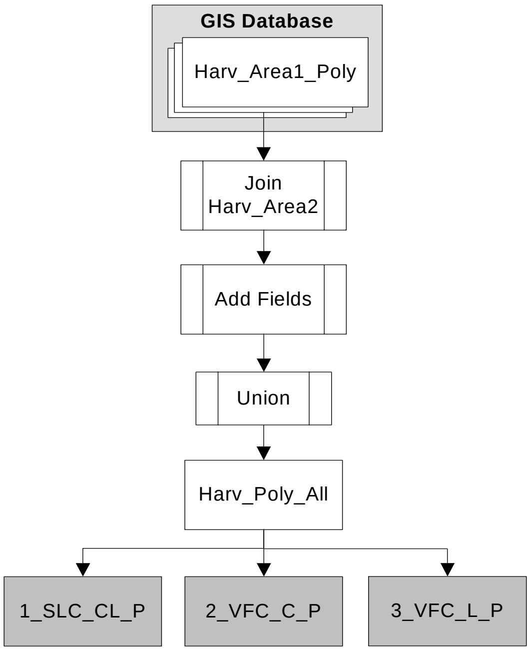


Figure 4.15: Process Flow for Specie-based Polygon Classifications

For the construction of the visitation frequency classification, two new fields were added (Conch_Presence and Lobster_Presence) to the Harv_Area1_Poly attribute tables for the purpose of using a binary code to signify species presence in each record or harvest area. A value of "1" (true) or "0" (false) was recorded in the associated record depending on species presence for both Conch and Lobster. Once completed, all the Harv_Area1_Poly shapefiles were unioned into one layer (Harv_Poly_All-species dependent) as described in Chapter 3, and the Conch and Lobster fields were summed. The result of this process yields a cumulative classification illustrating the number of harvesters that fish in any one area, on average, per species, per day.

For the species location classification, a "code" field was added to the Harv_Poly_All attribute table to signify which species type(s) were harvested from each record (harvest area). The "code" field was calculated based on the following expressions:

If "Conch_Presence" > 0 AND "Lobster_Presence" = 0 then "Code" = 1

If "Conch_Presence" = 0 AND "Lobster_Presence" > 0 then "Code" = 2

If "Conch_Presence" > 0 AND "Lobster_Presence" > 0 then "Code" = 3

where "1" equals areas where only Conch are harvested, "2" equals areas where only Lobster are harvested, and "3" equals areas where both Conch and Lobster are harvested. The resulting map illustrates where on the Banks Conch and Lobster are typically harvested on any given day.

The Harv_Area1_Line data layers and Harv_Area2 were used to prepare the visitation frequency and species location classifications for the linear features (4_SLC_CL_L, 5_VFC_C_L, and 6_VFC_L_L in Figure 4.16). Two methods were used for these features, respectfully to adjust for map bias and boat drift, namely the single buffer and the multi-buffer approach, as outlined in Chapter 3. Prior to the use of these methods, the Harv_Area1_line shapefiles were broken down into two groups, one for harvestable Conch (Conch_Line) and one for harvestable Lobster (Lobster_Line). This was done to ensure that only the harvestable species were being analyzed as well as simplifying the process by dealing with one species at a time. Thus, the linear harvest layer features (for Conch and Lobster respectively) were buffered as described in the single and multi-buffer methods discussed in Chapter 3.

In order to alleviate the problem of map bias (difficulties in reading maps, dealing with different map scales etc), a distance of 50m was used to buffer the lines for the single ringed buffer method. This distance was chosen because the study area exhibits generally calm weather, has relatively shallow bottom depths, and the fishing boats used are 12 to 15ft in length. Thus, a total buffer distance of 100 m would represent a realistic harvest area given these characteristics and allowing for boat drift, map bias, and species movement. For the multi-ringed buffer, the same 50 m distance was used in tandem with seven progressive buffers. Seven buffers were used in an attempt to represent better the effects of map bias and boat drift by constructing a non-statistical likelihood distribution around the lines identified by informants.

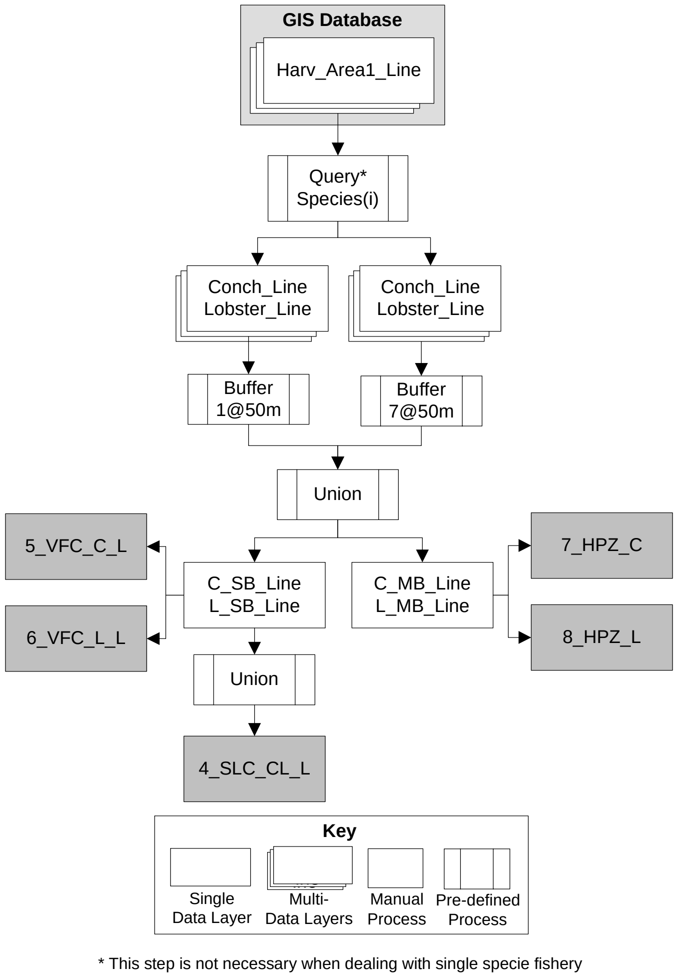


Figure 4.16: Process Flow for Specie-based Line Classifications

During the buffering process, attributes from the original unbuffered attribute table can be dropped unless otherwise specified. Because the harvest areas are already separated by species, and to quicken processing time, only the HAID attribute was carried over from the Conch and Lobster attribute tables to the new buffered attribute tables. The HAID was carried over because it can uniquely identify harvesters (by island and interview number) and their harvest locations after the final classifications are constructed. Even though the names of the harvesters were not recorded, the Harveter_ID illustrates what island the harvest originated from and the numbers of harvesters fishing in each area. Furthermore, the HAID values were also used to identify and display any applicable corresponding Extra_LK text files.

After the completion of the single buffer process, one new field was added to the buffered attribute tables, called "Presence_S(i)" where S(i) equals species type. Like the polygon analysis described above, the purpose of this field was to identify which records had fish presence. Since Conch_Line and Lobster_Line are already composed only of records where each of the species was caught, a value of "1" was coded in to all the records within the single buffer attribute tables. Once complete, each of the groups of Conch_Line and Lobster_Line shapefiles were unioned into one data layer (referred to in Figure 4.16 as C_SB_Line and L_SB_Line) for single buffer Conch and Lobster respectively. The classifications of the 5_VFC_C_L and 6_VFC_L_L were derived from these two species-specific shapefiles, in the same manner as the 2_VFC_C_P and 3_VFC_L_P above, illustrating the total number of harvesters that fish for either Conch or Lobster on any given day within the study area. The linear species location classification (4_SLC_CL_L) was derived in the same manner as the polygon species location classification (1_SCL_CL_P) noted above.

The final classification derived from the species location data is the high-pressure zone classifications (7_HPZ_C and 8_HPZ_L). This is derived from the visitation frequency classification using multi-buffer and likelihood values, as described in Chapter 3, to calculate areas of the highest likelihood of fishing activity. Thus, following the multi-buffer process, a new field of "Likelihood_S(i)" was added to the multi-buffered attribute tables. Using the rationale described in Chapter 3 with respect to the likelihood value assignment for the buffer rings, values were coded based on a range of [1,7] with 7 representing the highest likelihood of fish occurring and 1 representing the lowest likelihood of fish occurring. Once complete, the multi-buffered layers were unioned in the same manner as the single-ringed buffer method described above resulting in two final cumulative data layers, one for Conch and one for Lobster (referred to in Figure 4.16 as C_MB_Line and L_MB_Line for multi-buffer Conch and Lobster respectively).

Areas that received the highest fishing pressure can be illustrated based on a threshold likelihood value and an area threshold value as discussed in Chapter 3. Since classifications from the protocol used in this research is exploratory, a number of likelihood threshold values were investigated. The likelihood threshold values began with equation 3-3 from Chapter 3 in addition to the following four formulas:

$$\sigma(x)\ 2\ 1.5\omega \qquad (4\text{-}1)$$

$$\sigma(x)\ 2\ 2\omega \qquad (4\text{-}2)$$

$$\sigma(x)\ 2\ 2.5\omega \qquad (4\text{-}3)$$

$$\sigma(x)\ 2\ 3\omega \qquad (4\text{-}4)$$

where μ is the mean, x equals the range of likelihood values and ▯ is the standard deviation. Please refer to Appendix B for statistics and graphical depictions of the likelihood ranges for both conch and lobster resulting from the these formulas. The calculated likelihood threshold values are outlined in Table 4.6 with the results discussed in Chapter 5.

Threshold Formula	**Threshold Value for Conch**	**Threshold Value for Lobster**
$\sigma(x)\ 2\ 1\omega$	14	16
$\sigma(x)\ 2\ 1.5\omega$	16	19
$\sigma(x)\ 2\ 2\omega$	19	21
$\sigma(x)\ 2\ 2.5\omega$	21	24
$\sigma(x)\ 2\ 3\omega$	23	27

Table 4.6: Likelihood Values used for the High Pressure Zone Classification

Average species movement was used for area threshold values. According to telemetry studies done by Kelly (2001) and Hesse (1979), Lobster and Conch move, on average, between 29 to 1000 m/day and 50 to 100 m/day respectively. Since bottom dwelling organisms can move in any direction on a flat plain, minimum average squared distances were used as the area threshold values for Lobster and Conch. Thus, an area of 29 m^2 was used for Lobster and 50 m^2 for Conch. The results of each likelihood threshold and area threshold value combinations are discussed in Chapter 5.

The second part of the GIS component involved the construction of two bottom-type classifications derived from the LK data layers of Harv_Area1, Harv_Area2, and Harvester_Info described in Tables 4.2, 4.3 and Figure 4.12. The first classification was derived from the

Harv_Area2 dataset, or map portion of the interview (referred to as 9_BTC_Map in Table 4.5). The response from harvesters for bottom-type definitions in this portion of the interview was poor as only six of the 38 harvesters interviewed provided bottom-type data. In the context of a GIS database, this low level of response rate is not sufficiently complete or detailed enough to derive any meaningful classification. In the context of LK, however, albeit not strong in terms of numbers, this information could provide some input on the correspondence between LK and SK. Thus, a bottom-type classification was still constructed using the data provided by the six harvesters.

The construction of the 9_BTC_Map followed a similar approach as used for both the polygon features and multi-buffered linear features outlined for the species-specific classifications above. Unlike the classifications above, however, both the polygon and linear features were unioned together in a final map layer. This was done to compensate for the low response rate on bottom-types from harvester interviews.

Table 4.7 summarizes the bottom-type responses from the harvesters during the map portion of the interviews in addition to their class partitions. Although eight bottom-type answers were given, some terminology, although different, meant the same thing. Thus, while this could be up to user interpretation, for simplicity reasons, shoals and rock were classified as one class, and lower grass and grass were also classified as one class. Once the classes were established, the next step involved in the 9_BTC_Map was the segregation of these bottom-types into separate shapefiles by class.

In order to ensure that the bottom-types were distinguishable once aggregated into one layer, each bottom-type attribute table required a unique field identifying the bottom-type in question. For polygon features, the coding of the values followed the same methodology as the polygon visitation frequency classification described above by coding a value of “1” (true) or “0” (false) depending on bottom-type presence. For the linear features, the multi-buffer likelihood method was used, as noted for the high-pressure classifications above.

Once the values (both binary for polygon areas and likelihood for linear areas) were added, the layers representing each of the bottom-types were unioned into one aggregated bottom-type data layer. These values were then summed for each bottom-type within the aggregated attribute table and the bottom-type that had the highest score within each harvest area was marked on the final classification surface.

Bottom-type	Class
Shoals	1
Lower Grass	2
Grass	2
Rock	1
Grass & Coral	3
Sand	4
Middle Reef	5
Coral Head	6

Table 4.7: Bottom Structure Classification

The last classification of the GIS component of the protocol involved the combination of the species data from the Harv_Area1_Poly dataset and the Harvester_Info dataset to construct the 10_BTC_Verbal surface. One of the questions asked of the harvester was, "What type of bottom do you most often find Conch and Lobster?" Of the 31 harvesters that responded to Conch, 18 or 58% reported finding Conch on a grassy bottom. Similarly, of the 33 harvesters that responded to Lobster, 26 or 78% reported finding Lobster on a rocky bottom. Given these values, grass was coded for each harvesters' data layer wherever Conch were located, and rock was coded in wherever Lobster were located. The data layers were then unioned in the same fashion as the species location classification above and the bottom-types summed. Whichever record or area fished had the higher total incidence of either rock or grass, that bottom-type was recorded as the bottom-type for that harvest area.

In terms of accessing the Extra_LK text files, as indicated at the start of this section, the hotlink function in ArcView GIS was used in tandem with Notepad as the media device. Using this feature, a separate database table (called Extra_LK) was constructed to store the access information for each text file. Extra LK files were stored as text files with the Harvester_ID as the prefix. For example, if harvester SC06 provided additional information outside of the questions asked during the interview, then this information was stored as the filename SC06.txt under the Harvester_ID.txt field in the Extra_LK database table. To access this information in the final cumulative layer, the hotlink button can be used in ArcView to open any appropriate Extra_LK documents based on the selected feature type. Any LK text files associated with the harvesters of that feature would then be shown on the screen as illustrated in Figure 4.17.

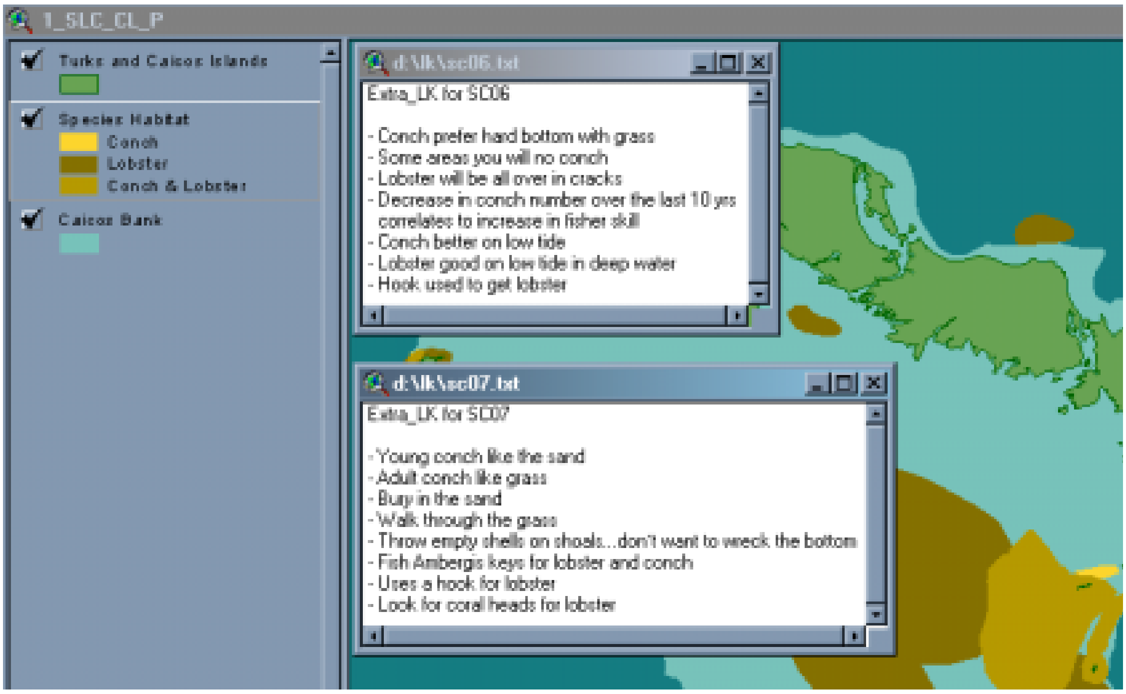


Figure 4.17: Extra_LK Text Files illustrated through ArcView

4.3.2 Remote Sensing Component

The RS component of the research protocol discussed in Chapter 3 involved the construction of a SK bottom-type classification to compare with the bottom-type classification derived from LK. This operation satisfies the 3rd objective of this thesis, namely to compare and contrast LK and SK by comparing sea floor types dictated by the harvesters to those observable from satellite imagery.

The LK-based supervised classification was derived using the 9_BTC_Map from the previous section as input for the training areas for the 1986 Landsat TM imager of TCI. These training areas were then used to classify the remainder of the Landsat image. The result was a classification of the entire Caicos Bank based on the spectral signatures from the input from 9_BTC_Map classification.

This image was then used in the following section to contrast against the LK classification of the same area.

As noted above, the ideal source for the SK classification is through the use of data collected from GPS units in a small boat, to use as inputs for a SK-based supervised classification as outlined in the protocols presented in Chapter 3. Unfortunately, this could not be completed in this research effort due to monetary and time constraints. Thus, in order to satisfy the comparison in the next section, an unsupervised classification of the 1986 Landsat TM image of the TCI was used instead as a secondary source of SK (SK in terms of the technology of RS).

4.3.3 Data Comparison

The data comparison forms the final portion of the protocol outlined in Chapter 3. As noted in Chapter 3, there are two knowledge-based comparisons in the protocol. The first comparison comprised of bottom-type data from the verbal portion of the interviews with bottom-type data from the map portion of the interviews. The second comparison involved a supervised classification derived from LK with an unsupervised classification derived from SK. The purpose of these comparisons respectively, is to illustrate the accuracy of information that has been divulged by the harvesters and to compare the knowledge provided by harvesters to that of the scientific community.

For the first comparison, 9_BTC_Map was compared with 10_BTC_Verbal with the results discussed in Chapter 5. Similarly, the results from the supervised LK-based classification were compared with the results from the unsupervised SK-based classification with the results also discussed in Chapter 5. It is important to note that this comparison is only exploratory due to limited data availability. The results of the comparisons are discussed in Chapter 5.

4.4 CHAPTER SUMMARY

This chapter has discussed the case study for the research followed by the operationalisation of the protocol outlined in Chapter 3. First, background information on the TCI was provided, including descriptions of the specific islands where field interviews took place, local harvesters, the DECR, the species of fish harvested and harvest regulations. Next, the primary and secondary data sources and methods of data collection used for the research were discussed followed by the methods used to construct and analyse the GIS and RS classifications outlined in the protocols. Finally, the methodology for the correspondence between SK and LK was outlined as dictated through the objectives of this thesis. The results of applying the general protocol and the specific methods are discussed in the following chapter.

Chapter 5

RESULTS OF ANALYSIS

Using the conceptual framework in Chapter 2 as a guiding reference, this chapter presents the results and implications of applying the general fisheries protocol from Chapter 3 using the methods outlined in Chapter 4. The chapter first presents the results of the verbal portion of the interviews. Second, the results of the 10 classifications constructed from the map portion of the interviews are presented and explained in the order that they appeared in Chapter 4. Third, the results are discussed in the context of the objectives of the thesis. The discussion concludes with an exploration of the implications of the protocol in conjunction with the general framework in Chapter 2 and subsequent Fishery First (FF) management approach presented in Chapter 3.

5.1 PRESENTATION OF RESULTS

In Chapter 4, a revised total of 10 interview questions were used to extract knowledge from the local harvesters within the TCI. These questions were broken down into two sections, namely verbal questions and map-based questions. This section first discusses the results of the verbal portion of the interviews, and then presents the map-based classifications derived from the map portion of the interviews.

Table 5.1 presents a summary of the results from the verbal portion of the harvester interviews, specifically questions 1 through 8. The answers to question 10 and any other addition information (referred to as Extra_LK in Chapter 4) collected were not analysed due to time limitations. These data would, however, be available to fisheries managers for further analysis.

Although a total of 38 harvesters were interviewed, not all of them answered every question. In this context, the average values presented in Table 5.1 were calculated based on the number of harvesters that responded to that particular question. Thus, the average years fished for the 38 harvesters interviewed is 17.7 years with 92% of them participating in both the Conch and Lobster fisheries. With respect to catch method, free diving is the method of choice for both harvest species. In terms of what the harvesters actually use to catch the species (hand, hook, or sling) is uncertain, as 47% of the Conch harvesters and 81% of the Lobster harvesters interviewed did not indicate their specific method.

A further interesting observation from Table 5.1 concerns the amount of money that harvesters receive per species. In question 8, an average good day's catch for Conch is 858.6 lbs, with a monetary equivalent of $687 US dollars (at $0.80 per pound as noted in Chapter 4). In contrast, an average good days catch for Lobster is 338.6 lbs, with a monetary value of $1185 US dollars (at $3.50 per pound). This Lobster catch equates to almost double the money for a third of the weight caught and therefore verifies the widely held view that Lobster earns more money than Conch. One other notable observation from the data concerns the conditions of the fishery. Roughly 80% of the harvesters interviewed indicated that fishing success has decreased over the last 10 years primarily due to more harvesters fishing the Turks and Caicos Banks.

#	Question	Answers
1	Ave Yrs Fishing	17.7 years
2	Species Caught	Conch = 2.6% | Lobster = 5.3% | Both = 92.1% (n = 38)
3	Most Money	Conch = 23.7% | Lobster = 68.4% | Other 2.6% (n = 37)
4	Days/week Good	5.1 days
4	Days/week bad	2.3 days
5	Conch Bottom	Grass = 58.1% | Sand = 25.8% | Rock = 12.9% | Shoals = 3.2% (n= 31)
5	Lobster Bottom	Rock = 78.8% | Shoals = 9.1% | Coral Heads = 9.1% | Gravel = 3.0% (n= 33)
6	Conch Method	Free Dive = 81.6% | Free Dive/Hook = 7.9% | Free Dive/Hand = 10.5% (n = 38)
6	Lobster Method	Free Dive = 47.4% | Free Dive/Hook = 47.4% | Free Dive/Sling = 2.6% | Traps = 2.6% (n = 38)
7	~ lbs/C Good Day	858.6 lbs (x$0.80 = $686.86) (n = 14)
7	~lbs/L Good Day	338.6 lbs (x$3.50 = $1185.00) (n = 14)
8	Conch last 10yrs	More = 7% | Less = 79% | Same = 14% (n = 29)
8	Lobster last 10yrs	More = 3% | Less = 87% | Same = 10% (n= 31)

Table 5.1: Summary of Results from the Verbal Portion of the Interviews

With the results of the verbal portion of the interviews now presented, the discussion turns to the presentation of the classifications that were derived from the map portion of the interviews (question 9).

In Chapter 4, 10 classifications were constructed based on the general LK-based fisheries protocol presented in Chapter 3. These 10 classifications were based on the species location and bottom-type data that were collected from the map portion of the interviews. Issues of map bias, boat drift, and species movement were addressed and incorporated into the construction of these surfaces. The classifications illustrate species distribution across the study area, visitation frequencies by harvesters, areas that receive a high degree of fishing pressure, and bottom-type locations. This section presents the results of these classifications through three groups of maps, beginning with polygon and linear harvest areas, followed by the multi-buffer harvest areas, and ending with bottom-type results. As discussed in the interview questions in Chapter 4, the time period for the first two groups of classifications is based on the number of harvesters fishing in any one location, *per day*. Furthermore, it should be noted that since all of the harvesters interviewed had access to the majority of the Turks and Caicos Banks, interview results are aggregated into one map layout regardless of the harvester's island of origin.

5.1.1 Polygon and Linear Harvest Areas

The first group of classifications constructed from the protocol were based on polygon and linear species locational data, namely visitation frequency classifications for both Conch and Lobster and joint species location classifications. The purpose of the visitation frequency classification was to determine the sites in the study area that received a high degree of fishing pressure based on the number of harvesters that fished there. The species location classification illustrates the range of fish species caught within the TCI, relative to the species examined. Two types of vector data, namely line and polygon-based feature types, were used to illustrate Conch and Lobster harvest locations by frequency of harvester visits. The polygon type classifications are illustrated in Figures 5.1, 5.2, 5.3 and 5.4, while the linear type classifications are illustrated in Figures 5.5, 5.6, 5.7, and 5.8.

Figures 5.1 and 5.2 illustrate the polygon harvest area visits for Conch and Lobster, whereas Figure 5.3 illustrates the Conch and Lobster range across the Turks and Caicos Banks. These maps were constructed based on polygon data collected from 23 of 38 (61%) harvester interviews. Generally, the overall pattern of species location and harvester visits for both Conch and Lobster occurred over four main areas (referred to as fisheries for this discussion), namely West Caicos, French Cay, Big and Little Ambergris Cay, and the area south of Grand Turk.

In terms of which harvester is using which fishery, common sense would dictate that distance to a fishery would be the main consideration given that the harvesters use small 12 to 15 foot boats as their fishing platform. Following this rationale, harvesters from Providenciales would fish the West Caicos and French Cay fisheries, harvesters from South Caicos would fish the Ambergris Cays fishery, and harvesters from Grant Turk would fish the Grand Turk fishery. To verify this, the database tables for each classification can be used to determine this information by means of the HAID or Harvester Area Identification number. As explained in Chapter 4, the HAID number identifies two key characteristics about each fishery, namely where harvesters fish and each harvester's island of origin. These characteristics can be used to determine not only the number of harvesters fishing in each fishery, but the number of locations that each harvester is fishing within each fishery (if more than one) and, most importantly, to determine which fishing port or island each harvester travels from. In this context, Tables 5.2 and 5.3 illustrate the numbers of harvesters that fish for Conch and Lobster in each of the fisheries noted above, by their island port of origin. Tables 5.4 and 5.5 illustrate which harvesters frequent which fishery in addition to the number of locations that any one harvester fishes within that fishery.

Pertaining to Conch, Table 5.2 verifies the assumption noted above, in terms of the relationship between island of departure and fishery visited. The one exception to this is that French Cay has one Lobster harvester per day travelling from South Caicos. With respect to harvesting of Lobster (Table 5.3), the segregation between fisheries in not as strong. Only three of the four harvesters fishing West Caicos travel from Providenciales, the French Cay fishery is split with one harvester travelling from Providenciales and one from South Caicos, the Ambergris Cays fishery sees one harvester from Grand Turk (this would most likely be a harvester who resides on Grand Turk but is actually departing for the fishery from the South Caicos port), and the Grand Turk fishery experiences one harvester per day from South Caicos.

Tables 5.4 and 5.5 illustrate the frequency of individual visits in each area, per day. The value in brackets indicates the number of fishing locations within the fishery that that particular harvester has visited per day. For example, the harvester designated "SC22" fished five different areas within the Ambergris fishery during the same trip. Also, the harvester designated "SC15" fished one location

Island Origin	West Caicos	French Cay	Ambergris Cays	Grand Turk
Providenciales	5	4	0	0
South Caicos	0	1	6	0
Grand Turk	0	0	0	6

Table 5.2: Numbers of Harvesters Fishing for Conch in each Fishery and their Island of Origin

Island Origin	West Caicos	French Cay	Ambergris Cays	Grand Turk
Providenciales	3	1	0	0
South Caicos	1	1	7	1
Grand Turk	0	0	1	2

Table 5.3: Numbers of Harvesters Fishing for Lobster in each Fishery and their Island of Origin

in each of the Ambergris and French Cay fisheries. Interestingly, the same harvester (SC15) is fishing for Lobster in each of the four fisheries (Table 5.5). Given that the intent of these data was to show harvester activity per day, on both the Turks and Caicos Banks, either harvester SC15 has a very fast boat or has misinterpreted the question, thus indicating areas on the Banks that he has fished in the past, but not necessarily on the same day. The latter explanation is most probable. This issue further stresses the importance of interview design and question clarity. With the data pertaining to the specific fisheries noted, the discussion now turns to the frequency of harvester visits across the Turks and Caicos Banks.

Fisheries	Harvesters (Number of Locations Fished by Harvester per day)
West Caicos	PR06(3), PR05(1), PR03(1), PR02(1), PR01(2)
French Cay	PR07(1), PR03(1), PR02(1), PR01(2), SC15(1)
Ambergris	SC22(3), SC21(1), SC16(2), SC15(1), SC06(1), SC03(1)
Grand Turk	GT06(1), GT05(1), GT04(4), GT03(2), GT02(5), GT01(3)

Table 5.4: Harvesters Fishing for Conch in each Fishery Plus the Number of Locations Fished by Harvester

Fisheries	Harvesters (Number of Locations Fished by Harvester per day)
West Caicos	SC15(1), PR04(2), PR03(1), PR01(1)
French Cay	SC15(1), PR03(1)
Ambergris	SC22(5), SC16(2), SC15(1), SC11(1), SC06(2), SC03(1), PR07(1), GT06(1)
Grand Turk	SC15(2), GT06(1), GT03(2), GT01(2)

Table 5.5: Harvesters Fishing for Lobster in each Fishery Plus the Number of Locations Fished by Harvester

In Figures 5.1 and 5.2, there were a total of five visits for Conch and four for Lobster to each fishing location for the visitation frequency maps. For ease of comparison, both the Conch and Lobster classifications are colour coded so that the first four colours on each map represent the same number of harvester visits. The fifth class on the Conch classification was coded red to allow these harvest areas to be seen more easily. However, at the scale shown in Figure 5.1, the high frequency (five visits) locations are still somewhat difficult to discern. One of the advantages of using digital map data and a GIS to depict harvest visit frequencies (or any other small geographic area of interest) is that a fisheries planner can zoom and pan the output and thereby identify the five frequency locations without the need for high-level knowledge of the GIS software. In this context, issues of map scale, such as that noted above, can be resolved through static map design concepts as those illustrated in Figure 5.4.

Through the visualisation of these data, it is evident that the harvesting of Conch (Figure 5.1) occurred with a higher frequency (four to five harvester visits per day) around French Cay to the west; north and south of Ambergris Cays in the south; and north of Six Hill Cay. In contrast, the harvesting of Lobster occurred over a more widespread area with a maximum of four harvester visits to the north of Little Ambergris Cay and two to three harvester visits in the south around White, Pear, and Bush Cays. Clearly, harvester activates are generally focused on the area south-southwest of South Caicos and to a lesser extent, south of Grand Turk. Travel from island bases to fish is more localised for Conch, whereas harvesters travel considerably farther out into the Caicos Bank and traverse more territory when looking for Lobster.

These patterns are even more evident when combined in Figure 5.3 where both Conch and Lobster range are displayed. The range for Lobster is significantly larger than Conch, spanning much of the central, and southern region of the Caicos Bank. In addition, this figure illustrates both Conch and Lobster harvesting located adjacent to West Caicos, however, the visitation frequency maps illustrate that this area receives only one to two harvester visits per day.

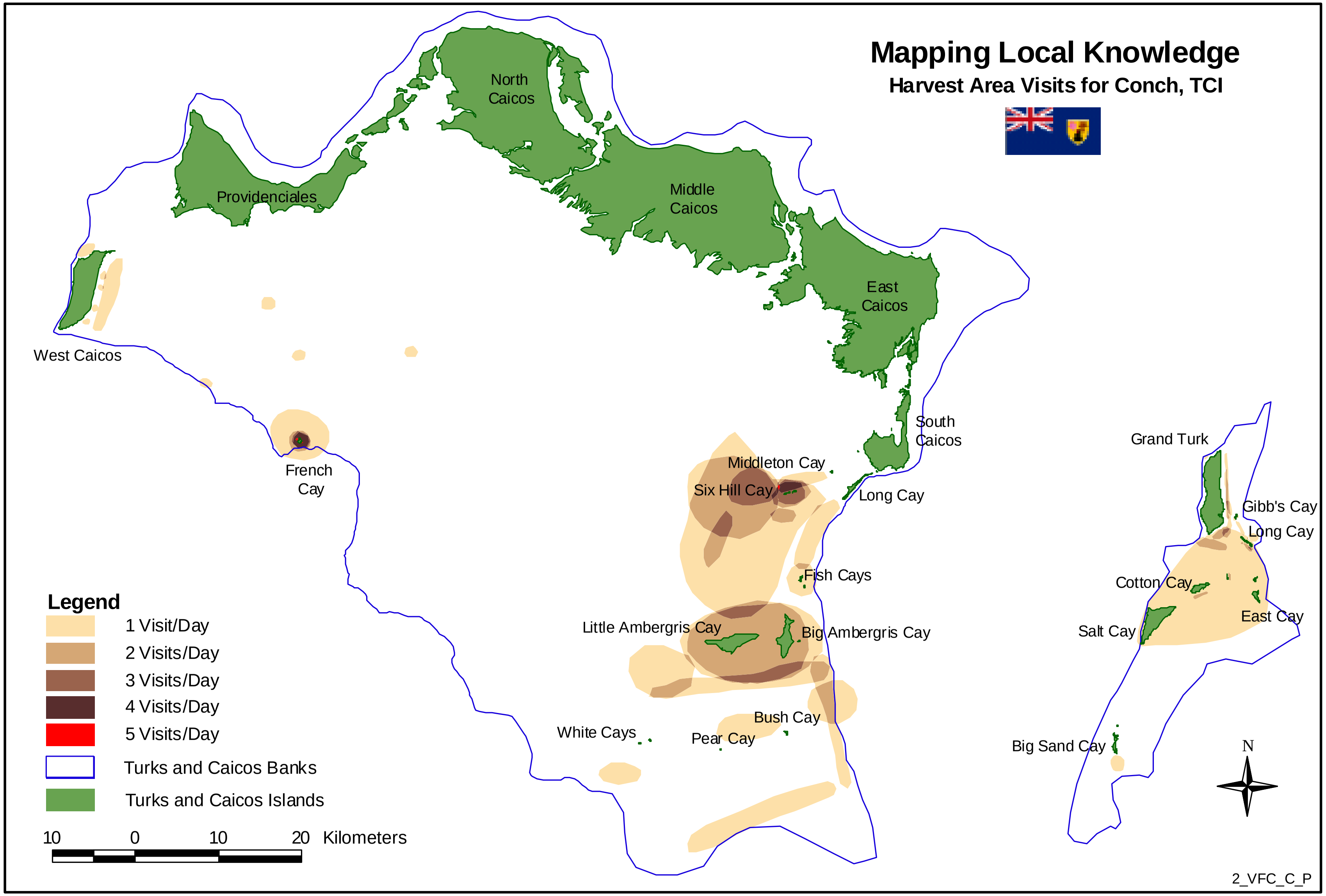


Figure 5.1: Visitation Frequency Classification for Conch in TCI

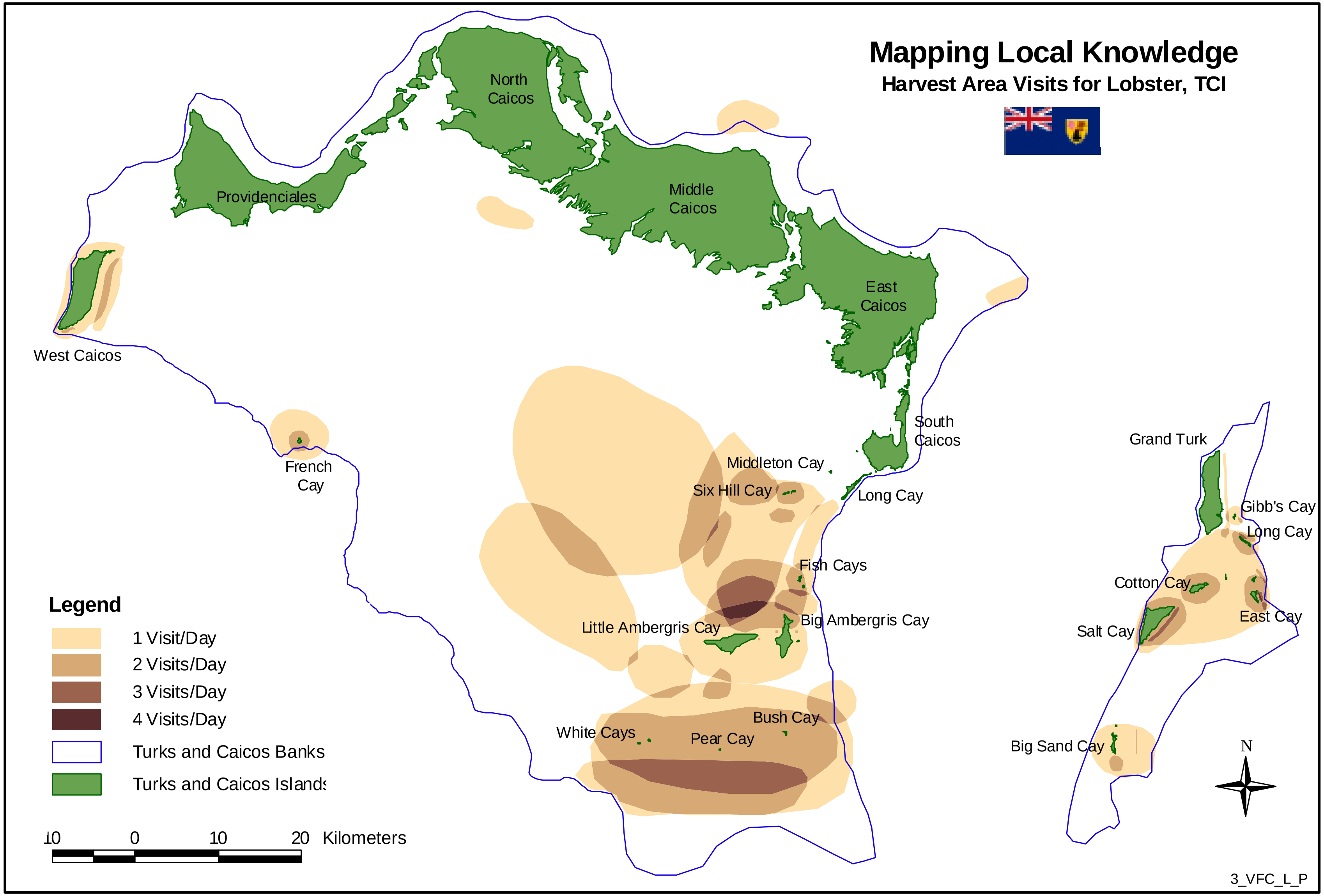


Figure 5.2: Visitation Frequency Classification for Lobster in TCI

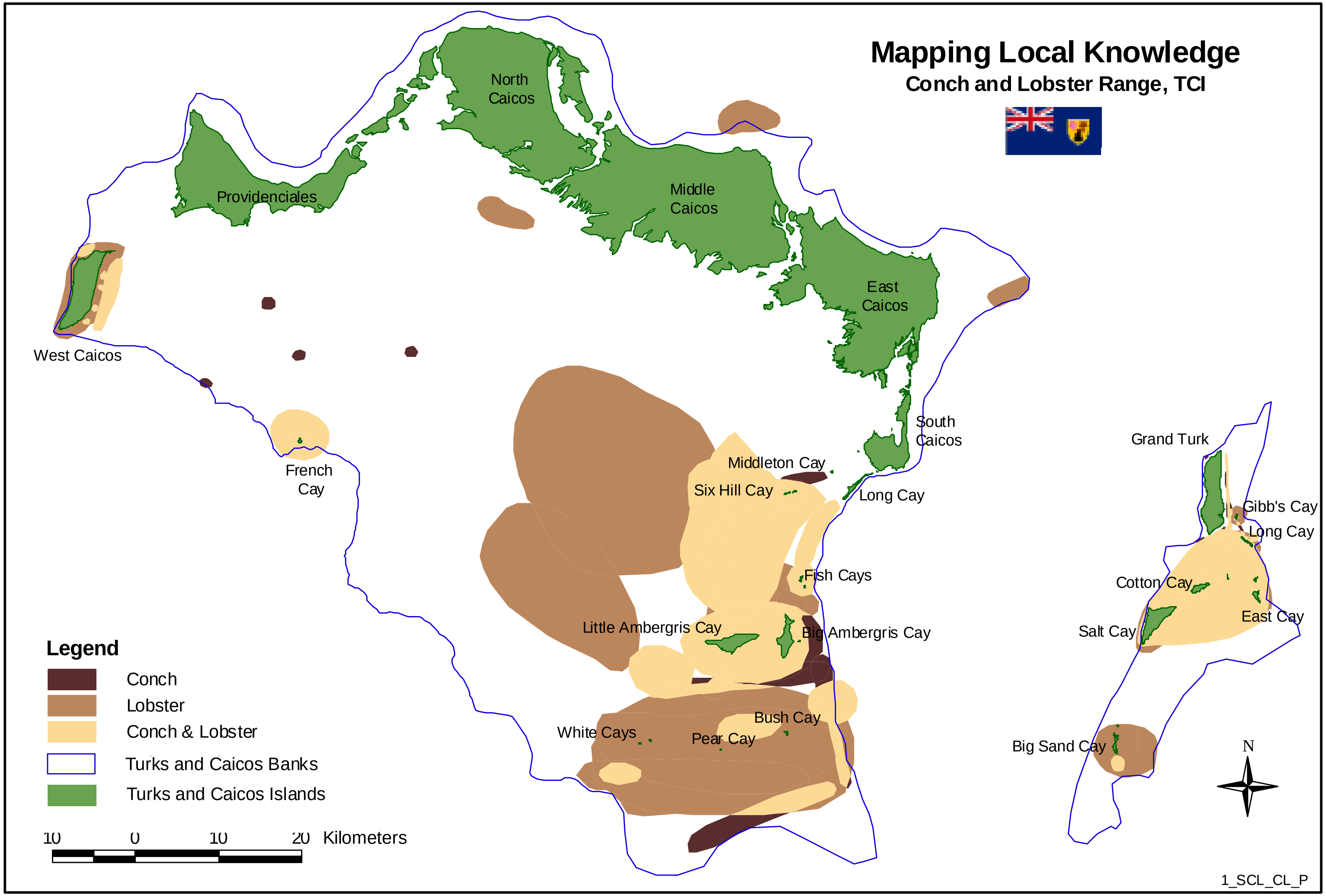


Figure 5.3: Polygon-Based Species Location Classification for Conch and Lobster in TCI

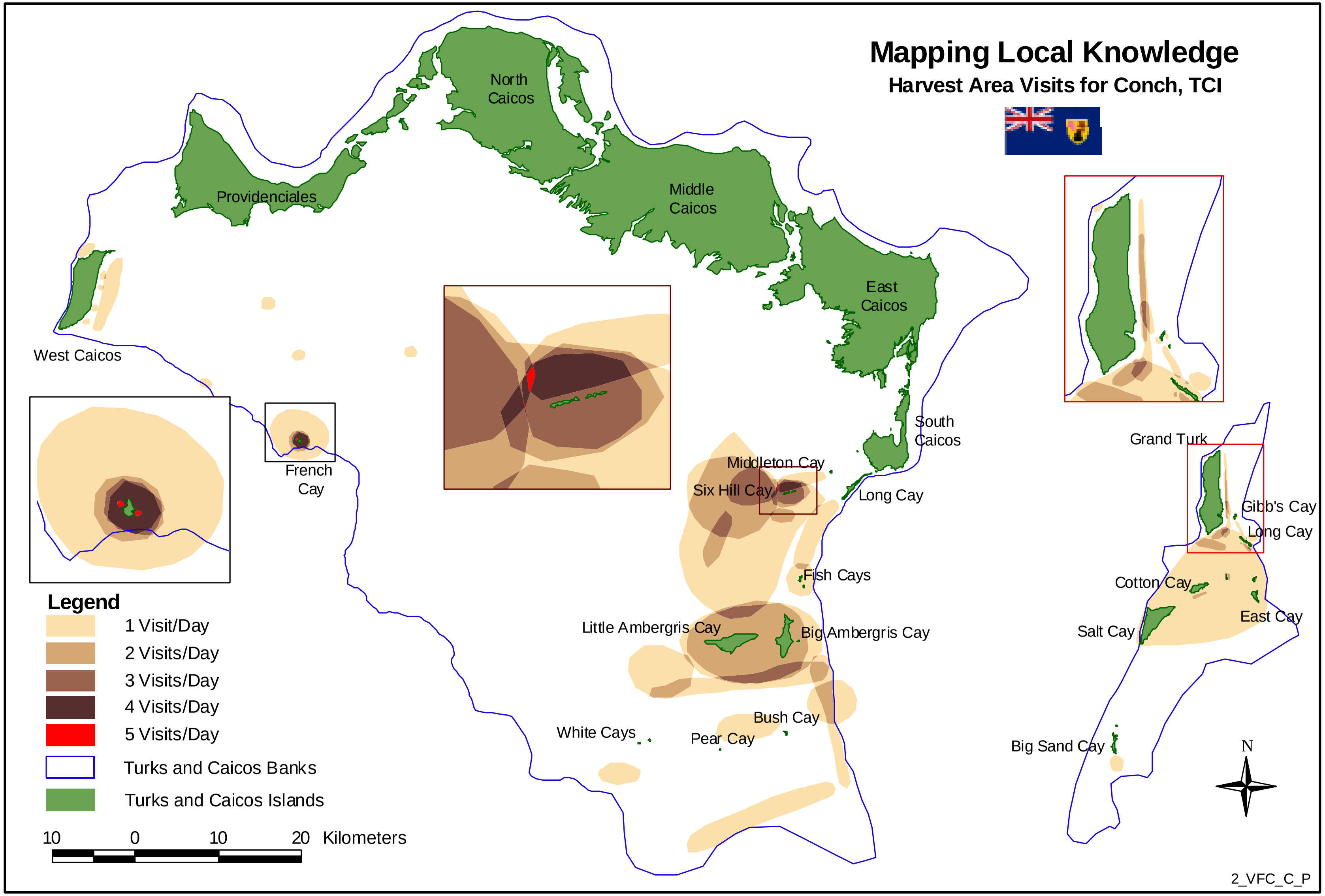


Figure 5.4: Modified Visitation Frequency Classification for Conch illustrating Smaller Harvest Areas

There are several other notable results evident in the polygon-based classifications. First, the area just north of Six Hill Cay is heavily fished for Conch, but not for Lobster. This area could be further investigated by fisheries control officers to establish species counts and to assess the potential for regeneration. Since Conch reach sexually maturity at 3.5 years, this area could be further investigated for potential protected and/or closed area designations. Second, as noted earlier, the generalized area around the south end of Grand Turk south to Salt Cay (Figure 5.3) is somewhat misleading as it illustrates that Lobster are present throughout the area. However, according to Figure 5.2, only the areas specifically adjacent to smaller islands including Cotton, Long, East and Penniston Cays are more heavily fished for Lobster (two to three harvester visits per day). Third, Lobster are caught in the southern, deeper parts of the Banks, while Conch are being taken in shallower water.

In terms of the linear harvest areas that depict specific harvester tracks, Figures 5.5 and 5.6 illustrate harvest frequencies for Conch and Lobster respectively, while Figure 5.7 illustrates the range of harvest activities within the TCI. These maps were constructed based on linear data collected from 25 of 38 (66%) harvester interviews. Similar to the polygon feature type maps discussed above, the overall pattern of species location and harvester visits occur over the same four general areas of West Caicos, French Cay, Big and Little Ambergris Cay, and Grand Turk.

The original purpose of these classifications was to serve as visualization of the linear fishing areas after taking into consideration the issues of map bias, boat drift, and species movement. Unfortunately, the outputs at the scale shown, do not illustrate the numbers of harvesters fishing in specific areas very well. Even at a larger scale, the figures do not work well, as illustrated in Figure 5.8. They do, however, indicate that Lobster tend to be harvested in the deeper water at the southern tip of the Caicos bank (south of White, Pear, and Bush Cays) and the south-eastern shore of West Caicos. Conversely, Conch harvest is more heavily concentrated around the Ambergris Cays. Aside from the location of harvestable species, theses maps illustrate quite clearly, the fishing tracks that harvesters take on any given day.

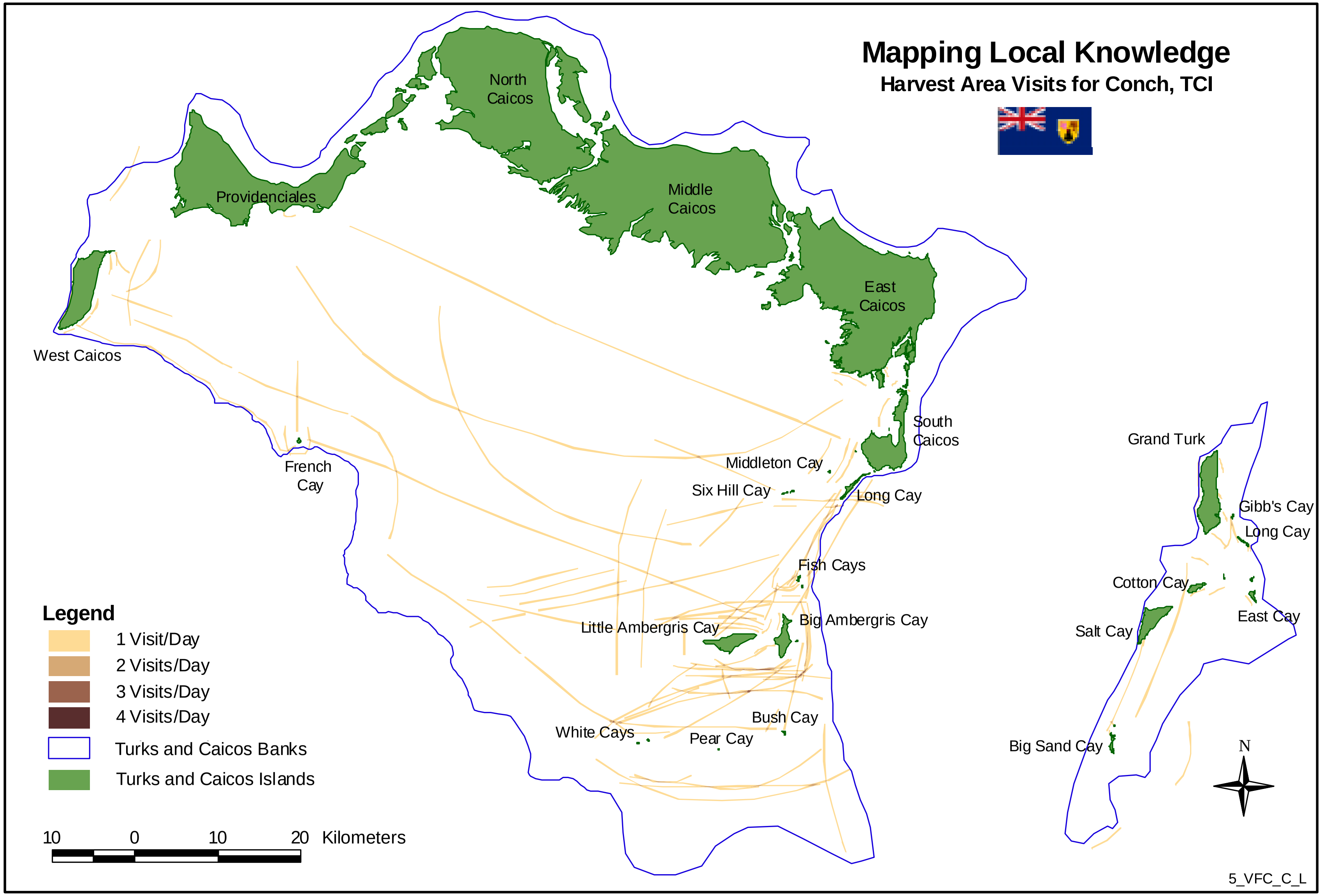


Figure 5.5: Linear-Based Visitation Frequency Classification for Conch in TCI

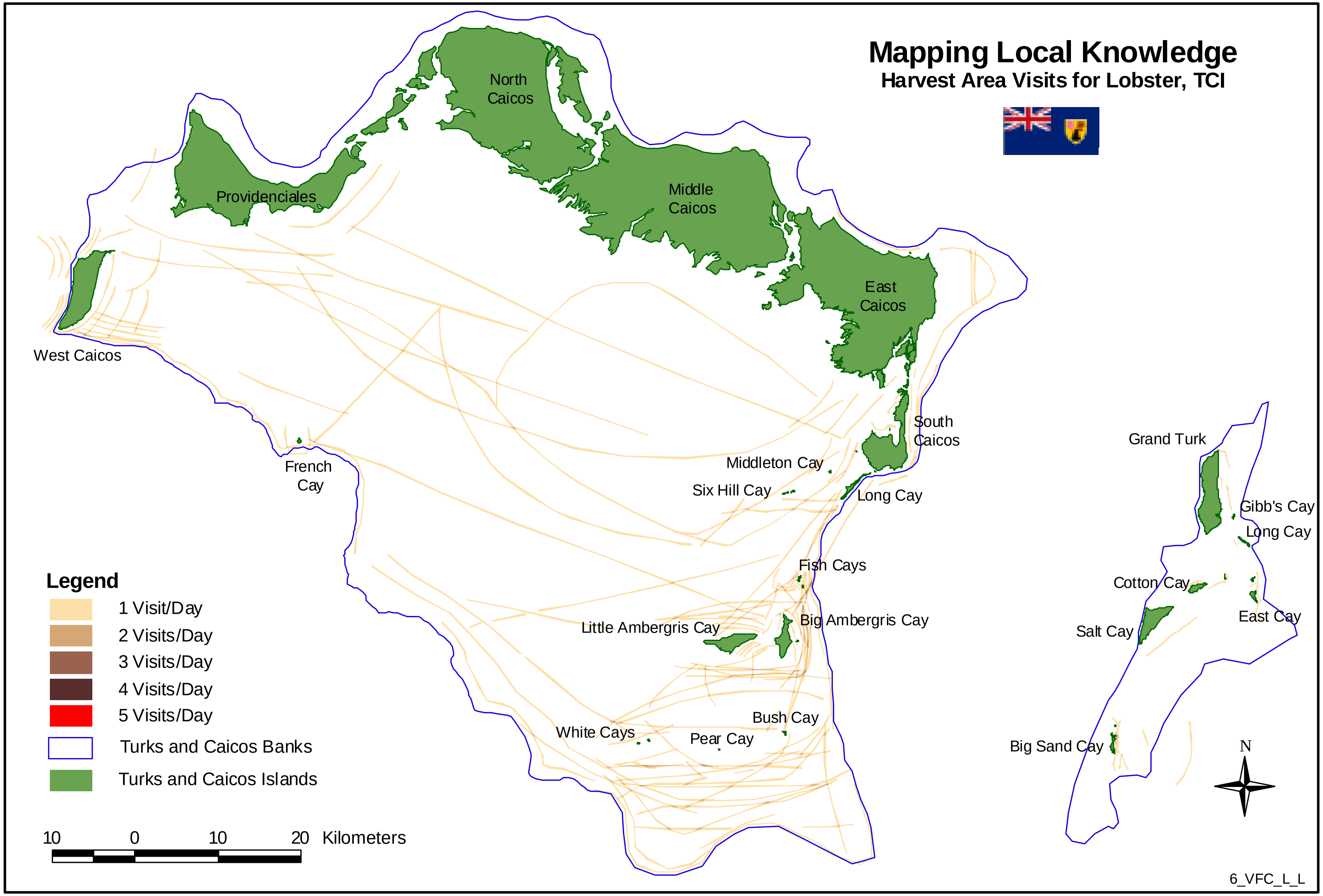


Figure 5.6: Linear-Based Visitation Frequency Classification for Lobster in TCI

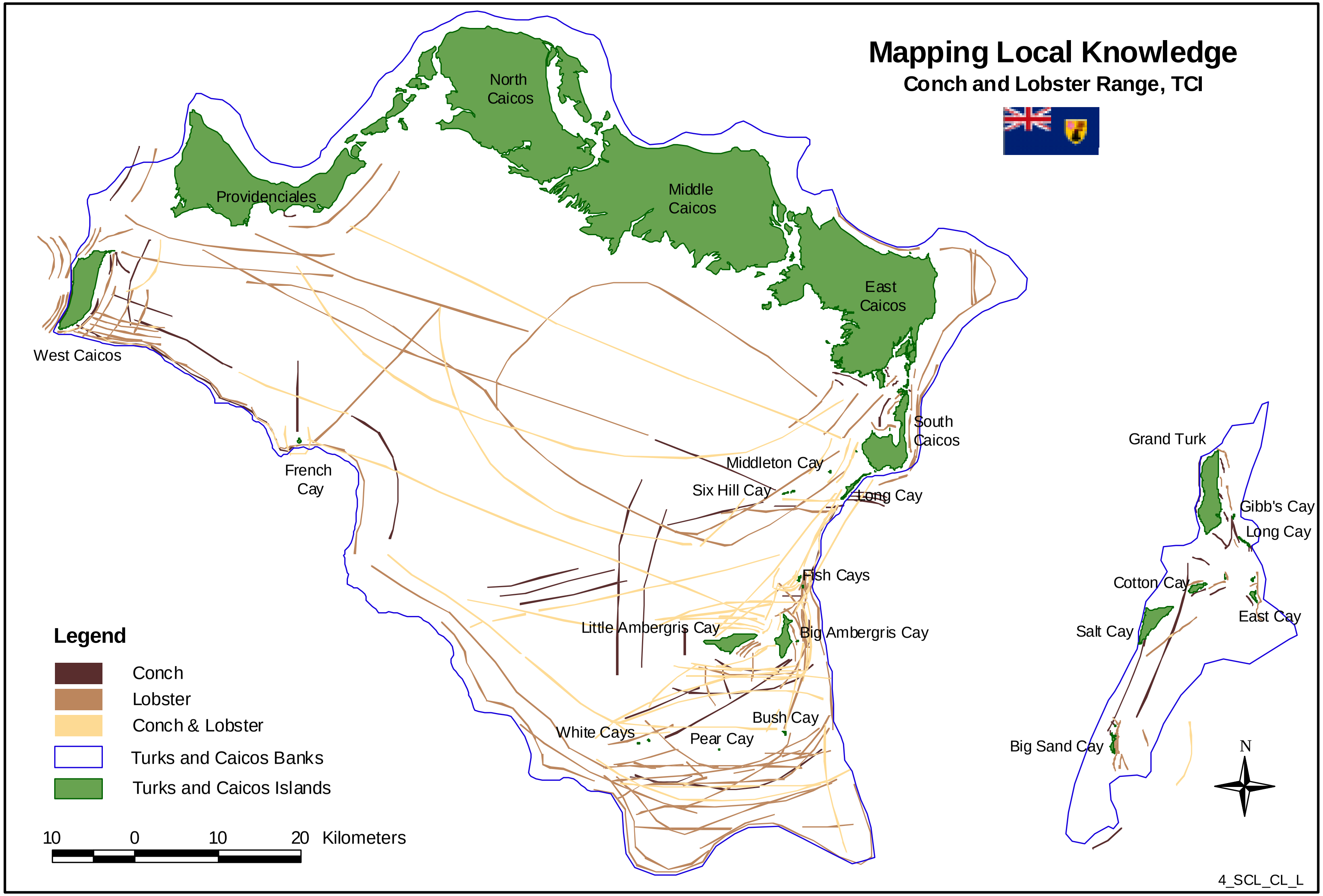


Figure 5.7: Linear-Based Species Location Classification for Conch and Lobster in TCI

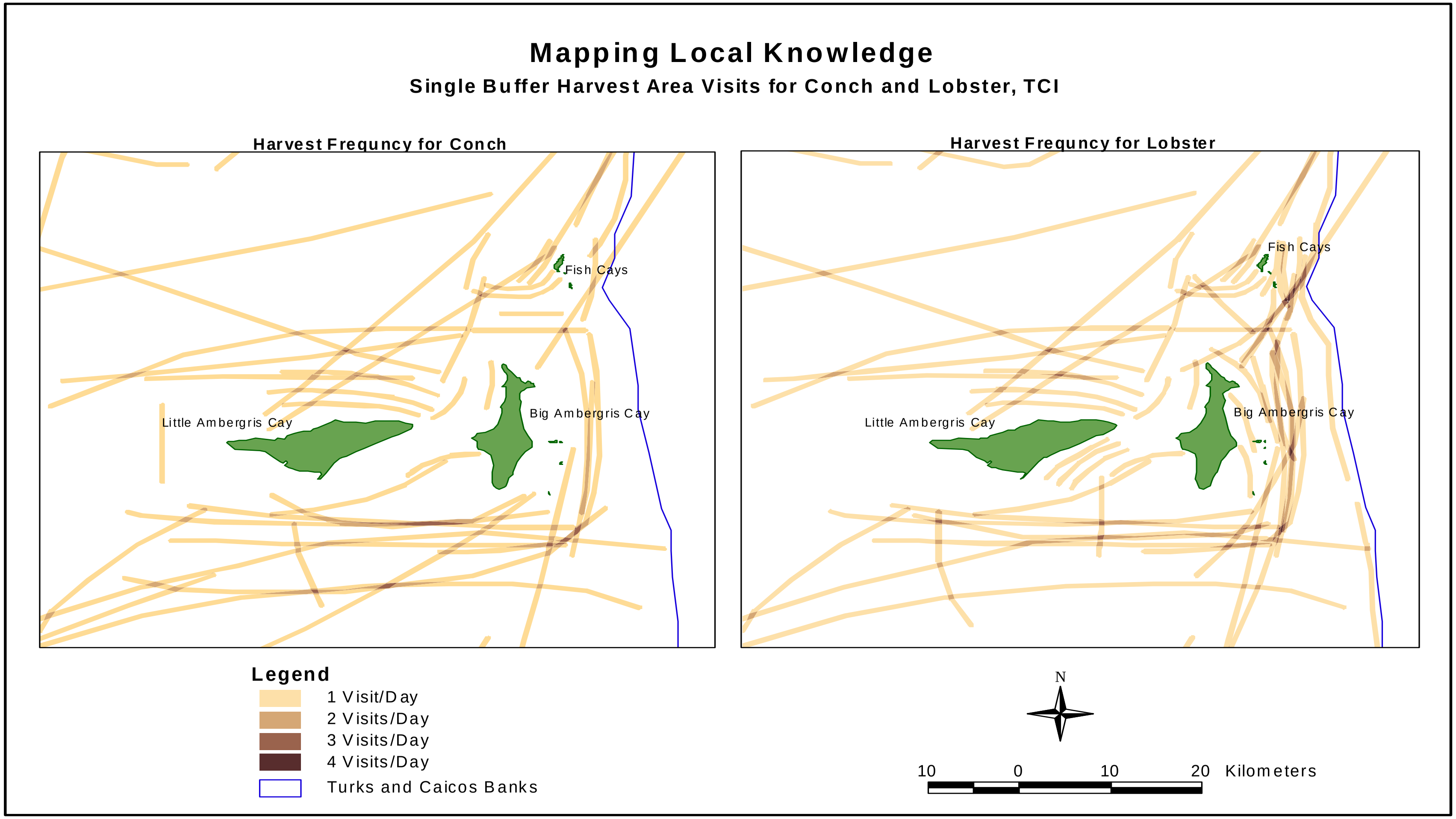


Figure 5.8: Linear-Based Visitation Frequencies for Conch and Lobster around Ambergris Cays

Initially, it was hoped that the linear visitation frequency classifications would be useful in showing the number of harvesters fishing in each area, similar to the polygon harvest classifications discussed above. However, on reviewing the visual results it was apparent that the maps more clearly illustrate the fishing tracks of harvesters across both the Turks and Caicos Banks. Furthermore, the maps can be used to quantify the distances that many of the harvesters must travel on any given fishing day. In this context, harvest tracks for Conch (Figure 5.5) are located primarily around the Ambergris Cays. In contrast, the harvest tracks for Lobster (Figure 5.6) occur more frequently across the Caicos Bank with a focus on the southern end of the Caicos Bank and the west and eastern shores of West Caicos. What is more interesting with these maps are the distances that these harvesters are travelling, specifically in reference to tracks that transverse almost the entire Caicos Bank. Harvesters are travelling distances of 60 to 70 km in one direction using small, open boats. This being said, the prevailing winds on the Turks and Caicos Banks are from West to East. Thus, harvesters from South Caicos would often drive out toward Providenciales and fish while the wind pushed them back in a south easterly direction toward South Caicos. One harvester noted that he was not fearful of fishing out towards Providenciales because if the weather turned poor or he had a mechanical problem, the prevailing winds would always push him back towards South Caicos.

One other observation of the linear harvest areas worth noting is the location of two sites located east of Big Sand Cay, one located on the outer edge of the Turks Bank and the other located off the Turks Bank to the east (Figures 5.6 and 5.7). The harvester that provided the information for the harvest site closest to Big Sand Cay was asked how far, approximately, the spot was off-shore. His response was one mile. When placed on the map, however, this area is actually 4km or approximately 2.5 miles off Big Sand Cay. Although every attempt was made to minimize this type of error from occurring, the example validates the importance of adjusting for map bias as discussed in Chapter 3.

With the linear and polygon data discussed, the next section presents the results of the multi-buffer and likelihood value approach to locating areas of high fishing pressure.

5.1.2 Multi-Buffer Linear Harvest Area Results

The high-pressure zone analysis represents the second group of classifications in the protocol. Similar to the single buffer visitation frequency classifications discussed above, these classifications were constructed using the multi-buffer and likelihood value approach to determine areas that receive a high amount of fishing pressure based on cumulative likelihood values. The results of the multi-buffer linear harvest areas are illustrated in Figures 5.9 through 5.11 for Conch and Figures 5.12 through 5.14 for Lobster. The results of the total range of all likelihood values for Conch and Lobster are illustrated in Figures 5.9 and 5.12 respectively.

The multi-buffer method is more effective in illustrating the areas of high fishing pressure than the single-buffer method discussed above, as the combined multi-ringed buffers and likelihood values provide a better indication of harvester activities. In this context, Figures 5.9 and 5.12 illustrate that the majority of the fishing activity occurs between Pear Cay and Long Cay with a higher intensity of fishing activity also occurring adjacent to the Ambergris Cays. However, as discussed in Chapters 3 and 4, in order to select out areas that receive the highest fishing pressures in the study area, combinations of likelihood and area threshold values were used to isolate these high-pressure zones.

As described in Chapter 4, five likelihood and area threshold combinations were used to isolate high-pressure harvest areas. To review, both the likelihood/area threshold combinations for Conch and Lobster are listed in Table 5.6. The likelihood values were determined based on standard deviations from the mean of the total number of the likelihood values. The area values were based on studies involving daily movement patterns of Conch and Lobster. Thus, in order to be selected as high-pressure harvest areas, the polygon harvest areas that met the threshold likelihood values above needed also to meet the area values of 50 m^2 for Conch and 29 m^2 for Lobster. Two map compositions for each species are presented to illustrate the results of the high-pressure harvest areas (Figures 5.10 and 5.11 for Conch; Figures 5.13 and 5.14 for Lobster). The first figure of each pair provides a view of the entire study area, while the second focuses on the area where the majority of the high-pressure harvest areas are located, namely the area surrounding the Ambergris Cays.

Conch Combinations (L=Likelihood A=Area)	Lobster Combinations (L=Likelihood A=Area)
L=14 A=50 m^2	L=16 A=29 m^2
L=16 A=50 m^2	L=19 A=29 m^2
L=19 A=50 m^2	L=21 A=29 m^2
L=21 A=50 m^2	L=24 A=29 m^2
L=23 A=50 m^2	L=27 A=29 m^2

Table 5.6: Conch and Lobster Likelihood and Area Combinations used to Isolate High Pressure Harvest Areas

Figures 5.10 and 5.11 illustrate the results of the high-pressure harvest areas for Conch. Figure 5.10 shows four groups (circled on the map composition) of harvest areas that satisfy the likelihood and area threshold values. The majority of the high-pressure harvest areas are located around the Ambergris Cays. However, only the likelihood values of 14 and 16 occur in the area between Fish Cay and Long Cay, in addition to the areas north west and south east of the White Cays to the south. Of the 23 high-pressure harvest areas that satisfy at least the first criterion noted in Table 5.6, 19 are located adjacent to the Ambergris Cays (Figure 5.11). Hence, this area is the focus of the remainder of the discussion.

Ideally, a fisheries manager would use only one of the criteria noted in Table 5.6. Thus, if the first likelihood/area combination was used (likelihood (L)=14 and area for Conch = 50 m^2), then the areas of high pressure would encompass areas 1 through 16 on Figure 5.11. If the second combination was used (L=16), the areas of high-pressure would be indicative of areas 2-4, 6-8,10-15 and 17. However, some of the surface areas for the first two criteria combinations are quite large as listed in Table 5.7 (Please note that the values in this table are approximate). For example, areas 10 and 11 have a surface areas of approximately 1530 m^2 and 2500 m^2 respectively for L=14 and an area of roughly 1330 m^2 for L=16. Overall, these surface areas could potentially be too large to be deemed viable for further study, as illustrated in Chapter 3, Figure 3.21.

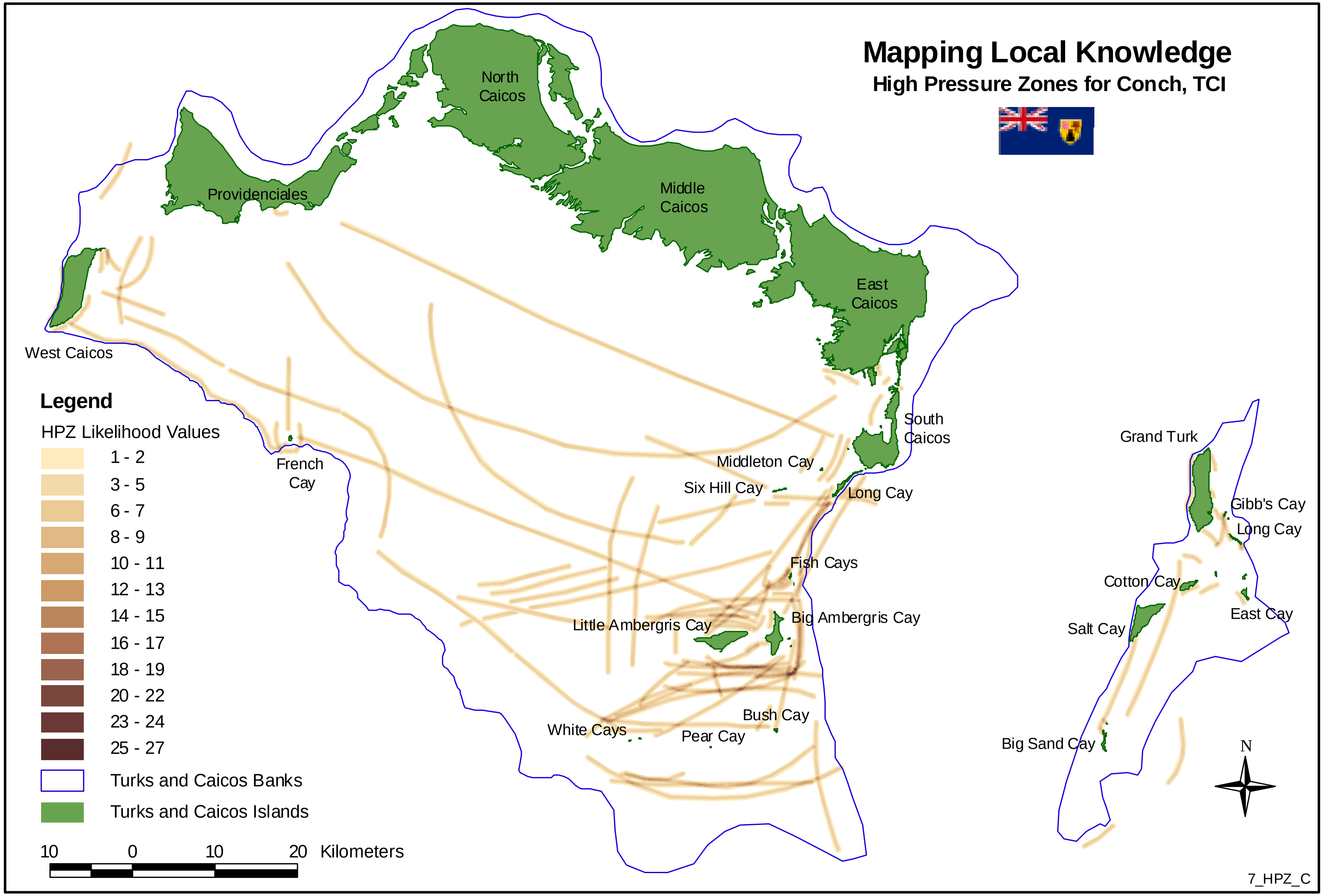


Figure 5.9: Range of Likelihood Values for the High Pressure Zone: Conch Classification

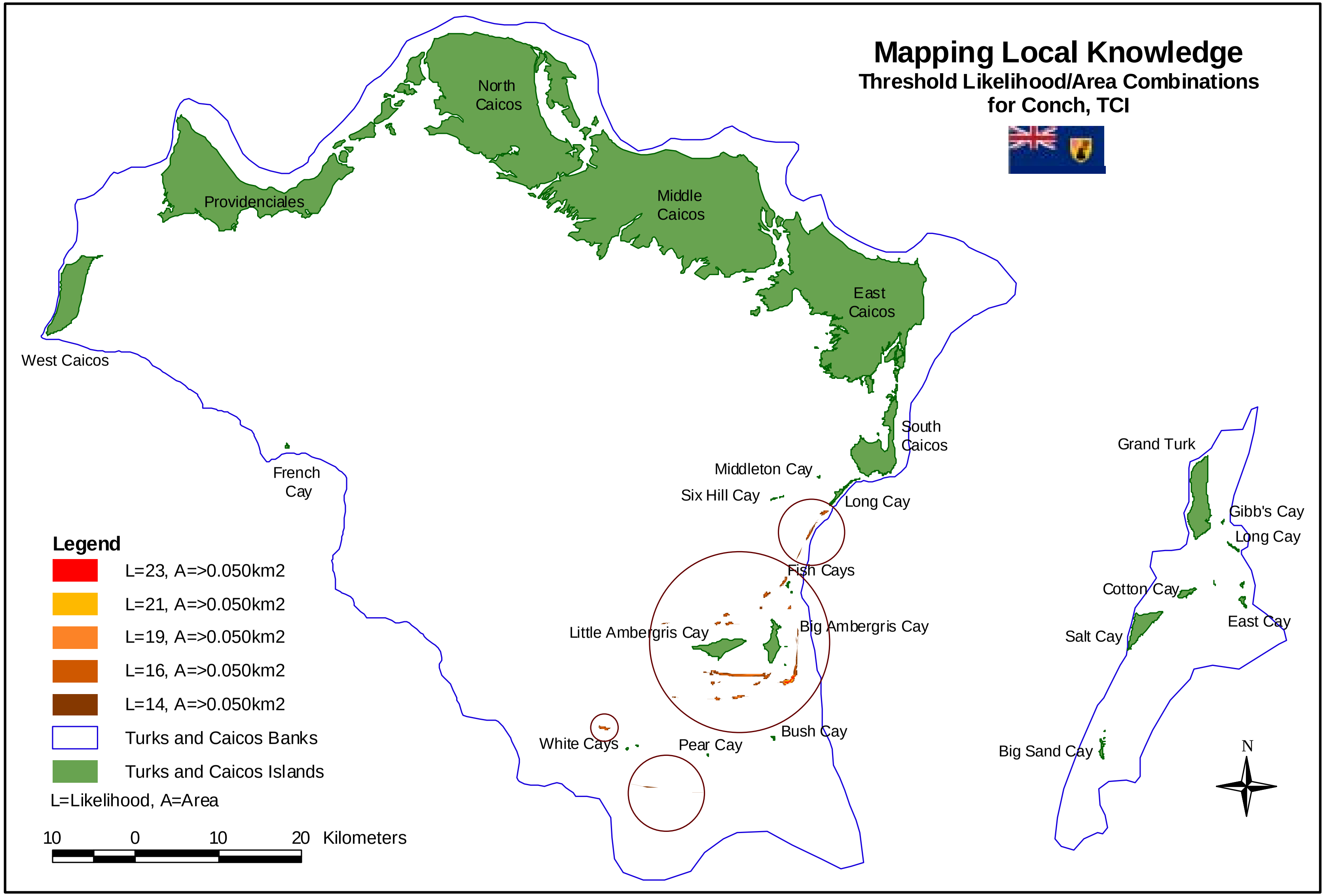


Figure 5.10: General Locations of High Pressure Harvest Areas for Conch

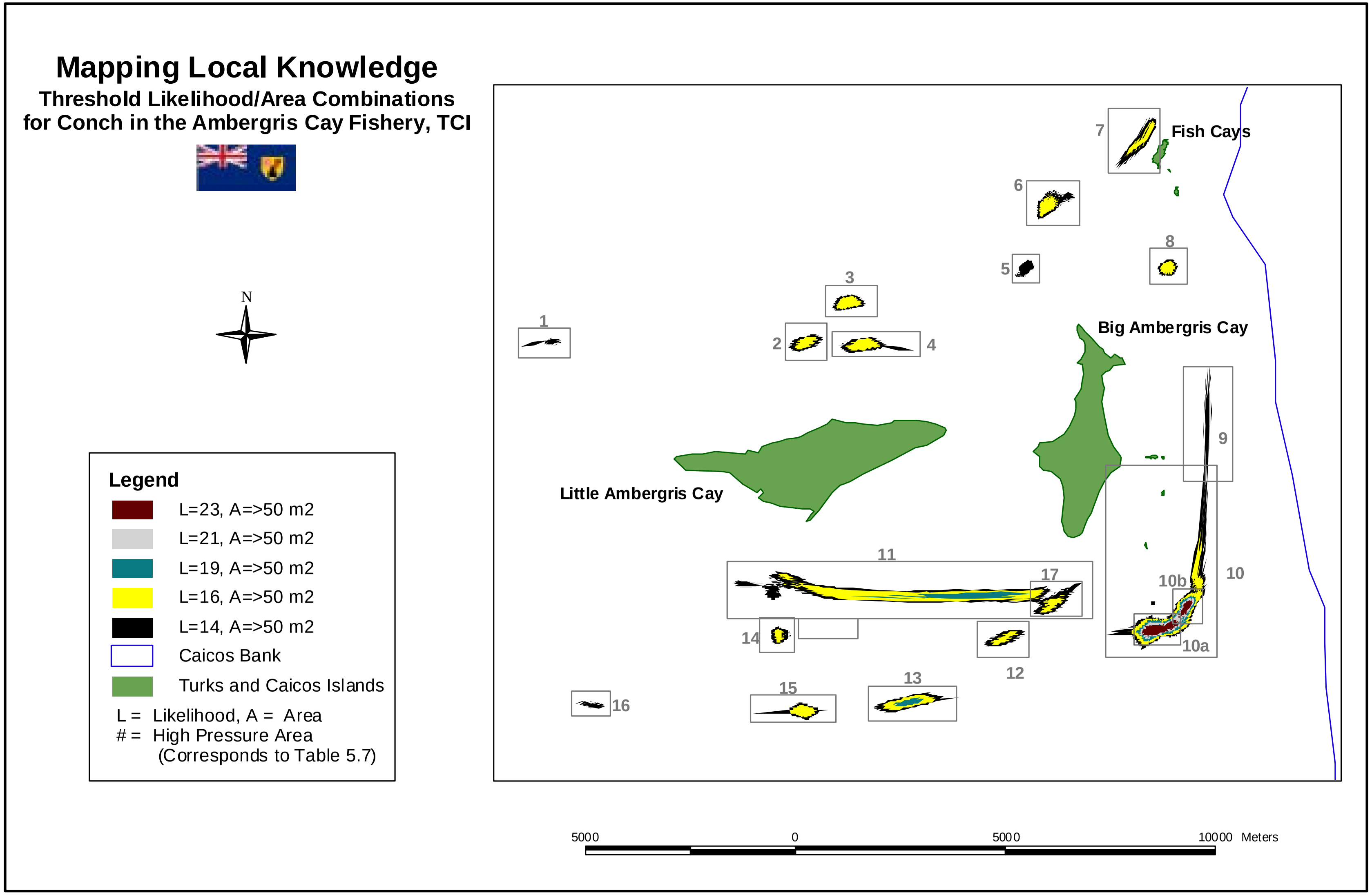


Figure 5.11: Locations of High-Pressure Fishing Areas for Conch

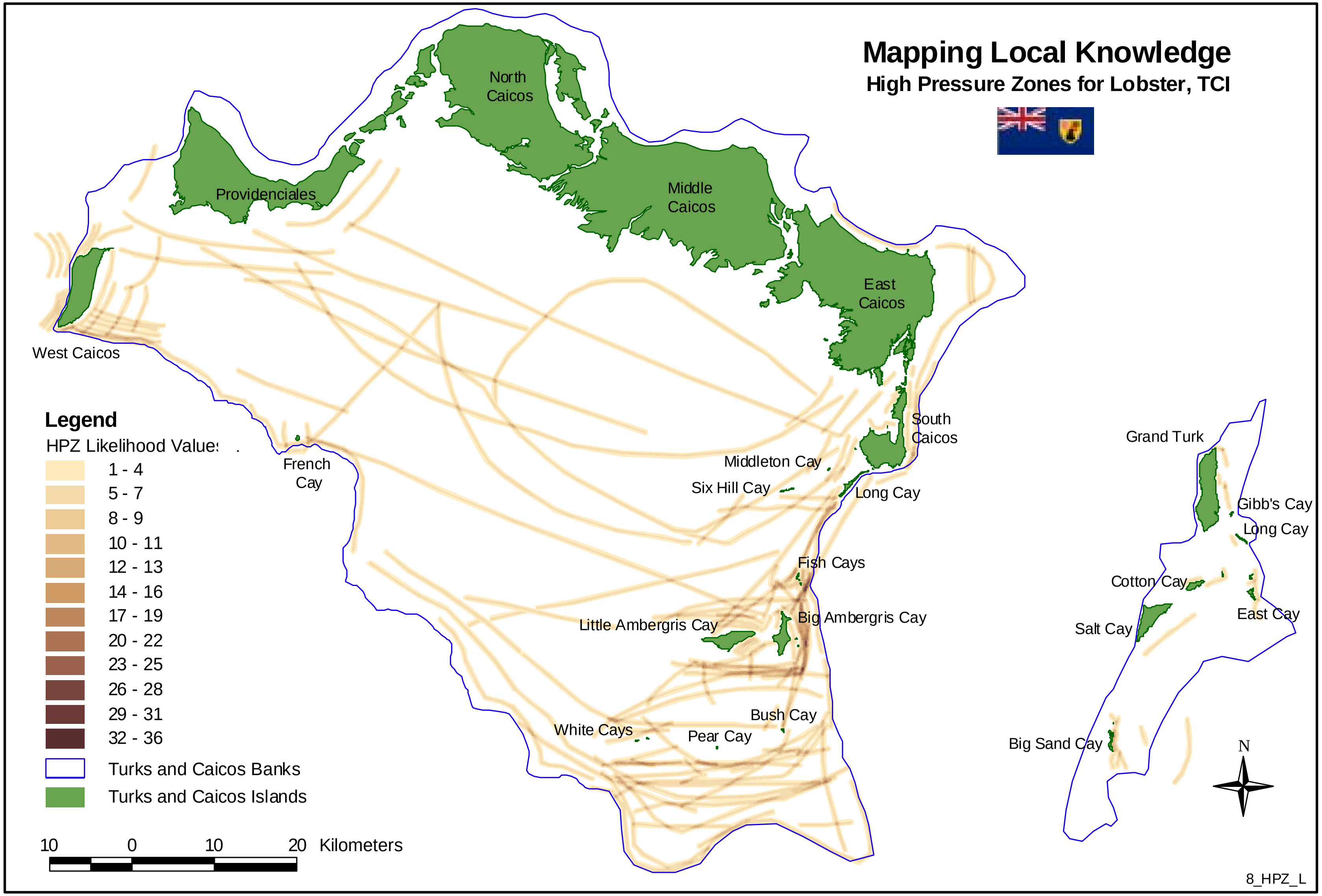


Figure 5.12: Range of Likelihood Values for the High Pressure Zone: Lobster Classification

Area #	Likelihood=14	Likelihood=16	Likelihood=19	Likelihood=21	Likelihood=23
1	66				
2	208	330			
3	211	126			
4	313	151			
5	100				
6	234	133			
7	332	116			
8	141	820			
9	266				
10	1530	330	553	384	
10a					162
10b					57
11	2500	1330	344		
12	215	75			
13	420	250	77		
14	150	54			
15	243	125			
16	62				
17		360			

Table 5.7: Area in m^2 of Conch Harvest Areas by Likelihood Threshold Value (Please note that all values in this table are approximate)

If the combination of L=19 was used, than areas 10, 11 and 13 would be considered high-pressure zones. Given the issues of map bias as discussed in previous chapters, the higher the likelihood value, the more likely it is that harvesters will fish in these locations. However, it would be interesting to conduct further research on the likelihood areas of 14 and 16 to determine the accuracy of the LK collected for these areas. The remaining areas of L=21 and L=23 indicate a high density of harvesters fishing in there areas and thus these areas would be worth investigating for determining either habitat or environmental characteristics that make these locations productive, or for species closures to allow for species regeneration.

Similar to the Conch maps discussed above, Figures 5.13 and 5.14 illustrate the high-pressure harvest areas for Lobster. Figure 5.13 shows seven groups of harvest areas that satisfy the likelihood and area threshold combinations for Lobster. Similar to Conch, the majority of the high-pressure harvest areas are located around the Ambergris Cays. Again, the areas that satisfy all five likelihood and area combinations can be found in this general area with all other areas only having the two lower-end likelihood values of 16 and 19. These high-pressure areas include the areas south east of

West Caicos, north of White Cays, south of White, Pear, and Bush Cays, the area between Fish Cay and Long Cay and finally, one small spot located in the centre of the Caicos Bank. Interestingly, many of these areas coincide with the lower end likelihood values for the Conch fishery, further strengthening the argument that the LK extracted through this exercise is accurate.

For the likelihood/area Lobster combinations from Table 5.6, 32 areas satisfy the lowest likelihood/area criterion. Of these, 20 are located around the Ambergris Cays and thus are used for the remainder of the discussion. Figure 5.14 illustrates these high-pressure areas and Table 5.8 lists the surface areas for each high-pressure area. Similar to the Conch high-pressure zones, a fisheries manager would typically use only one of the criteria noted in Table 5.6. In this context, areas 1 to 8, 9 to 11, and 12 to 15 satisfy the L value of 16 and a square metre area value 29. For the second likelihood value of 19, the areas of 1, 6, 8a, 8b, 10, and 11 through 15 would be selected as high-pressure areas. The reminder of the likelihood values (L=21,24, and 27) are located to the east and south east of Big Ambergris Cay (areas 8a, 8b) and south and south east of the Fish Cays (areas 11a and 11b). These areas could be marked for either management through closed areas, location for a marine protected area, or marked for further research as noted above.

In terms of deciding which likelihood value is best to use for each fishery would be dependent on the range of likelihood values for each species harvested. For the Conch and Lobster fisheries in the TCI, there are many lower-end likelihood values, that may not warrant further field study. The fact that many of the higher likelihood areas for Lobster coincide with those of the Conch fishery, suggest good accuracy for these locations. Given this, fisheries managers could make management decisions based on these areas without the need for further research, which in turn, would save time and resources. In this context, the likelihood value of 19 for Conch and 21 for Lobster could be used as the threshold value in which to determine the high-pressure fishing areas (the higher-end likelihood values of L=21 and 23 for Conch and L = 24 and 27 for Lobster would be included in this cut off point). Furthermore, these areas could be closed for the time it takes Lobster and Conch to mature, thus allowing each species to spawn at least once before harvest. Currently in the TCI

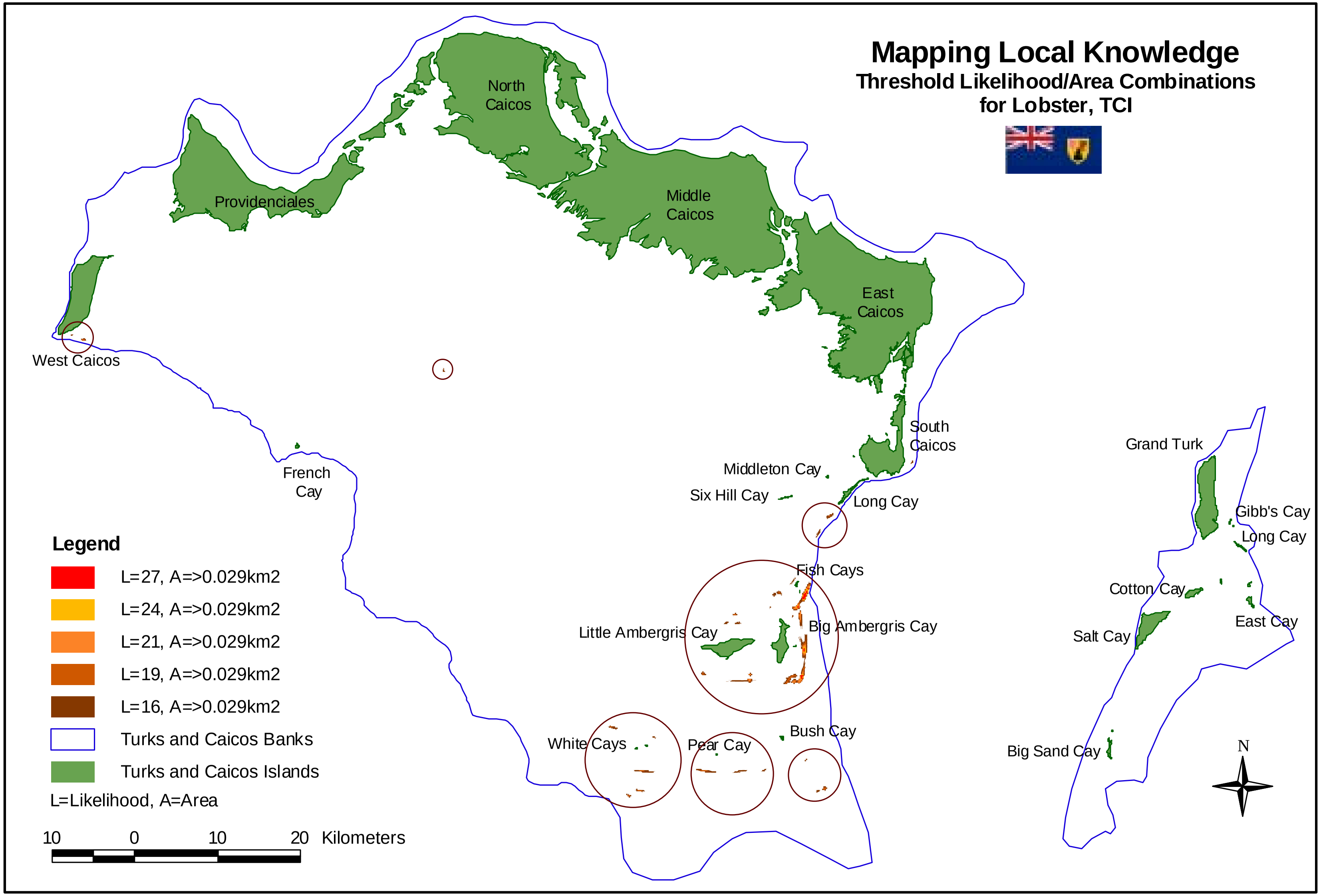


Figure 5.13: General Locations of High Pressure Harvest Areas for Lobster

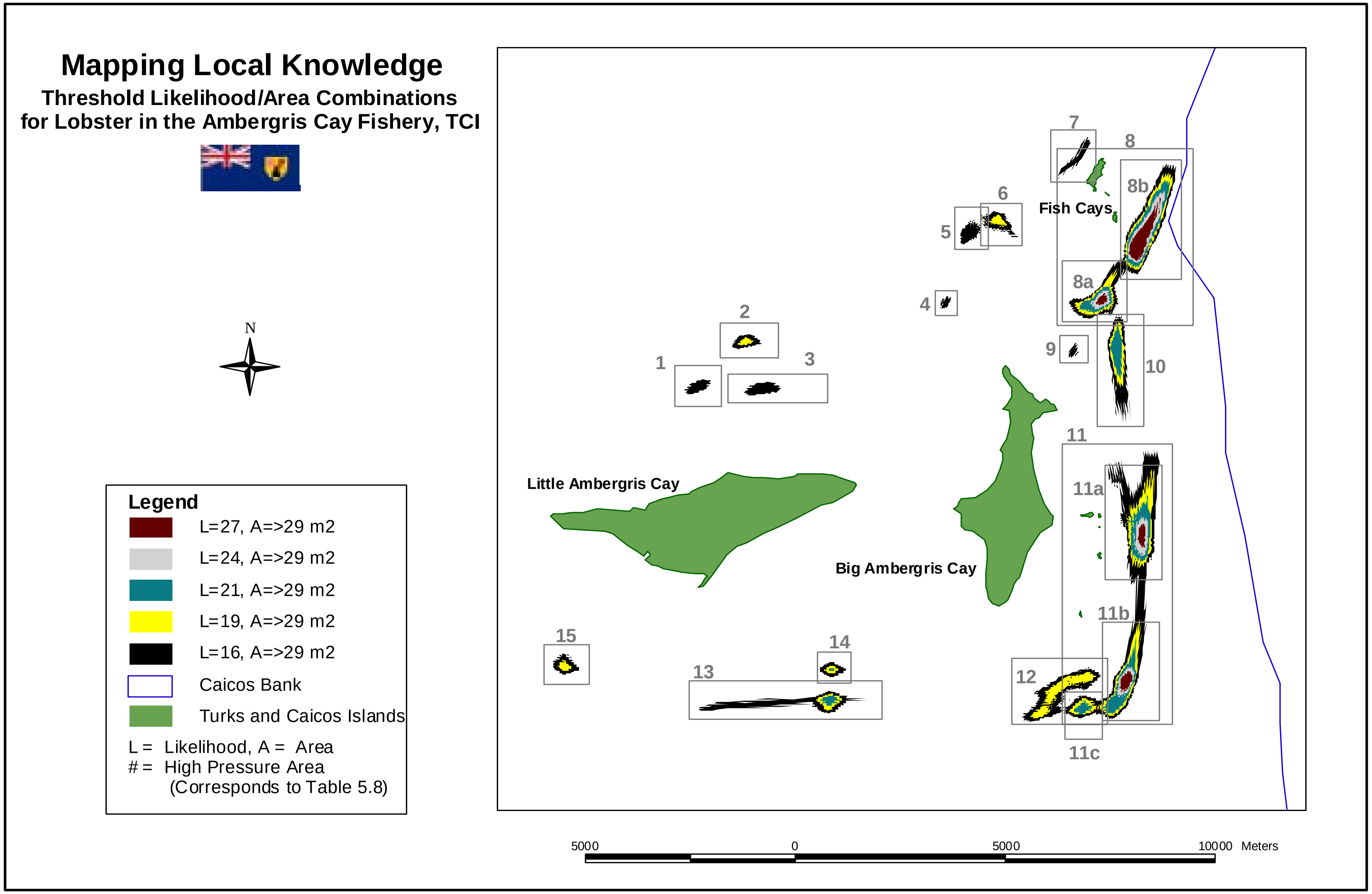


Figure 5.14: Locations of High-Pressure Fishing Areas for Lobster

fishery, Conch are allowed to be harvested before they reach sexual maturity and this is perhaps not in the interests of the long-term sustainability of the fishery.

Area #	Likelihood=16	Likelihood=19	Likelihood=21	Likelihood=24	Likelihood=27
1	99	340			
2	126				
3	151				
4	33				
5	133				
6	191	49			
7	118				
8	1178				
8a		865	691	494	264
8b		354	223	101	37
9	32				
10	607	295	168		
11	2815				
11a		670	415	184	62
11b		575	374	148	74
11c		1330	620		
12	724	288			
13	578	115	54		
14	117	34			
15	152	41			

Table 5.8: Area in m^2 of Lobster Harvest Areas by Likelihood Threshold Value (Please note that all values in this table are approximate)

With the high-pressure zones for Conch and Lobster discussed, Figure 5.15 illustrates the distances that these high-pressure fishing areas are located in reference to the three islands studied (Providenciales, South Caicos, and Grand Turk). These high pressure areas are located 70 to 80 km from Providenciales, 10 to 50 km from South Caicos, and although not applicable, 45 to 80 km from Grand Turk (harvesters fishing the main Caicos Bank are likely to fly over to South Caicos and take their boats out from there instead of traversing the deep water of the Turks Island Passage).

One further observation worth noting is that although the areas south of White, Pear and Bush Cays do not have high likelihood values associated with them, there is still a lot of fishing activity in this area. Thus, a more detailed study of the harvest activity and its impacts on the local aquatic ecosystem could be undertaken in this location.

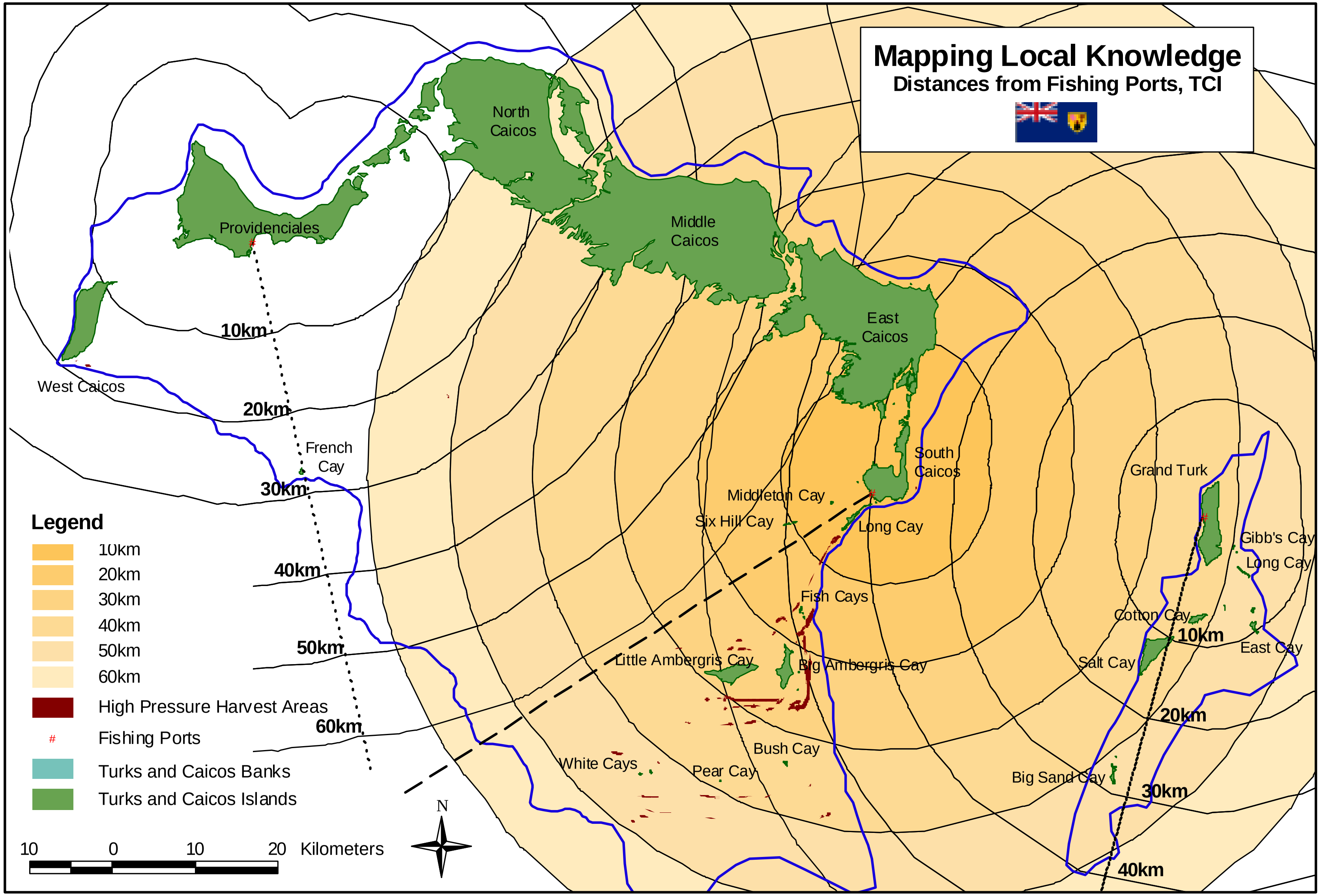


Figure 5.15: Distances of High-Pressure Fishing Areas from Fishing Ports within the TCI

5.1.3 Bottom-type Results

This section represents the third and final group of classifications from the 10 listed in Table 4.5. In addition to these classifications, the results from the RS and data comparison portions of the protocol are also presented.

As explained in Chapter 4, the last two bottom-type classifications required for the GIS component of the protocol included bottom-type maps derived from both the map and verbal portions of the harvester interviews. Figure 5.16 illustrates the bottom-type results from the map portion of the interviews and Figure 5.17 illustrates the bottom-type results from the verbal portion of the interviews. As noted in Chapter 4, the response rate for the map portion of the interviews was low with only six of the 38 harvesters interviewed providing bottom-types for each harvest location. Given this low response rate, the results of the map-based bottom-type classification are very generalised. For example, the area described as having a bottom-type of sea grass (shoreline immediately south of North, Middle, and East Caicos) covers a large area (approximately $848km^2$) and is unlikely to be completely characteristic of this area.

The result of the bottom-type classification derived from the verbal portion of the interviews is presented in Figure 5.17. This classification follows the same layout as the polygon-based species location map presented in Figure 5.4. However, the class type was changed to reflect the bottom-type where each species was most commonly found. In this context, many of the larger areas (for example, the area south of Grand Turk extending to Salt Cay to the south and East Cay to the east, the areas located east of Six Hill Cay, and the area encompassing White Cay, Pear Cay, and Bush Cay to the south of the Caicos Bank), like the grass area in the map-based classification above, have the potential to generalize many different bottom-types into one. Regardless of these issues, the two maps are compared to determine if similar bottom-types from the map-based classifications match those derived from the verbal classification.

The correspondence of these two classifications, as outlined in the data comparison component of the protocol described in Chapter 3, is presented in Figure 5.18. This figure illustrates only the bottom-type areas that are common to both Figures 5.16 and 5.17. Table 5.9 shows the frequency of areas that fall under each bottom-type combination. Of the 405 total bottom-type areas, 99 show an exact correspondence where grass from Figure 5.16 corresponds to grass from Figure 5.17. This equates to an overall correspondence rate of only 24%. There are, however, 92 of the 405 or 23% of the bottom-type combinations where there is some resemblance of the same bottom-type. For example, sand and grass (combination #1) could be considered similar in that many of the varieties

Combination #	Verbal	Map	# of Areas
1	***Grass***	***Grass***	99
2	**Grass**	**Sand**	8
3	Grass	Shoals\Rock	7
4	Grass	Middle Reef	1
5	Grass\Rock	Coral Heads	1
6	**Grass\Rock**	**Grass**	35
7	Grass\Rock	Grass\Coral	4
8	**Grass\Rock**	**Sand**	48
9	Grass\Rock	Shoals\Rock	1
10	Rock	Coral Heads	51
11	Rock	Grass	4
12	Rock	Grass\Coral	59
13	Rock	Sand	87

Table 5.9: Bottom-type Combination Results for the GIS component of the Protocol

of grass on the Caicos Bank grow sparsely rooted in sand. This rationale could also hold true for the grass\rock and sand (combination#8). For the combination of grass\rock and grass (#6), two-thirds of the grouping was grass, thus these areas have a higher probability of being grass. If these combinations of bottom-types are accepted as valid, the correspondence between verbal and map-based descriptions increases to 47%.

The second data comparison from the protocol presented in Chapter 3 involved the use of RS technology to classify bottom-types based on LK and SK. To construct the LK classification, Figure 5.16 was used as the input to establish training areas for the classification of a 1986 Landsat Thematic Mapper satellite image of the TCI, as discussed in Chapters 3 and 4. Figure 5.19 illustrates the training areas in relation to the Landsat image. Initially, all of the bottom-type areas from Figure 5.16 were used in the supervised classification. Due to the 848 square kilometre grass area encompassing a wide range of pixel or reflectance values (colours) in the image (as illustrated in Figure 5.19), the resulting classification depicted the entire Caicos Bank as being grass.

Subsequently, this area was removed as a training site and the image was reclassified using the remaining, smaller training areas. Given that the remaining training areas still encompassed variability in pixel values, (Figure 5.19 inset), the resulting classification is illustrated in Figure 5.20. According to the LK data, the majority of the Caicos Bank is made up of grass with the areas adjacent to the Cays classified as sand.

To construct the SK classification, an unsupervised classification was performed on the image. Ideally, the SK classification would have been best achieved through a well formulated supervised classification using training sites determined by the use of GPS units in the field to plot the different bottom-types across the Caicos Bank, however due to money and time constraints, this was not possible. Instead, an unsupervised classification was performed on the 1986 Landsat Thematic Mapper image to serve as the SK aspect of the research as described in Chapter 4. Because an unsupervised classification classifies bottom-types based on similar pixel values (reflectance), an interpretation of these output classes was required. This was completed using *in situ* knowledge and a previously classified Landsat image of the TCI performed by Green et al (2000). The results are presented in Figure 5.21 and illustrate more variation in bottom-types across Caicos Bank with the inclusion of two new bottom-types namely, macroalgae and sand/grass. Additionally, the southern most section of the Caicos Bank is classified as ocean, while this area was classified as grass/coral in the LK classification above.

The correspondence of Figures 5.20 and 5.21 is presented in Figures 5.22 and represents the second data comparison described in Chapter 3. Again, this figure illustrates only the bottom-type areas that are common to both Figures 5.20 and 5.21. For ease of comparison purposes, the classification shown in Figure 5.22 was converted to a polygon vector data. Thus, Table 5.10 shows the frequency of areas in Figure 5.22 that fall under exact and partial correspondence of bottom-types. Of the 6943 total bottom-type area polygons, 1208 or 17% show an exact correspondence, and 493 or 7% show a partial correspondence. Figure 5.23 illustrates the results of only the exact and partial bottom-type results. Following the same rationale described above for the GIS correspondence, if the exact and partial combinations are accepted as valid, then the correspondence rate increased to 24%.

LK Figure	SK Map	Correspondence	# of Areas
Sand	Sand	Exact	605
Sand	Grass	Partial	337
Grass	Grass	Exact	505
Grass	Grass\Coral	Partial	19
Sand\Grass	Sand	Partial	122
Sand\Grass	Grass	Partial	2
Coral	Coral Heads	Exact	98
Grass	Sand	Partial	13

Table 5.10: Bottom-type Combination Results for the RS component of the Protocol

With the results of the classification presented, the discussion now turns to the construction of these classifications and the objectives of this research relative to the development of a locally relevant fisheries management plan.

5.2 DISCUSSION

The general research framework presented in Chapter 2 proposed that SK alone is not an adequate knowledge base from which to devise resource management decisions and that the inclusion of LK can help to fill the gaps that currently exist in resource knowledge bases. The general objective of this thesis, namely to develop a process-driven operational framework for the integration of LK with SK within an SIT environment, is now revisited. Using the fisheries protocol in Chapter 3 as a guiding reference and the classifications described above, this section first discusses how the specific objectives of the thesis were satisfied in the context of the general research framework presented in Chapter 2. Next, the practical primary and secondary implications of the fisheries protocol are explored through a discussion of how the protocol, in general, can serve to empower local communities (both government and harvester collective) to devise their own, low-cost FMP through the Fisheries First (FF) management approach.

5.2.1 Collecting and Storing LK in a GIS

The first objective of this thesis was to devise a method for collecting and storing local knowledge in a GIS database and, using basic GIS functionality, utilise this knowledge for resource management

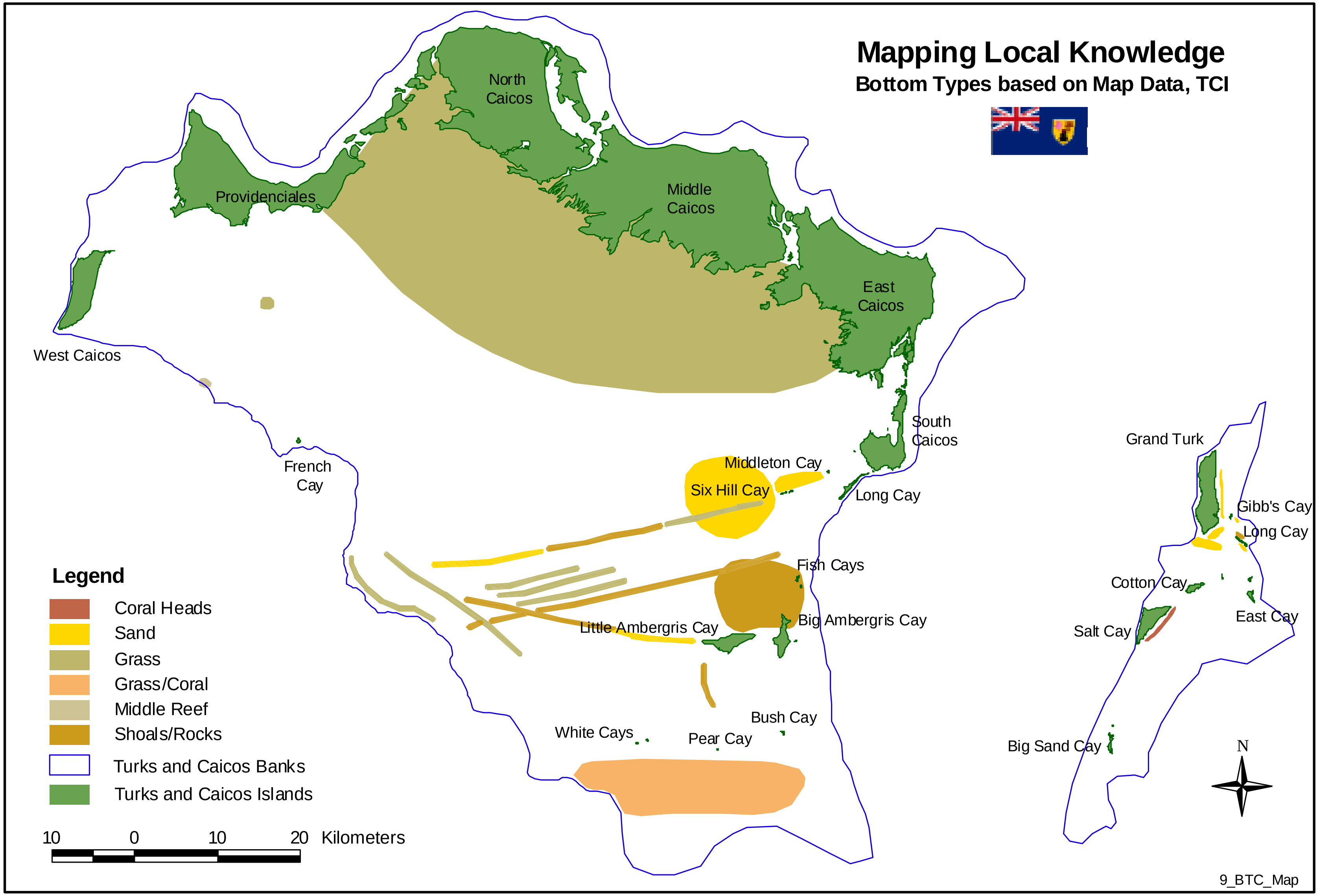


Figure 5.16: Bottom-Type Classification Based on Data Collected from the Map Portion of the Interviews

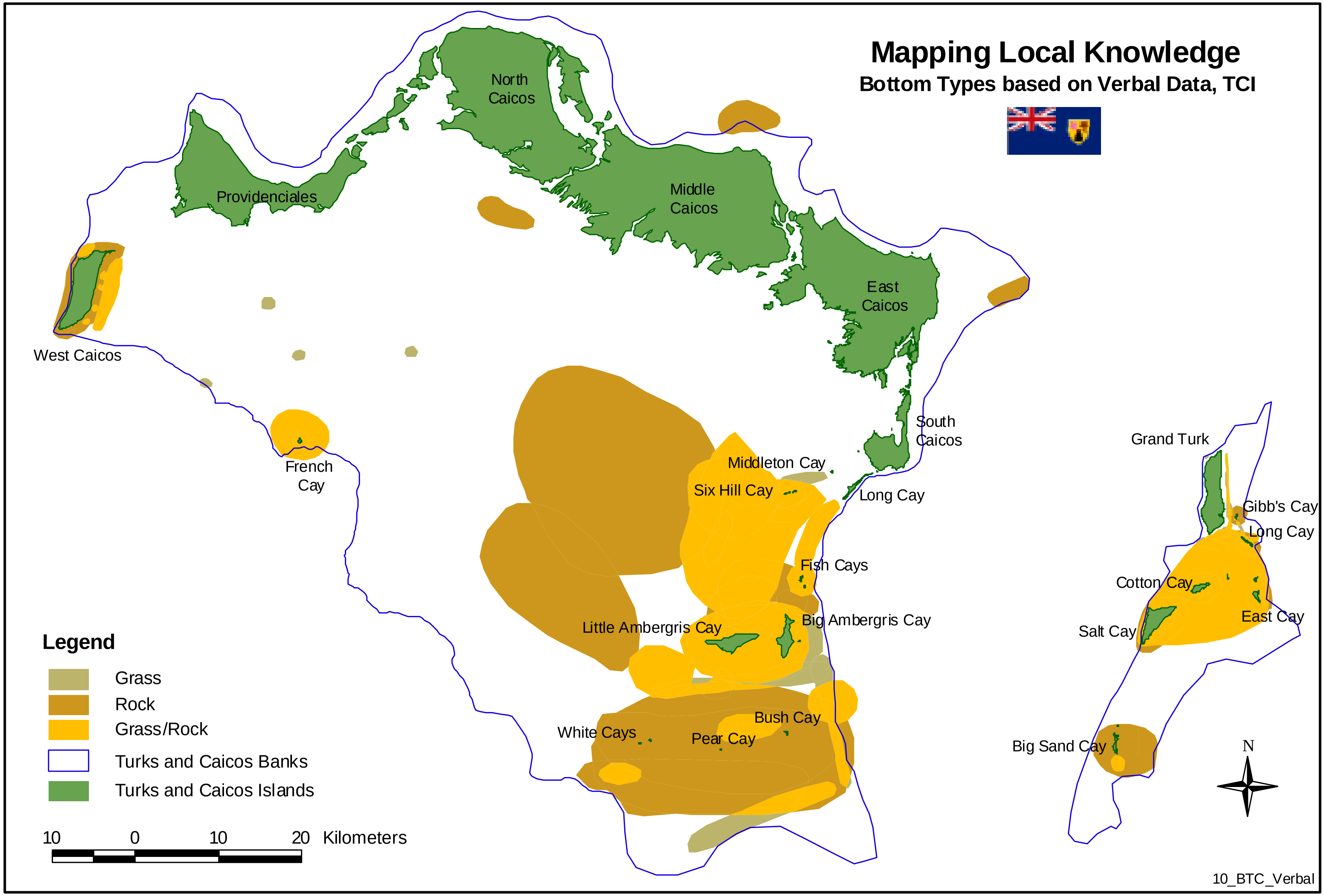


Figure 5.17: Bottom-Type Classification Based on Data Collected from the Verbal Portion of the Interviews

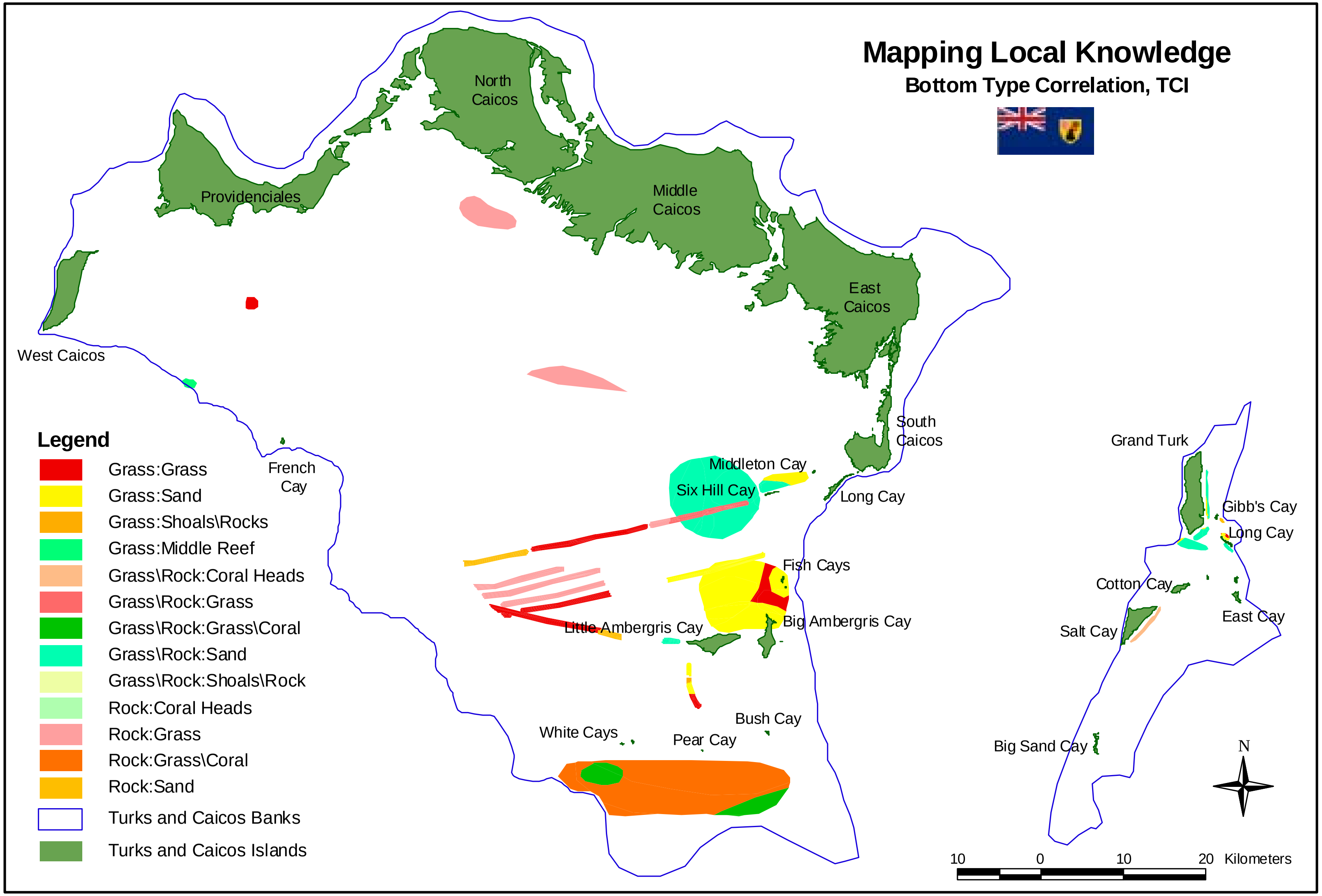


Figure 5.18: Correlation Between Bottom-Types from the GIS Component of the Protocol

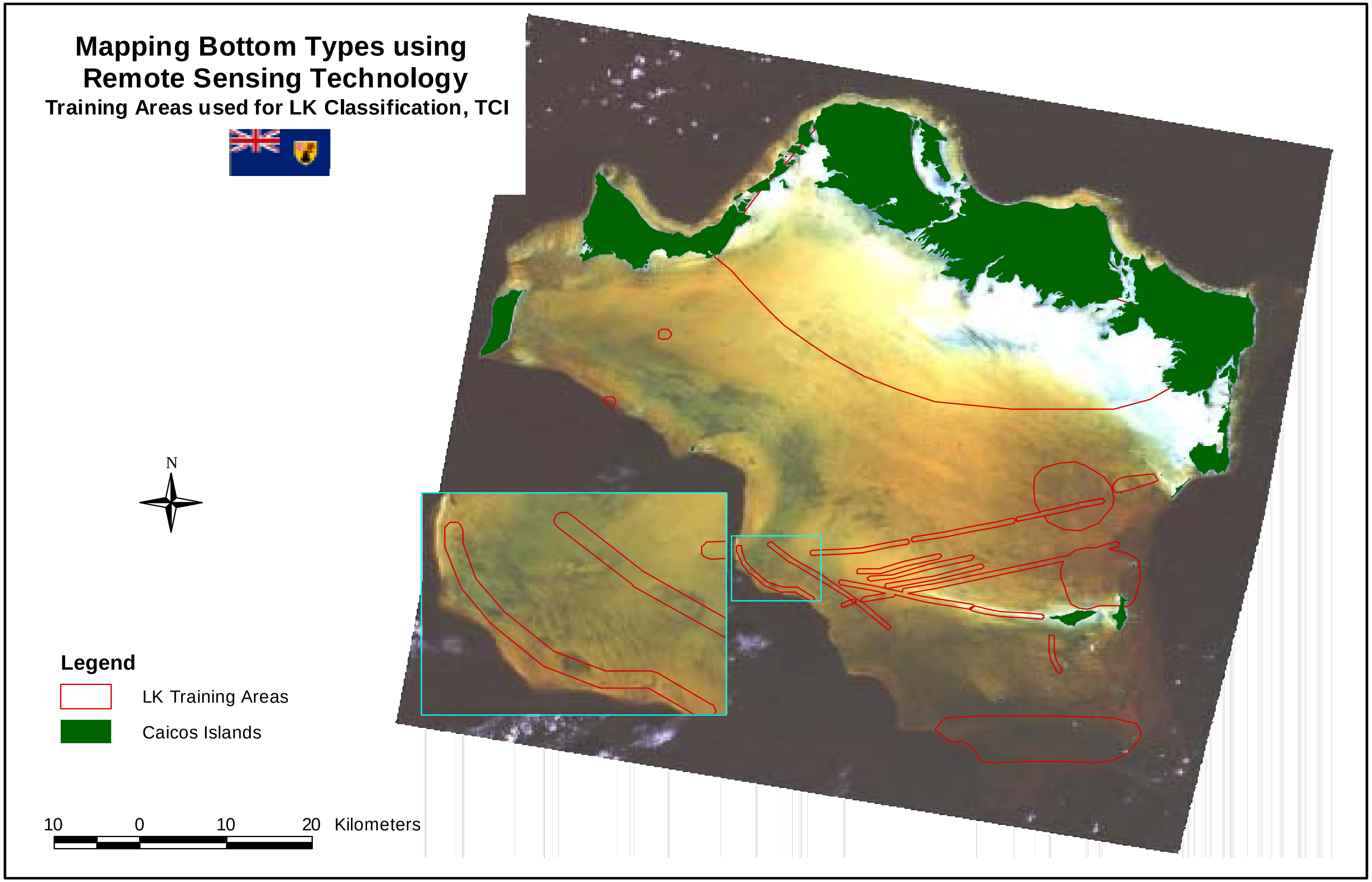


Figure 5.19: Training Areas used for the Supervised Classification of LK

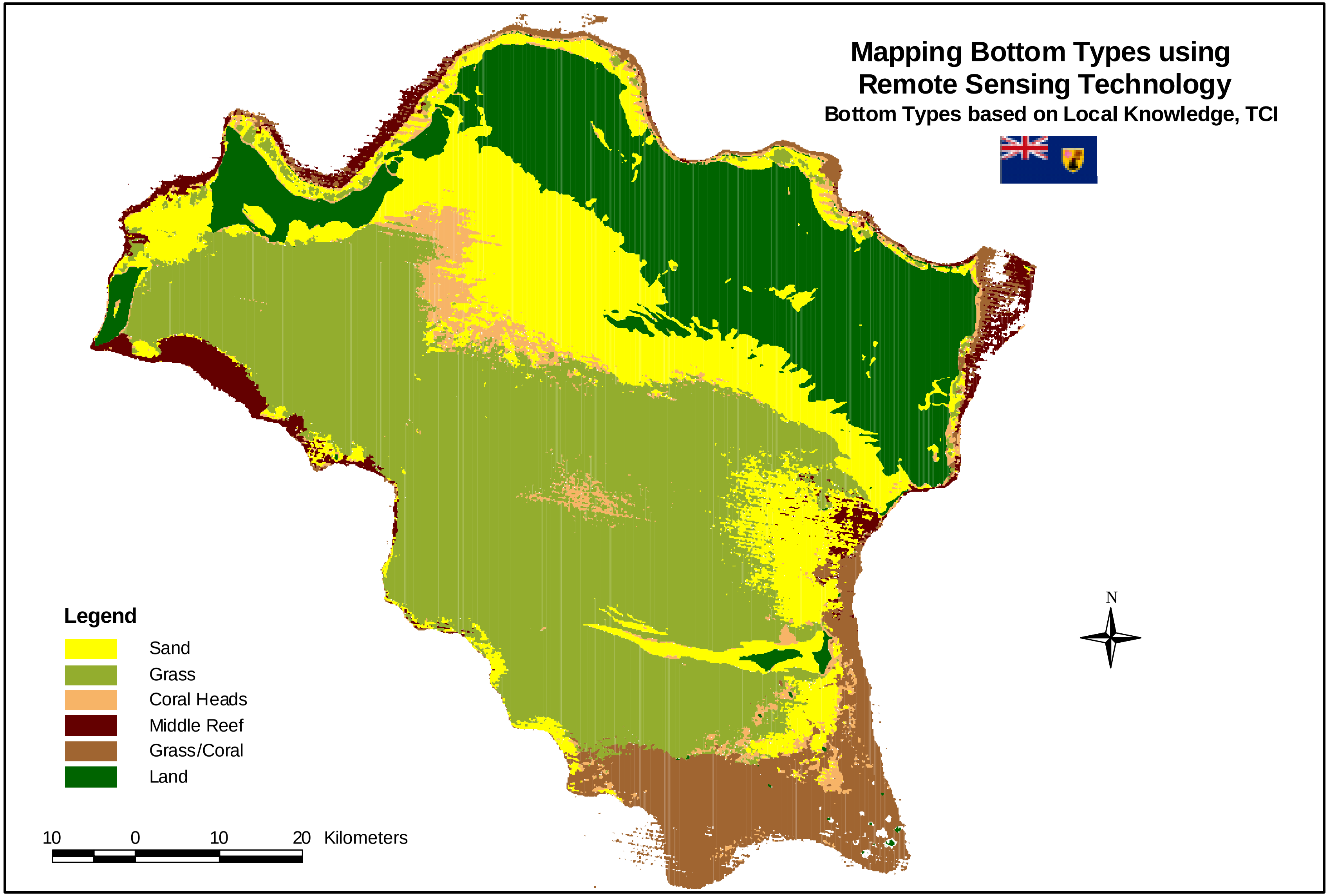


Figure 5.20: Bottom-Type Classification Based on LK Map Data input for Training Areas

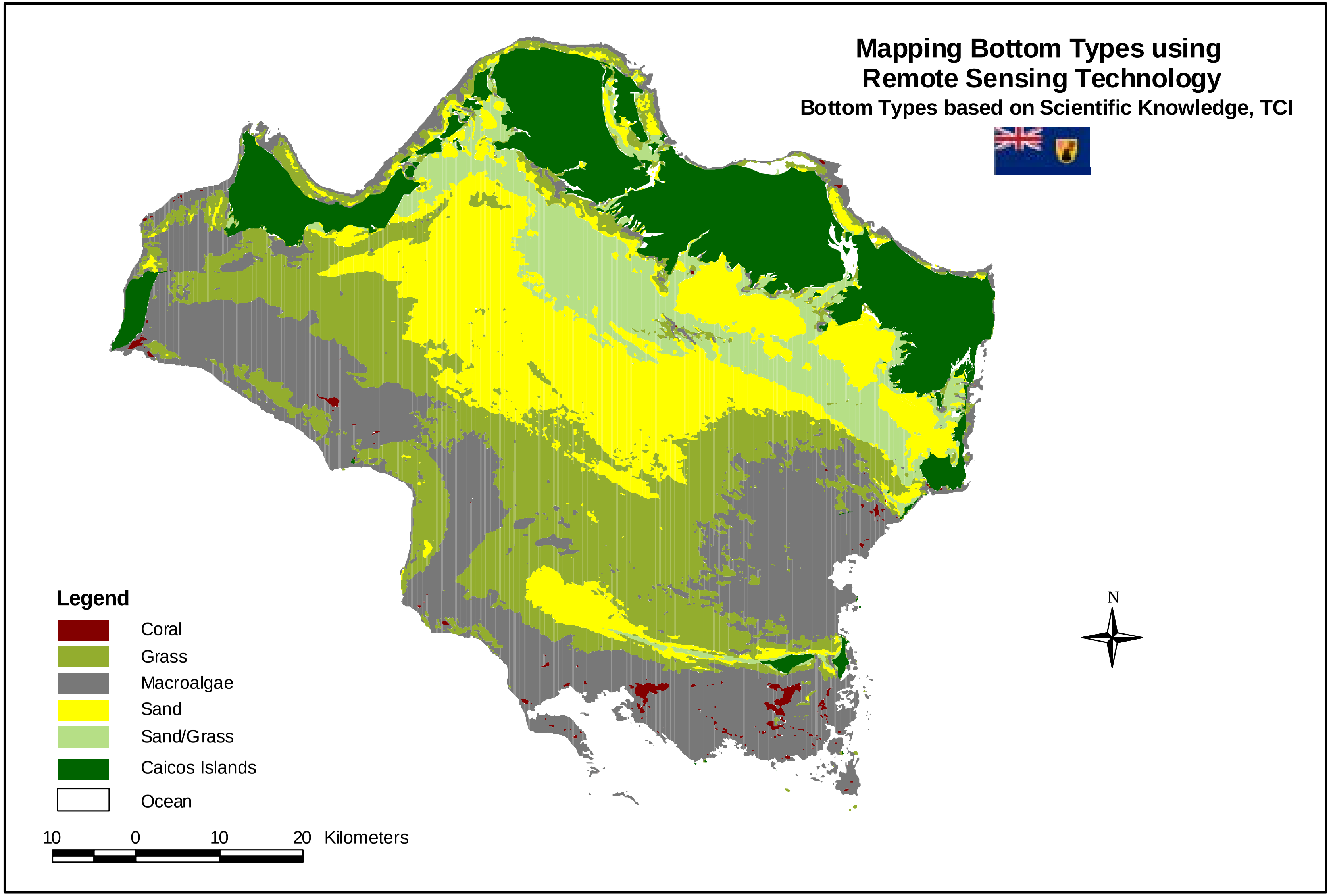


Figure 5.21: Unsupervised Bottom-Type Classification for SK

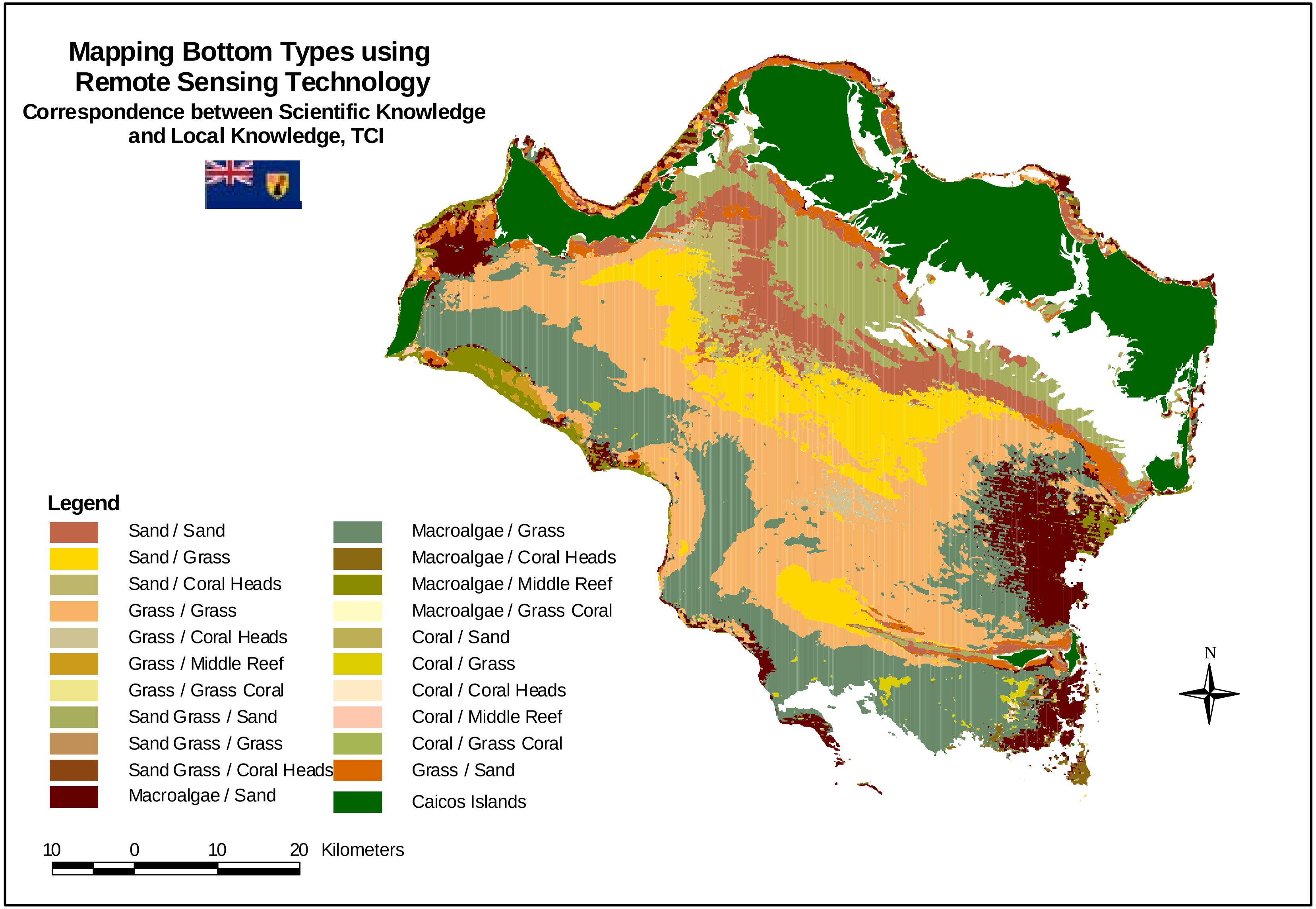


Figure 5.22: Correlation Between Bottom-Types from the RS Component of the Protocol

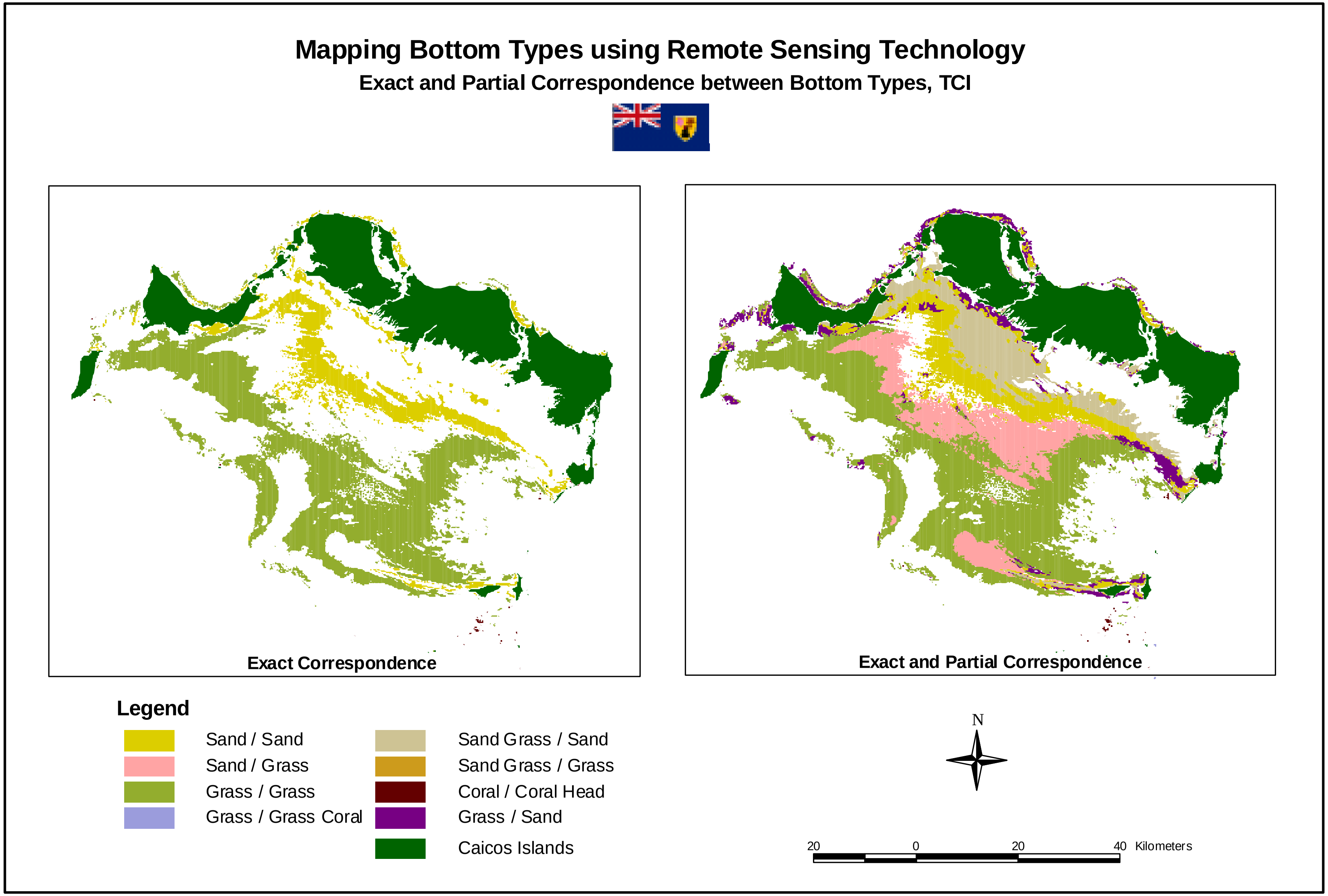


Figure 5.23: Exact and Partial Correlation Results

and planning. This objective was satisfied through the development of the general fisheries protocol or SIT translator detailed in Chapter 3. The classification methodology outlined in Chapter 4 and the results presented above (with the exception of the RS classifications) are a direct result of using this protocol in the field.

Through the devised LK classifications, a fisheries manager or representative group from a harvester collective can see the extent of the harvest area, species distributions across the study area, areas that are being frequented by harvesters, frequency of harvester visits per day, harvester trip routes per day, and areas that are under varying degrees of fishing pressure per day. These classifications could be used alone or in conjunction with classifications of similar data derived from traditional SK and its associated data collection methods.

The actual method of inputting LK into a GIS database was, in the final analysis, quite simple as the data that harvesters provided were similar to other spatial data used in GIS on a daily basis. The major difference when dealing with local resource users, however, is the error associated with map bias, as discussed in previous chapters. Once a method of compensating for map bias was devised and utilised (use of the single and multi-buffer described as in Chapter 3), the issues of conflicting data types, as discussed in Chapter 2, could be addressed.

Chapter 2 began with the discussion that, although the LK of resource users is gaining prominence in the field of resource management due to the scientific community's inability to acquire complete data about many natural resources, there are problems that exist in the integration of this new knowledge. As illustrated in the general research framework, these problems translate into impediments that block the flow of LK into its relevant knowledge base. One specific impediment upon which this research was built, is the integration of qualitative and quantitative data types. By adding a spatial component to LK, the protocol discussed in this research allows LK to be visualised spatially, in map form, and analyses to be performed upon it like any other quantitative GIS data source. Given that each harvester's knowledge is by itself qualitative, inputting and analysing the data into a GIS gives LK a quantitative character. For example, the harvest areas for Lobster as illustrated in Figure 5.2, shown by virtue of number of harvesters, areas that are heavily fished. Furthermore, giving LK a spatial context gives the LK-based classifications measurable meaning in that a fisheries manager can reference harvest areas on a map and thus compare that measurable 'meaning' with other quantitative data. Moreover, although not collected in this research, the number of species harvested per trip, per harvest area could prove invaluable in determining quantitative stock values. Through this ability to view LK in a visual and quantitative manner, resource managers have the option of using a well-rounded, unified SK-LK knowledge base.

In the event that SK is not available, however, there are enough data about the fishery present in the classifications illustrated at the beginning of this chapter to make management decisions without any input from the scientific community. In this context, local fishing communities potentially have the power to assess their fishery using their own LK.

5.2.2 Building an Updatable LK Database

The second objective of this research was to explore the feasibility of building an updatable LK database. This objective was satisfied using the combined functionality of Microsoft Access and ArcView GIS, as suggested in Chapter 4. Part of the usefulness of any GIS database is the ability to update it. As mentioned in Chapter 3, the more data that can be collected, the greater the confidence that can be placed in making management decisions, specifically in the case of LK. Furthermore, if multi-year or multi-season data can be collected on a fishery, it should be possible to build a more complete view of the resource and how best to manage it. For example, with a detailed approach it would be possible to determine trends in harvest activity or to track harvester fishing patterns over time. In order for multi-year data to be collected from the fishery, the protocol used in this thesis would need to be refined, as suggested in Chapter 6, and implemented on a yearly basis to ensure a temporal 'picture' of the fishery could be constructed. Moreover, rather than collecting data only from a sample of harvesters, it should be feasible to collect information on fishing locations by species from *all* artisanal harvester active on each island.

When dealing with small-scale fisheries, however, where monetary support from the local government may be limited, a relatively inexpensive method of collecting data on a yearly basis is required. As noted in Chapter 4, a combination of Microsoft Access and ArcView can provide such technology. Both Access and ArcView are relatively inexpensive (ArcView is approximately $1000 US; Microsoft Access is roughly $300 US) and can be customized to suit the needs of the fishery in question.

Other factors that must be considered in this endeavour include, but are not limited to, issues associated with the integration of the FF protocol in the host country and harvester participation issues. Examples of problems that could be encountered with the integration of the FF protocol include end-user knowledge of the computer programs used, and the host country's acceptance of and willingness to use this protocol.   Examples of harvester participation issues that must be addressed include: i) harvester fishing location confidentiality; ii) benefits the harvesters are likely to receive from participating in the production of a coordinated management plan; iii) will the harvesters be truthful in the LK that they provide, and vi) do the harvesters want to share their knowledge of harvest locations on a yearly basis or at all. These are all issues that would need to be addressed and may differ depending on the country in question before implementation of the protocol can proceed.

Suggestions to attract harvester participation could include incentives such as extra quota catches, reductions in licensing fees, or the collection of LK could be part of the licensing process. Harvester confidentiality could be maintained through a random identifier code that would be automatically generated each time a harvester fills out a new data form. Ideally, LK collection should occur at the end of the season when conditions and activities are fresh in the minds of the harvesters.

5.2.3 Comparison of Local Knowledge versus Scientific Knowledge

The third objective of this research was to compare and contrast LK and SK by comparing sea floor types as described by harvesters, relative to those observable from satellite imagery. This objective is satisfied through the maps illustrated in Figures 5.16 to 5.23.

For the first comparison, Figures 5.16 and 5.17 were compared to see if bottom-types from one image corresponded to the same or similar bottom-types from the second image. There was a 24% accuracy rate for same bottom-types and a 23% accuracy rate of similar bottom-types. As noted in the results section, if these combinations of bottom-types are accepted as valid, the correspondence between verbal and map-based descriptions of bottom-types increases to 47%. However, given that the data collected for the map-based classification were somewhat weak in terms of number of harvesters providing bottom-type data and the verbal portion of bottom-type data was based on percent of bottom-type for each species caught, Figure 5.19 still shows a good correspondence. Despite this good correspondence, more research would need to be conducted before any concrete conclusions could be made concerning the accuracy of LK. This being said, the results do indicate that the accuracy of LK has the potential to be higher. If this is the case, the significance of these results can help to verify the accuracy of LK and thus providing increased confidence in the use of LK within the scientific community.

With respect to the second knowledge comparison, Figures 5.20 and 5.21 were compared to see if bottom-types from LK-based classification corresponded to the exact or partial bottom-types from the SK-based classification. In this context, there was a 17% accuracy rate for the same bottom-types and a 7% accuracy rate for partial bottom-types. If the combinations of exact and partial bottom-types are accepted as valid, then the correspondence increases to 24%.

A low accuracy rate was expected given that the input for the LK classification was weak in terms of numbers of bottom-type responses, high variability of pixel values within the training areas, and the uncertainty of unsupervised SK classification. Furthermore, as noted in Chapter 3, the classification of the marine environment using RS technology is problematic due primarily to two issues, namely remote sensing imagery has trouble penetrating the water column and sensor technologies have not advanced far enough to distinguish between bottom-types of similar reflectance within the context of a marine environment (for example, detritus and sea grass) (Green et al, 2000). Thus, further research would be required to make this study more viable. For example, bottom-type questions during the interview sequence would need to be stressed more, bottom-types for SK would need to be collected through GPS units and finally, a more detailed analysis of the satellite imagery would need to be performed, specifically issues associated with mapping marine environments.

5.2.4 Exploration of Harvester Decision Processes

The fourth and final objective, namely to study harvester decision processes, specifically how they decide which species (if multiple species are harvestable during the same time period) to fish for, relate to the knowledge collection portion of the interview sequence. While no concrete conclusions can be drawn from this, the research in this thesis found that the majority of harvesters made their decisions based first on what species were in season and second, on which species brought in the most money.

As discussed in Chapter 4, Section 4.1, the Lobster season in the TCI starts on August 1st and ends on March 31st. Conch, on the other hand, is in season from mid-October to mid-July. This leaves approximately 5.5 months where the end of the Lobster season overlaps with the beginning of the Conch season, as illustrated in Figure 5.24. Thus, fishing activities follow a clearly defined seasonal sequence. If Lobster were in season, then the harvesters would fish for Lobster. The only times that harvesters would fish for Conch would be when the Lobster season is closed, or if Lobster fishing was not productive on a particular day when Conch was in season. This being said, nine of the 38 harvesters interviewed said that Conch brought in more money. However, as revealed by the harvesters, Lobster fishing is only best during the first week of the season. After this initial time period, the Lobster become harder to find, with fewer large Lobster available. Still, many harvesters indicated that regardless of this drawback, a poor catch of Lobster was better than a good catch of Conch, as verified by the verbal results presented in Table 5.1 above. Furthermore, it was unclear if the nine harvesters who found that Conch brought in more money, would switch to Conch when the Conch season opened or would remain fishing for Lobster because of their greater monetary returns.

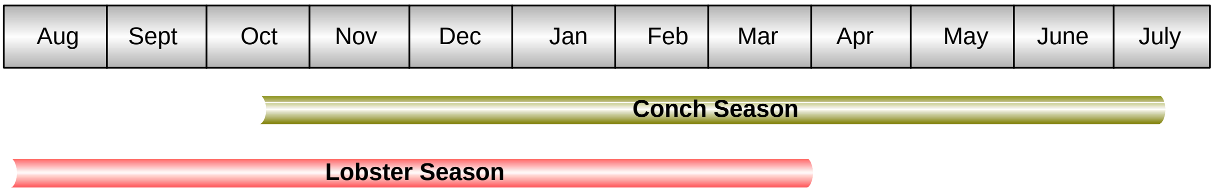


Figure 5.24: Comparison of Open Seasons for Lobster and Conch

With the objectives of the thesis satisfied, discussion now turns to the potential implications of using the general fisheries protocol as a tool to assess a small-scale fishery within the framework of the FF management sequence.

5.2.5 Implications of the Fisheries Protocol

This section discusses the broader implications of the general fisheries protocol and the plausibility of using it as a means to empower small-scale fishing communities to combine local and, if available, scientific knowledge in assessing their own fishery, thus laying the groundwork for a locally relevant FMP.

Chapter 3 (Section 3.1.1) introduced a Fishery First (FF) procedural sequence for the management of a small-scale fishery. The main premise of this revised sequence allows local fishing communities to assess their own fishery using the local knowledge of the harvesters that exploit the resource. In order to facilitate this assessment, a relatively inexpensive method for incorporating LK into management, as suggested in this thesis, is through the use of SIT as a knowledge translator.

The results of the application of this translator in the TCI, illustrate the plausibility of empowering local fishing communities to access their own stock under the FF management approach. Furthermore, through this SIT translator, the four principal issues that contribute to fisheries management failures identified by Cochrane (2000), could potentially be diminished through the FF procedural management sequence as explained below.

Figure 5.25 illustrates the potential primary implications of using the research protocol within the FF framework. As noted in Chapter 3, there are six stages in the FF management approach, namely get to know your fishery, stock assessment, determine the needs of the community, formulate management strategies, implement management, and establish policy. The stage of particular importance to the success of the FF sequence is the stock assessment stage. Through this stage, the research protocol or SIT translator can be used as a relatively affordable method to collect and assemble LK data, as outlined in previous chapters, to formulate a locally relevant assessment of the fishery. In this context, the research protocol gives a local fishery access to affordable, essentially free data about their fishery. With these data and associated classifications, the capacity for self-sufficiency through local control and local management of the fishery is possible. The concept of local control is used here in a general sense in that a fisheries department would not have to rely on outsiders for information and that they have the choice of who their researchers are and what is to be researched. Additionally, harvesters (if working under the guise of a collective) would not only have control of their own knowledge, but could control what LK is given to the local fisheries department. Local management is a more specific term with respect to the ability of the fishing community to make management decisions based on the condition of their own fishery and the needs of their own community.

A secondary implication of the fisheries protocol used through the FF management sequence is a potential reduction in the limitations that Cochrane (2000) stated as the leading causes of fisheries management failings. As discussed in Chapter 3, Cochrane highlighted four limitations to fisheries management namely, high biological uncertainty, conflict between the constraint of sustainability and social and economic priorities, poorly defined objectives, and institutional failures related to access rights and participation in management by the users. Initially, this research aimed to alleviate points one and four of Cochrane's four limitations. However, on evaluating the results the fisheries protocol using LK collected from the TCI, the protocol has the potential to alleviate all four limitations, as discussed next.

First, biological uncertainty is characterized as a lack of complete knowledge about an aquatic species. While completely removing biological uncertainty is impossible, the more knowledge that is acquired about a fishery, the higher the likelihood that biological uncertainty will be decreased. The protocol presented in this thesis presents a method that a small-scale fishery could employ to collect data on their own fishery, thus constructing a larger knowledge base from which to derive management decisions. For this to occur, however, the fishery using this methodology would need to obtain yearly LK data concerning the fishery, utilizing improvements to the general fisheries protocol including more complete data collection, as noted in Chapter 6.

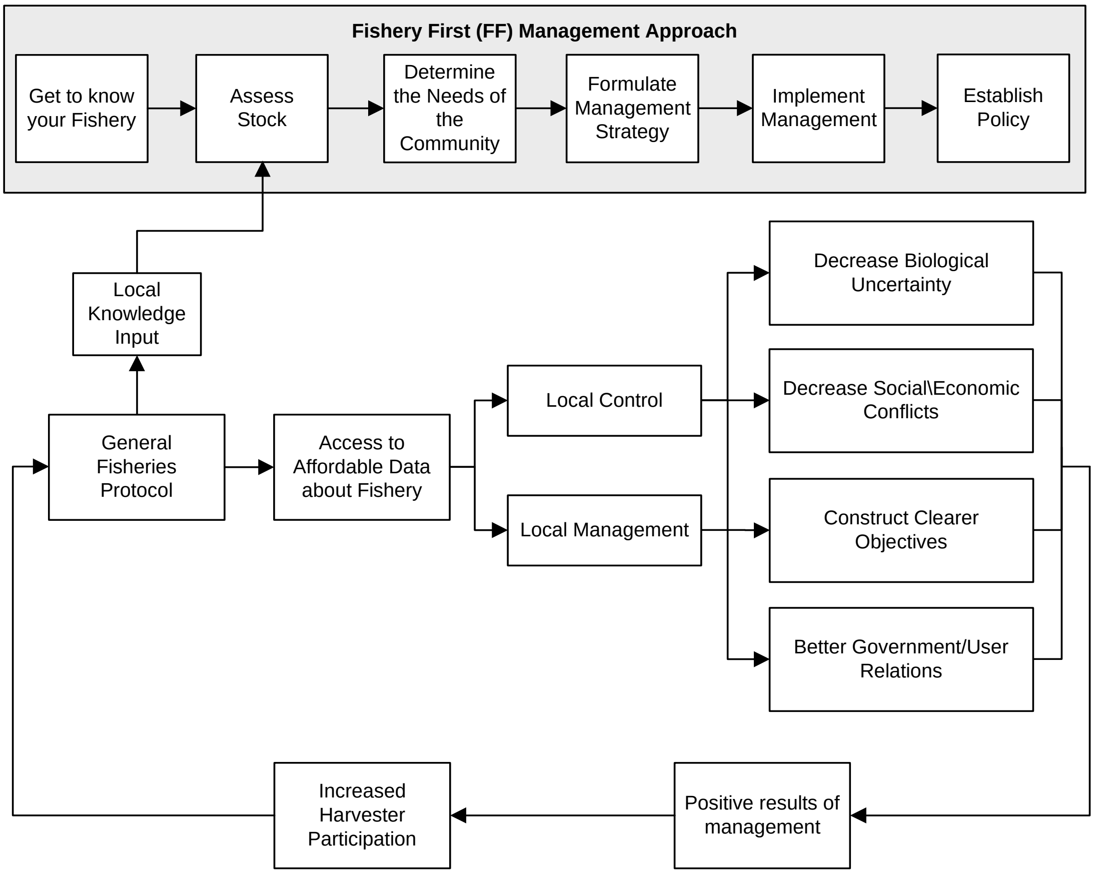


Figure 5.25: Implications of using the Fishery First Management Approach

Next, the conflict between social and economic priorities and poorly defined objectives can be explained together because they are intrinsically linked. Conflict between social and economic priorities commonly arise because economic issues are prioritised above social issues, which in turn can conflict with fisheries management objectives that are in place to promote resource sustainability. Poorly defined objectives occur when governments struggle to find a balance between economic interests and long-term resource sustainability. As noted above, the FF sequence can serve to alleviate both of these issues by helping to improve managers' levels of understanding of the condition of the fishery and the needs of the community. If the government knows the condition of the fishery and what the community needs, then the objectives of fisheries management could be more clearly set. This would, in turn, serve to reduce the conflict between social and economic priorities, and potential conflicts between harvesters, resource managers, and government.

The final reason for the failure of fisheries as noted by Cochrane (2000) is institutional weakness. As discussed in Chapter 2, institutional weakness is a problem that arises when governments use a top-down, management approach of common pooled resources. Top-down management approaches tend to produce poor communication among and between fisheries managers and harvesters that can lead to frustration amid the harvester community that often results in poor compliance with fishery regulations. Again, if the objectives are set according to the needs of the community and the condition of the resource as discussed above, then harvesters could see the benefits of the management process and perhaps be more willing to participate in the collection of LK through the general fisheries protocol. This would provide positive feedback into the FF systems, thus providing the basis for a tightly knit, self-sufficient fishery, where the country has control of its own fishery and community needs.

5.3 Chapter Summary

This chapter presented the results of the fisheries protocol from Chapter 3 using the case study of the TCI. The results of the 10 classifications from the GIS component of the protocol were discussed in terms of how they fit into a Fisheries First management framework. The results of the RS and data comparison components of the protocol were also discussed. The objectives of the thesis were reviewed and shown to have been satisfied through the results of using the proposed fisheries protocol. Finally, the primary and secondary implications of the protocol, namely, the empowerment of local fishing communities through the FF sequence to assess and manage their own fishery, and the potential decrease in Cochrane's (2000) four limitations to fisheries management, were discussed.

Chapter 6

CONCLUSIONS

This thesis has explored the integration of LK for use in fisheries management planning using SIT. While there is a large body of literature discussing the potential of using LK in fisheries management, there are very few occurrences of the operationalization of LK using SIT for the assessment of harvest activities and their subsequent incorporation into species management and planning. The thesis considered the use of ArcView GIS as a relatively inexpensive medium upon which to integrate and visualise spatial distributions of both quantitative SK data and qualitative LK data for the purposes of producing scientifically valid and locally relevant fisheries management plans in a small-scale fishery in the TCI. This was achieved through the development of the general fisheries protocol presented in Chapter 3.

This chapter concludes the thesis by first reviewing its contributions to resource and fisheries management. Second, the significant findings of the thesis are discussed relative to existing research. The chapter concludes with a discussion on improvements and directions for further research.

6.1 CONTRIBUTIONS

Beyond satisfying the initial objectives as discussed in Chapter 5, the research in the thesis has made a number of contributions to resource management in general and fisheries management in particular. First, the research protocol presented in Chapter 3 provides a methodology that allows for the inclusion of LK, an additional knowledge source other than SK, into resource management by alleviating two of the four barriers that hinder the extraction and integration of LK into resource management bases and decision-making. As outlined in Chapter 2, these barriers include the validity of LK and treatment of local resource harvesters as equals by the scientific community and the advantages and disadvantages of qualitative versus quantitative data. Through this inclusion, LK can help to fill the gaps that currently exist in resource management knowledge bases, which in turn, can lead to more complete resource knowledge bases from which to devise well-rounded resource management plans.

Second, the research protocol, in addition to the Fisheries First sequence presented in Chapter 3, provides an alternative approach for small-scale developing countries to assess and keep track of their own fishery in a relatively inexpensive manner. Further, the protocol empowers small-scale fishery managers with the ability to enact control over their own fishery in terms of research directions. More importantly, it provides them with a means of devising management plans that suit the needs of their community for the long term. In the absence of reliable SK, the fisheries protocol could be used as a method for local fisheries departments to assess their fishery using the LK collected from their own community. For example, in the context of the TCI case study, the DECR could take the base program of ArcView GIS and, with limited data sets, collect knowledge from the local harvesters in the TCI. From this knowledge, the DECR could then build a visual picture of their fishery, as illustrated through the results presented in the previous chapter, upon which the DECR could then use in future fishery management plans.

6.2 SIGNIFICANT FINDINGS

Relative to existing research, the case for LK in fisheries management using spatial information technologies (SIT) is in its infancy. While there are many occurrences in the literature concerning LK and fisheries management and SIT in fisheries management, there are few examples that discuss methodologies for the convergence of all three issues (LK, fisheries management, and SIT), specifically in the context of species assessment and management. The research in this thesis fills this void by illustrating not only how the use of a relatively inexpensive GIS can alleviate conflicting data types associated with the lack of LK in resource and fisheries management, but also how this incorporation of LK through the FF sequence can lead to the reduction in Cochrane's (2002) four limitations to fisheries management.

As noted in previous chapters, the qualitative nature of LK does not correspond with the quantitative configuration of SK. While this remains correct in the truest sense of the definition, by adding a spatial component to LK, the protocol discussed in this research allows LK to be visualised and analysed like any other quantitative GIS data source. Furthermore, given that each harvester's knowledge is by itself qualitative, the inputting and analysing of combined instances of harvesters' knowledge (for example harvest locations) into a GIS, gives aspects of LK a quantitative character. Through this ability to view LK in a visual and quantitative manner, resource managers have the option of using a well-rounded, unified SK-LK knowledge base.

With a more complete knowledge base from which to devise management decisions, Cochrane's (2002) four limitations to fisheries management, namely high biological uncertainty, conflict between sustainability and social and economic priorities, poorly defined objectives, and institutional failures related to access rights and participation in management by the resource users can be alleviated. While completely removing biological uncertainty is impossible, the more knowledge that is acquired about a fishery, the higher the likelihood that biological uncertainty will be decreased.

In terms of alleviating both the conflicts between sustainability, social and economic priorities and poorly defined objectives, the knowledge translator discussed and used in this thesis can help to improve managers' levels of understanding for both the condition of the fishery through the fisheries protocol and the needs of the community. If the government knows the condition of the fishery and what the community needs, then the objectives of fisheries management could be more clearly set. This would, in turn, serve to reduce the conflict between social and economic priorities, and potential conflicts between harvesters, resource managers, and government. If harvesters see the benefits from this improved management process, then perhaps they would be more willing to participate in the collection of LK through the general fisheries protocol.

Despite successfully demonstrating the potential for LK inclusion, clearly there are several aspects of the research that can be improved. These are discussed in the following section.

6.3 Improvements and Directions for Future Research

Given the positive results from the use of this protocol in the TCI, there are a number of improvements can be made. Thus, this section discusses improvements to the protocol followed by directions for further research.

The first improvement to the protocol would be the inclusion of more data. In this context, because harvesters typically work with three harvesters to a boat (one captain and two divers), it may be more beneficial to interview harvesters on a per boat basis. This could potentially cut down on the amount of redundant data and ensure that all of the harvesters are included in the data collection.

Second, the need to determine the numbers or pounds of fish caught per area is vital in ascertaining a numeric stock model of the fishery. This approach, however, depends upon active participation from harvesters in the fishery. Furthermore, the timing of the LK extraction would have to be considered. For example, should this information be collected on a daily basis or over a season based on the average fish caught in each area? While the former would be ideal from a management standpoint, it would be much more time intensive for both parties involved. Given that harvesters can be quite tired after a day on the water, not to mention the infringement of harvester confidentiality with respect to divulging exactly where they catch fish and how much, harvesters may be unlikely to participate. Thus, collecting an average value of fish caught per area over a season would be a better option.

A third improvement to the protocol would be the inclusion of an underwater elevation model (UEM) or bathymetric surface. While this surface would require additional extensions for ArcView GIS, thus additional cost, this surface could be used to evaluate areas of high fishing pressure (similar to Figures 5.9 through 5.14) for bottom structure and it relation to species and/or fishing productivity.

Fourth, if the exploratory RS component of the protocol was to be repeated, the use of a GPS unit to map bottom-types would provide a better representation of the SK aspect of the research. Further, through a combined SK-LK effort, a GPS could be used to plot harvester trips and harvest locations that would indicate very accurate harvest locations. However, this approach would require more cost to the protocol, thus violating its main premise of devising a relatively inexpensive method for collecting LK. This could, of course, be explored with fisheries that are interested and have the funds to support this type of technology.

A fifth improvement to the protocol could be the use of a GIS tablet. A GIS tablet is like a hand held GIS, similar to a Palm Pilot, where locations of harvest areas could be drawn and thus recorded right on the screen of the hand held unit. It could be taken into the field and the harvester could point out and record their harvest areas similar to the paper map method used in this research, only no heads-up digitizing would be required. Again, however, this is a relatively new technology that would have additional costs and logistics associated with it, such as issues of map scale and detail of base maps. With a small screen, it is unlikely that a representative and accurate scale of the study area could be shown.

Finally, the number of years fishing per harvester could be used an indication of accuracy or confidence in terms of the higher the numbers of years fished, the more experience the harvester has. In this context, more credibility could be given to that harvester's fishing areas. This idea, however, would require more thought and research as to its plausibility in the protocol.

With or without the inclusion of the above improvements, the research in this thesis could be considered a stepping-stone for further research in this area. First, the GIS portion of the protocol can be automated through scripts and bundled together in the form of an ArcView extension for distribution. And second, similar to the physical participatory 3-dimensional terrestrial models designed by Rambaldi and Callosa-Tarr (2001) for the collection of terrestrial LK, a similar physical UEM could be designed and used as a method to collect marine LK. If harvesters dive for bottom dwelling fish, then they will know the structure of the ocean floor.

To conclude, the general fisheries protocol detailed in Chapter 3 outlined a methodology for the extraction and incorporation of LK into the resource management process using a simple GIS framework. This was achieved through previously tested PRA and RRA LK collection techniques outlined in Chapters 2 and 3 and basic GIS functionality of union and buffer detailed in Chapter 3. Through this protocol, a common ground was found where LK and SK can come together to help fill the gaps that currently exist in resource management knowledge bases. Further, since basic GIS functionality was utilized through the core functionality in ArcView GIS, this protocol can be used equally well regardless of a country's economic status and extent of modernization. Although not tested, this protocol was also designed to be functional independent of geographic location or type of fishery. Given this, the protocol presented in this thesis is not a final solution for successful fisheries management. Rather, it is a tool to help aid in the integration of LK into fisheries management, thus successfully bridging the gap between LK and SK. Through this coalition the level of uncertainty and complexity inherent in fisheries systems could be minimized.

Appendix A

Listed in Table A.1 are the original interview questions that were tested on a sub set of harvesters on the island of Grand Turk.

Table A.1: Original Interview Question

Questions asked of all informants to determine species caught

1. Approximately how long have you been fishing commercially (as a source of income) here in TCI? (# of yrs)
2. Which species generates most of your income?
3. Roughly how many times a week on average would you go out?

Information on catch

4. How many Lobsters would you typically catch in an outing? Conch? <5 / 5-10 / 10-15 / 15-20 / >20
5. Can you point on the map the locations of where you typically take Lobster? Conch?
   a. How would you rate each location on terms of catch: Good / not too bad / poor
6. Can you describe the general conditions at each of these spots (last time out; last season)?
   a. Direction of current?
   b. Was the tide in or out?
   c. Are there plants there? What type?
   d. Is there coral? What type?
7. Roughly how deep is it at each location?
8. For Lobster, do you free dive or use traps?
9. Do you find that you visit these same spots every season?
10. Are there any spots that you used to fish all the time, but don't anymore? If yes, why?
    a. Could you point out these old sites out on the map?
    b. Why do you think there was a decline in stock there?
11. For Lobster, do you find that there is one particular spot that you visit every time out? What about Conch? (show and mark most regular sites on map - by species)
12. Do you have a set number of places that you go to every time out (If yes, mark on the map)? For Lobster? Conch?
13. When would you typically look for a new spot?
    a. Every time out?
    b. When your typical spots are not working?

14. When looking for new Lobster spots, is there a particular bottom-type you avoid, prefer? What about Conch?
15. Do you look for certain current patterns (speed or direction of currents? Mixing of currents?)
16. Over the last 10 seasons was there any one particular year that stands out with respect to a good year? Poor year?
    a. Did you notice anything unusual during that year?
        i. Water temperature?
        ii. Storms?
        iii. Different species in the area? Predatory species?
        iv. Extreme hot or cold weather?
        v. Changes in current patterns?
        vi. Changes in bottom structure or type?
17. In your experience, what type of bottom do Lobsters prefer? Conch?
18. Do you ever fish for both Lobster and Conch during the same trip? If yes:
    a. Would you fish for both on the *same or separate* fishing trips?
    b. Do you always start with the same species Lobster or Conch?
19. What would make you change to the alternate species?
    a. Lack of fish caught?
    b. Time of day/year more productive for one species over another?
    c. Tides?
    d. Currents?
    e. Moon Phase?

Lobster Specific Questions:

20. Are there any areas where you typically see many (mark all on map):
    a. Male Lobsters?
    b. Female Lobsters with eggs? Do you recall the colour of the eggs?
    c. Female Lobsters without eggs?
    d. Young Lobsters?
21. When would you normally see them there? Time of day/year?
22. Did you notice any similarities during these sightings?
    a. Current Patterns?
    b. Bottom-type?
    c. Tide?
    d. Moon phase?
    e. Weather?

Conch Specific Questions:

23. Are there any areas where you typically see an abundance of:
    a. Adult Conch
    b. Juvenile Conch

24. Could you point these areas out on the map?

25. What time of the day/year would you normally see them there?

26. Did you notice any similarities during these sightings?
    a. Current Patterns?
    b. Bottom-type?
    c. Tide?
    d. Phase of moon?
    e. Weather?

General Questions Concerning Fishing Regulations

27. Are you generally satisfied with how the fishery resource is managed in Turks and Caicos? Yes/No

28. Are there any regulations that you disagree with? Yes/No
    a. If yes, which ones and why the disagreement?

29. Are there any regulations that you feel need to be put in place? Yes/No
    a. If yes, what regulation would you like to see put in place and why?

30. Do you find a general increase or decrease in catch numbers over the last 10 years? Why do you think this is?
    a. Environmental issues?
    b. Over fishing?
    c. Management issues?

31. How do you feel the Lobster and Conch fishery can best be managed?

Appendix B

Tables A2 illustrate the statistics for determining the likelihood threshold values and Table A.3 shows the results of the mean values used in the equations in Chapter 4.   Figure A.1 illustrates the range of likelihood values for conch and lobster.

Measure	Conch	Lobster
Range	1-27	1-31
Mean	9.36	10.39
Standard Deviation	4.62	5.51
½ Standard Deviation	2.31	2.75
# of Records	23990	54074

Table A.2: Basic statistics for determining Likelihood Threshold Values

Mean	Conch Calculated	Conch Used	Lobster Calculated	Lobster Used
Mean +1	14.0	14	15.9	16
Mean +1.5	16.3	16	18.7	19
Mean +2	18.6	19	21.4	21
Mean +2.5	20.9	21	24.2	24
Mean +3	23.2	23	26.9	27

Table A.3: Results of Likelihood Threshold Values

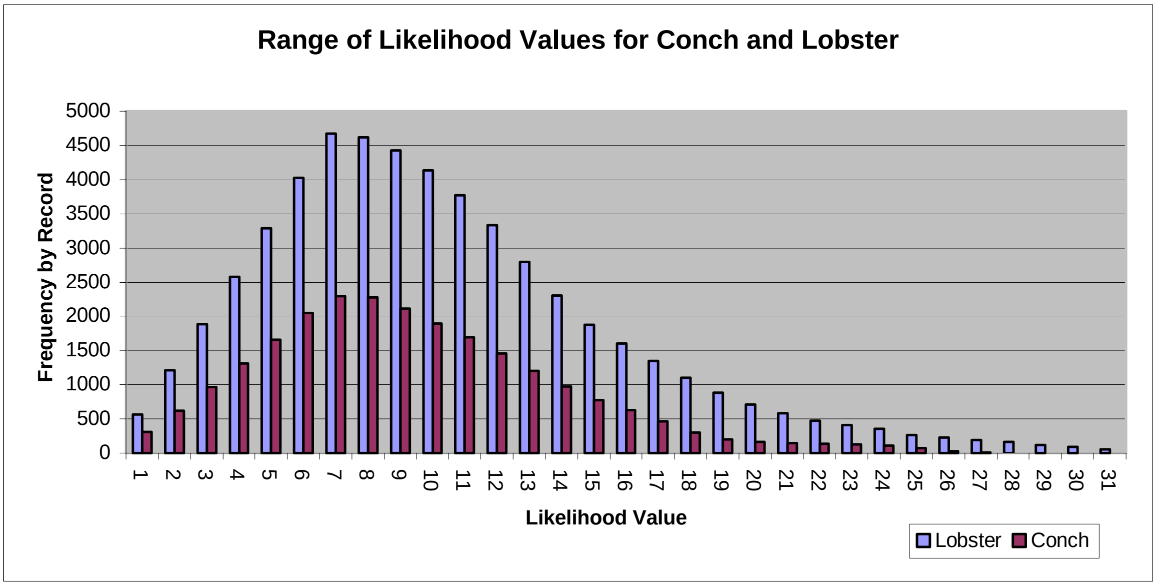


Figure A.1: Range of Likelihood Values for Conch and Lobster

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