A SOCIO-ECOLOGICAL ASSESSMENT OF WATERSHED ECOSYSTEM SERVICES OF SOUTHERN PATAGONIA

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This thesis utilizes a theoretical framework which links biophysical and social domains of ecosystems via ecosystem services (ES), in order to conduct a socio-ecological assessment of urban watersheds in three communities in Chilean and Argentine regions of southern Patagonia.

Results from this study show that expanding urban areas may be undermining the ability of local watersheds to provide for high quality ES posing potential risks to community wellbeing. Secondly, researchers and decision makers influencing regional natural resource management share similar values to general community members but do not capture the diversity of values that exist within the broader community, and dialogue between these groups on management issues is poor. A community-based management structure is recommended for the creation of adaptive and locally relevant management strategies.

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CHAPTER 1

INTRODUCTION

Theory and Practice

The Need for Integrating Social and Ecological Research

The link between global ecological change and human well-being is of increasing interest and relevance to scientists, policy makers and the general public, as the effects of environmental degradation are increasingly evident to society as a whole. The Millennium Ecosystem Assessment (MEA 2005), for example, estimated that up to 60% of the world's ecosystem services (ES) are being degraded. In turn, this research points to significant implications for human societies, ranging from impediments in the global efforts to alleviate poverty and hunger to detrimental impacts on public health. The recognition that humans are drivers of ecosystem change and simultaneously are affected by modifications to ecosystems has led researchers to seek to address both the social and ecological dimensions of global ecological change (Carpenter et al. 2009). Integrated social-ecological research, therefore, attempts to broaden the theoretical understanding of ecosystem structure and function by encompassing a more realistic framework of the way the world works with humans as a central driving factor and member of ecosystems; yet, in spite of the recognized importance of this line of inquiry, empirical research and appropriate methodologies are lacking (Liu et al. 2007a,b).

While the emphasis on social-ecological units and dynamics has recently enjoyed resurgence and recognition in ecology, such integrated research between the natural and social sciences has been a topic of intense interest in other fields such as anthropology and geography for some time. Particularly since the mid-20th century, the sub-disciplines of environmental anthropology, human ecology and political ecology have addressed this interface, as exemplified by the works of Julian H. Steward (1937) and Roy Rappaport (1968). These sub-disciplines, for their part, have made considerable progress in understanding social-ecological systems, but given their historical disciplinary and epistemological backgrounds, these contributions have gravitated towards generating social and/or spatial data and not greatly affected the ecological sciences (Dove and Carpenter 2007).

At the same time, even within mainstream ecology, the topic of the link between humans and ecosystems has been discussed since the origin of the field, even if it did not gain ascendance in the broader discourse or application of ecology for some time. For example, E.P. Odum in his foundational textbook *Fundamentals of Ecology* (1959) wrote:

> Although it is a blow to our ego as men, we are forced to admit that we know less about our own population than we know about that of some other organisms-which is little enough! Consequently, a lot of diligent study of man and nature (as a unit, not separately) is in order before we can even begin to entertain the idea that we are masters of our destiny.

Odum's writings were seminal in the development of modern ecology, but it would appear that the "study of man and nature (as a unit…)" was largely left out, since the integration of social and natural science data in ecological studies has only recently come to the forefront of the discipline (Berkes et al. 2003). Indeed, Odum's emphasis on the human/nature unit can even be predated, as C.C. Adams, then the president of the Ecological Society of America, coordinated a symposium at the behest of the American

Academy for the Advancement of Science entitled Ecology and Human Welfare, which subsequently produced a special edition of *Ecological Monographs*, where Adams (1940) notes:

> One of the best methods of assisting in this re-orientation is by the dispassionate discussion of the relations of a person's specialty in relation to the larger field, including its implications, and likewise to the extension of this same process to the integration of the "natural" and the "social" sciences, in order to facilitate the appreciation of their mutual interrelations and to obtain a proper balance between theory and practice.
>
> Ecology is the study of the relation of organisms to their complete environment. The effort to obtain a thorough understanding requires estimates of relative influences and relative values. Values involve theoretical and philosophical conceptions. To the degree that the integration and synthesis of science advances there is a corresponding advance in philosophy. A proper balance is what is needed.
>
> One important practical aspect of an ecological approach is that it may facilitate the integration of the subject matter, and a mutual understanding by scientists and philosophers, as well as the social orientation of both groups.
>
> Ecology occupies a middle ground between the physical, biological, and social sciences, and must deal with human values, as the ultimate tests of value are social, and therefore the theoretical aspects cannot be ignored. Without the social orientation of both science and philosophy, both tend to become perverted to anti-social uses, and scientists and philosophers may waste their lives and lose the freedom necessary for science, philosophy, and a satisfactory society.

In part, today’s renewed emphasis on human-nature systems can be considered an outgrowth of a broader disciplinary paradigm shift in the field of ecology that has given new legitimacy and applicability to these old ideas. On the theoretical level, the “balance of nature” paradigm en vogue in the early part of ecology created a need to study systems that were not impacted by humans, as seen by Clements’ (1936) assertions that human disturbances interfered with his idealized climax communities from attaining their deterministic essences. By the 1970s and 80s, however, this perspective had proven untenable, leading to what Pickett and Ostfeld (1995) called the “new paradigm” in ecology, which was based on dynamic and open systems that explicitly included humans.

During the 1980s and 90s, the Ecological Society of America also formally endorsed the need for ecologists to be involved in applied research, as laid out in the Sustainable Biosphere Initiative, thereby legitimizing researchers working on more human-influence systems and outcome-driven investigation (Lubchenco et al. 1993). Indeed, relevant questions not only for theory, but also application came to be dominated by human-oriented issues of sustainability research, as embodied in such approaches at the end of the 20th century (Kaufman 2009). For instance, the U.S. National Science Foundation created a program entitled Dynamics of Coupled Nature and Human Systems (CNH), which “promotes interdisciplinary analyses of relevant human and natural system processes and complex interactions among human and natural systems at diverse scales” with an annual budget of $17 million in fiscal year 2012 (NSF 2012). The CNH program strives to determine the social and ecological thresholds and feedbacks of these complex systems and emphasizes the study of a single research unit, the socio-ecological unit, which is a shift from looking only at how ecosystems are affected by humans.

The U.S. Long-Term Ecological Research (LTER) Network has confronted the issue of human-nature systems by proposing a conceptual model known as the pulse-press dynamics framework (PPD, Figure 1.1) to synthesize a holistic strategy for LTER sites to recognize the relationship between the “biophysical domain” and the “human/social domain” of how the world works (Collins et al. 2011). The “biophysical domain” is the traditional purview of ecologists, which involves the study of the relationship of structure and function of ecosystems in response to internal and external drivers and disturbances and the “human/social domain” is the study area of social scientists and humanists, which involves values, perceptions and behavior. The PPD sets out to integrate these two domains, using ecosystem services as a connecting concept between ecosystems and human systems, and likewise recognizing human behavior as a driver of ecosystem change through pulse-press dynamics. The PPD model provides two main attractive features for use in socio-ecological research. First, it does not assume that human behavior is only governed by financial incentives and is therefore more amenable to a broader social-ecological integration than previous economic frameworks. Second, it allows for the generation of research questions between every component of the model, fundamentally allowing an integration of social and ecological research and thus paving the road for an understanding of social-ecological systems.

Ecosystem Goods and Services

How Expansive is an Economized Approach?

The PPD model uses ecosystem services (ES) to link biophysical and human domains to address the human-nature dimensions of ecosystems that gained significant global attention and prominence via the MEA's global assessment. Methodologically, ES research attempts to quantify the benefits of the "goods and services" that humans receive from the environment to better understand the natural world's role in supporting social well-being and how this role is being modified through cultural and socio-political processes. ES research has created a burgeoning and useful academic and applied literature (Daily 1997, Seppelt et al. 2011), but it is founded largely on principles from economics. In this context, ecological economists have sought to incorporate into political-economic models the largely non-monetary economic values that ecosystems provide, putting "ecosystem goods and services" into a natural capital framework that is mostly based on use and the economization of nature (Farber et al. 2006). Following suit, newly proposed ES studies and applied management projects that assign value to ES often base their analyses on the monetization of ecosystem functions that benefit humans (Daily & Ellison 2002, Engel 2008, Carpenter et al. 2009). Menzel and Teng (2010) make the case that ES projects typically begin with an identification of ecosystem processes that provide for ES by "experts"; then a biophysical assessment of those processes occurs, and finally, economic or market value is assigned to the designated services. In such projects, ES are taken out of context by assuming that values are fixed for all of society and driven only by economic concerns. Furthermore, Sagoff (2008) argues on epistemological grounds that since scientific information tends to be "centralized, collaborative, collective and consensus-based" and market information is "ephemeral…dispersed and decentralized" the integration of these two knowledge systems inappropriately values ES. Additionally, because ecosystem change is not linear, unlike the linear models used to derive market value, and is subject to thresholds, the resilience of an ecosystem to resist shocks and disturbance is not easily captured in the marginal value of an ecosystem service (Kremen 2005). Perhaps, then, monetization is not the only appropriate method to sufficiently derive value for the socio-ecological unit. Indeed, it may be considered harmful in some contexts because only those ecosystem processes that are easily transferred into monetary terms get incorporated into the discussion.

However, as a framework that not only generates but also applies knowledge, the ES approach has great power. We see ES used not only by the U.N. in MEA (2005), but also the recent creation of an Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; http://www.ipbes.net). The IPBES intends to operate in a manner that is similar to the Intergovernmental Panel on Climate Change (IPCC) and seeks to synthesize and analyze global research on biodiversity and ES to better inform planetary decision-making (*Nature* 2010, Perrings et al. 2011). In addition, a recent analysis of international development projects funded by both private organizations (e.g., non-profit organizations) and governmental agencies (e.g., Inter-American Development Bank) showed a net increase in the amount of funding for conservation projects that develop goals based on the ES approach as compared to those that focus solely on biodiversity.

Using the ES approach, therefore, allowed projects to broaden the types of financial tools that were being used and include socio-ecological landscapes, thereby attracting a more diverse set of funders to conservation projects (Goldman et al. 2008) and showing its relevance not only to government planners, but also the private sector.

At the same time, while there are advantages to the market-based approach for ES valuation, including the fact that it allows for the costs incurred from degrading ecosystem processes to be incorporated into current economic models, it may be counter-productive in social-ecological research, if it is the only approach to understand the ecosystem's role in supporting social and ecological well-being. Consequently, there is increasing recognition in the scientific community that ES methods needs to be complemented and enhanced by encompassing a broader suite of values embodied in human relationships with nature, which in essence is less volatile than valuation assigned using market based models. This fact was recognized, for example, in the MEA which also considered spiritual, aesthetic and other cultural values of ecosystems.

Similarly, calls are being made not only to broaden the definition of values, but also to diversify how they are brought into the discussion. Therefore, the incorporation of public and stakeholder participation is required not only in the implementation of results from research, but also in the definition of the study questions and priorities (Menzel & Teng 2009). As a result, new conceptual frameworks are required to address broader socio-ecological research questions and to define appropriate study units and methodologies to better understand the complex and dynamic nature of socio-ecological systems (Liu et al. 2007a,b). For example, Raymond et al.'s (2008) "community values" proposal attempts to create a social-ecological management strategy, but also explicitly includes three innovative features: i) It is based on ecosystem service and natural capital paradigms; ii) It integrates community-derived social values and threats to ecosystem services and natural capital early in the natural resource management process, and iii) It incorporates a spatially explicit and place-based data collection methodology. Consequently, their results provide a richer tapestry of values at the landscape level, and combined with policy making apparatuses, begin the process of creating a robust, adaptive and locally-relevant environmental management system for the region. Additionally, by using the community values approach, ES can indeed have the capacity for dialogue between scientists and non-scientists regarding the effects that ecosystem change have on human well-being (Carpenter & Folke 2006, Raymond et al. 2008).

Putting Concepts into Practice

Community-Based Ecosystem Service Management and Research

Since ecology and other environmental sciences began to recognize humans as an embedded component of ecosystems, various academic proposals have been made to conceptualize and study integrated human-nature systems (e.g., social-ecological systems-SES, Redman et al. 1997; long-term socio-ecological research-LTSER, Haerbel et al. 2006). However, examining the connection between human perceptions and ecosystem services is necessary not only on academic grounds, but it also provides a practical foundation for developing adaptive and collaborative ecosystem management that ultimately achieves more effective conservation strategies (Burkhard et.al 2010).

From an ecosystem management perspective, the inclusion of community values and perceptions of ES allows a more nuanced and accurate understanding of these socio-ecological interactions and therefore better helps prioritize ecosystem management decisions that affect community well-being (Smyth et al. 2007). Such an understanding of community perceptions by necessity integrates broader human values into management and conservation than those used in traditional top-down strategies, which typically emphasize values held by the economists, natural resource managers, and/or scientists that develop them (Rapport et al. 1998). As a response, community-based ecosystem management and research (CBEM) has been proposed to address these multiple issues.

Failure to recognize the diversity of values that exist within a community in ecosystem management structures and strategies can lead to policies that are incongruous with local needs and perceptions of ES, creating communication and knowledge barriers between those who manage ecosystems and those who depend on them. Detailed discussions have occurred within the scientific community over the potential advantages of the CBEM approach, which include: the reduction of stakeholder conflict; better addressing local cultural, economic, and even political dimensions of ecosystems; integration of diverse knowledge systems; building local support for management strategies; equal distribution of benefits; enhancing the transparency of management decisions and generating a sense of empowerment by providing the local community with an increased ability to affect the decision-making process (Rhoades et al. 1999, Conley & Moote 2003, Fleeger & Becker 2010, Menzel & Teng 2010, Tuler & Webler 2010, Hirsch et al. 2010, Paetzold et al. 2010). Furthermore CBEM strategies can also help overcome communication barriers in the science-society dialogue. As the future of management decision-making aligns itself with the ES paradigm, a CBEM approach could be a practical way to integrate a better understanding of the diversity of both monetary and non-monetary values for ES with more adaptive and contextualized conservation and management strategies.

Community involvement may occur at various stages and at varying degrees in the management process (Reed 2008). Menzel and Teng (2010) and Chazel et al. (2008) have called for the integration of stakeholder values at the early planning stage of the ES research itself, as well as the management, but in general the inclusion of broader society is in the implementation phase (Menzel & Teng 2010). Public involvement at the planning and proposal development stages begins the dialogue process early concerning potential management strategies and the way to structure the relationships between scientists and multiple stakeholders. In turn, this generates immediate feedback on the potential effectiveness of the new management system, and the early inclusion of the community in ecosystem management therefore can better guarantee the long-term success of new strategies put in place to deal with ecological change that is better supported by the local community.

This approach, of course, is not with out its critics. Brosius et al. (1998) brings attention to the use of CBEM rhetoric by multilateral lending agencies and powerful national and international institutions in order to validate and implement exogenous strategies of development and thereby shifting resources away from true locally based natural resource management and/or grassroots strategies of livelihood and empowerment. R. Rhoades (1998) points out a number of cultural aspects of CBEM projects which often get left out in their implementation such as the failure to recognize established culturally defined management units and instead imposing scientifically supported, but culturally foreign, geophysical management units leading to "tensions and antagonisms" between the community and the institutions promoting the community-based approach. F. Berkes (2004) also discusses the consequences of ignoring cultural context in CBEM, particularly the danger of facilitating or exacerbating unequal power distributions between social groups and stakeholders leading to unequal distributions of benefits. These potential drawbacks of CBEM stem in part from the failure to approach community-based strategies as bottom-up processes that carefully integrate the equal distribution of benefits as a main objective. Such dangers should be considered when developing any new CBEM strategy. In all cases, however, these scholars offer solutions to address these problems while at the same time recognizing CBEM as the preferred strategy over traditional command-and-control approaches.

Thesis Overview

Objectives

Given the conceptual and practical needs at local, regional and global levels to better understand the link between social and ecological domains of environmental issues and apply such social-ecological research to management and conservation, the overall objective of this thesis is to build upon previous attempts to study "biophysical" and “human” dimensions of ecosystems. Since ES are defined broadly as the benefits that people obtain from ecosystems (MEA 2005), they provide an amenable conceptual framework for examining these social-ecological connections and can be applied in a way that transcends mere economic values as discussed previously (Brauman et al. 2007). Furthermore, by approaching communities directly to better understand place-based social-ecological relations, I have broadened the definition of values by incorporating a “community values” and participatory approach.

Specifically, I set out to establish baseline ecological and social data on watersheds and watershed ES to facilitate understanding and development of locally relevant CBEM strategies using the ES concept. In so doing, I employ components of the PPD framework (see Figure 1.1), to generate specific research questions, thereby initiating an understanding of specific socio-ecological systems. In this context, the ES concept helps bridge the gap between ecological and social dimensions of watersheds and seeks to quantify what ecosystems do and what society wants or needs them to do.

Study Area: Southern South America

This study took place in southern South America’s Patagonian and Sub-Antarctic Ecoregions, which are shared between Chile and Argentina and recently identified as two of the world’s last great wilderness biomes, based on three criteria: i) low human population densities (<5 people km^{-2}), ii) high percentage of intact native vegetation cover (>70%), and iii) extensive size (>10,000 km^{2}) (Mitttermier et al. 2003). At the same time, southern South America experiences both local and globalized environmental threats such as tourism development, climate change and the Antarctic ozone hole (Rozzi et al. 2006). Invasive species have also been identified as a region-wide problem (Anderson et al. 2006), and in certain areas, peat extraction (Iturraspa 2010) and urbanization are intensifying (Amin et al. 2011). While local and global human societies put increasing strain on local environments, natural resource management institutions must develop sustainable management strategies, which is an especially challenging task considering more than 50% of the region is designated as protected area, but in the Chilean portion most of these are "paper parks" that lack implementation with management plans, infrastructure and personnel (Jax & Rozzi 2004, Rozzi et al. 2012).

Public participation is a goal of both Argentine (Resolution 766/03) and Chilean (Article 4, Law 19.300) environmental policy, which explicitly includes such topics as access to information and promoting education campaigns. Chile's law also states that consideration should be given to strengthening the identity, languages, institutions and social and cultural traditions of indigenous communities. However, participation has traditionally taken the form of public consultations regarding environmental impact assessments for private and governmental investment projects. Now, the newly created Ministry of Environment in Chile is seeking to implement a "local environmental management" office, as a way to decentralize authority, promote greater participation and generate co-responsibility with regards to environmental decision-making. It accomplishes this by working with local municipalities and citizen groups to ensure best practices through a Municipal Environmental Certification system, which seeks to unify local administrative structures based on Agenda 21 structures of environmental democracy and governance. For its part, Argentina is also in a similar process since 2003 to fulfill its commitment as part of the U.N. Environmental Program's "environmental citizen" program. Argentina's Ministry of Environment and Sustainable Development has likewise created a Participation, Environment and Society Program, which is in the process of being implemented. Therefore, both of these countries are actively searching for methods and processes that allow a greater integration of local communities, but without formally consolidating programs such as CBEM.

Biophysically, the area contains the world's southernmost forested ecosystems, making up the largest area of high latitude, temperate forests in the Southern Hemisphere (Rozzi et al. 2012). In addition to forests, however, the region is also a mosaic of other habitat types defined by stark geography and climatic gradients. The Andes Mountains reach their southern terminus, arching in a west-east direction along the southern portion of the Fuegian Archipelago, known on Isla Grande as the Darwin Range. To the west and south of these mountains, the islands experience high precipitation (>2,000 mm per year) and cloudy, colder conditions that generate bogs and rainforest. Only a few tree species are common and largely segregate along the precipitation gradient: evergreen coigüe (*Nothofagus betuloides*) and Winter's bark (*Drymis winterii*) constitute the rainforests, while the deciduous lenga (*N. pumilio*) makes up extensive monocultures in the drier interior of Isla Grande. For its part, the deciduous ñirre (*N. antarctica*) inhabits extremely wet and adverse areas, such as bogs and tree line) and also mature forests along the ecotone with the grasslands to the north. As one travels to the north and west, we find more arid and windy conditions that produce grasslands and shrublands, found principally to the north of the city of Punta Arenas on the Brunswick Peninsula and on the central, eastern and northern portions of Tierra del Fuego Island (Moore 1983). Peat bogs, which dominate the south and west of the region and are found in wetter areas throughout the forested habitats, are composed mostly of large communities of bryophytes and are a major feature of these southern ecosystems (Iturraspa & Urciuolo 2000). The diversity of vertebrates and vascular plants in the region is relatively poor due to its recent glacial history, but among these taxa there is a considerably high rate of endemism (Armesto et al. 1995).

The study area includes the Argentine and Chilean portions of southern South America's extreme tip, which include the following political jurisdictions: Magallanes and Chilean Antarctic Region (Chile) and the Tierra del Fuego, South Atlantic Island and Antarctic Province (Argentina). In the case of both, the study only includes the South American portion of the districts, i.e. excluding the territorial claims of Chile and Argentina to adjacent islands or Antarctica (Figure 1.2). With 51% of its area under protected legal status, the political district known as the Magallanes and Chilean Antarctic Region sets a high standard for formal conservation. Based on 2005 regional census data main economic activities include communal and social services (29.3%), Commercial (18.5%), and manufacturing industry (13.3%). In addition, 8.7% of economic activity was concentrated in the agricultural, hunting and fishing industries (Table 1.1). Major economic activity in this region based on 2010 regional census data includes service industry (19.0%), manufacturing industry (17.20%) and commercial industries which in this case includes activity generated from hotels and restaurants

(16.95%) (Table 1.1). Though some characteristics are consistent across the region, specific study sites were chosen as they portray a diversity and gradient of some ecological and social variables. For this thesis, research was conducted in Puerto Williams, Ushuaia and Punta Arenas.

Urban areas aggregate the vast majority of the regional population in both countries. In Chile, 93% of a population total of 150,826 is found in urban areas, including Punta Arenas, Puerto Natales, Porvenir, and Puerto Williams. In the Tierra del Fuego, South Atlantic Island and Antarctic Province, 97% of a total population of 101,079 are considered urban which includes the cities of Rio Grande, Ushuaia and Tolhuin (Table 1.2). Puerto Williams, Ushuaia and Punta Arenas represent approximately 65% of the total population of these regions in Chile and Argentina (see Tables 1.1 and 1.2), and therefore trends found based on the results of this research will be assumed to be representative of the region.

Puerto Williams

Puerto Williams, Chile located on Navarino Island along the Beagle Channel, is the southernmost town in the world. It constitutes a highly isolated community only accessible by boat through a small shipping port or by plane through a small airport. Puerto Williams is the capital of the Chilean Antarctic Province that extends from the summits of the Darwin Mountain Range on Tierra del Fuego Island to the South Pole. The study took place in the portion of the province that also corresponds to Cape Horn County and the Cape Horn Biosphere Reserve (CHBR). Puerto Williams represents the study site which has the smallest population and a population growth rate, as well as urban density (population/urban area), between that of the other two sites (Table 1.3). Puerto Williams is the most rural site with a small population, an only moderate urban density, and a noticeable lack of overall urbanization. Most streets are unpaved, most buildings are no more than one-story high and forests and peat bogs can be found within the urban limits. In other words, the population of Puerto Williams has easy access to minimally impacted ecosystems.

In previous studies (Arango et al. 2007, Berghoefer et al. 2008, 2010, Schuettler et al. 2011), the population of Puerto Williams has been categorized *a priori* as permanent residents segregated as i) the Yaghan indigenous community, centered around Ukika Village on the eastern edge of Puerto Williams; ii) families supported by the fishing industry, largely from Chiloé and Punta Arena's and that are part of the Fisherman's Union and the Hulliche-Mapuche Community; iii) public employees and ex-Chilean Navy officers that have determined to stay on the island; while the transitory population consists of iv) temporary workers from the fishing industry with a typical period of residence less than nine months; v) temporary state-appointed public employees; vi) Chilean Navy officials assigned to a specific post in Puerto Williams for a period of two to five years and which consist a significant portion of the residential population in the community.

The town of Puerto Williams lies on the shores of the Beagle Channel between two watersheds that drain the Dientes de Navarino Mountains and have their outlets to the sea: i) the Ukika and ii) the Róbalo. Both watersheds are predominantly covered in mixed *Nothofagus* forests in their lower portions with a heterogeneous mosaic of habitat types, including peat bogs and high Andean formations. The area receives approximately 650 mm of annual precipitation (rain and snow) and an annual average temperature of 6˚ C (Rozzi et al. 2006). The Róbalo River is the primary source of drinking water for Puerto Williams and is protected by the Omora Ethnobotanical Park and other state-owned lands dedicated for conservation to ensure long term flow regulation and water quality (Rozzi et al. 2010). The Ukika River valley, though not formally protected, is also part of state-owned lands and is similarly unaffected by direct anthropogenic effects in the upper reaches. The river's main stem runs directly adjacent to Ukika Village, the residential area of the Yaghan indigenous community and further upstream there are areas that are accessible for light recreation. Both watersheds contain a network of hiking trails that allow access to hiking and camping and potentially horseback riding. Both watersheds also experience some level of livestock impact in their lower reaches (currently grazing is a relatively uncontrolled activity on Navarino Island). Specific potential threats to these watersheds have been identified as the presence of exotic species (particularly beaver, mink, and trout), tourism development, climate change, persistence of the ozone hole, and biocultural homogenization (Rozzi et al. 2006).

Ushuaia

Ushuaia is the capital of the Argentine Province of Tierra del Fuego, South Atlantic Islands and Antarctica (Tierra del Fuego Province for short). It is located on the Argentine side of the Beagle Channel on Tierra del Fuego Island approximately 45 km north and west from Puerto Williams. Ushuaia represents a medium-level population size compared to the other two sites, but has the greatest population growth rate and a population density similar to Punta Arenas (Table 1.3). The data available for Ushuaia did not report numbers on ethnicity nor the growth of an immigrant population from Bolivia, which has settled in various informal “shanty towns” in the urban area and therefore would also increase density estimates. Ushuaia often is referred to as the world’s southernmost city, compared to Puerto Williams’ status as “the southernmost town.” Though also located on an island, logistically Ushuaia is better connected to continental South America and the global market by being accessible by vehicle, by a well-developed shipping port, access to Río Grande, an even larger city approximately 205 km away by highway and by a major airport. Ushuaia now exists as the business and administrative hub of the Argentine region where, along with the population, the internationally recognized tourism industry is steadily increasing and is well supported by local government policies (Snyder & Stonehouse 2007).

Four main watersheds are encompassed within the urban boundaries of Ushuaia; they all drain south from the southern end of the Andes Mountains into the Beagle Channel. These watersheds are: 1. Olivia River; 2. Pipo River; 3. Grande Stream; 4. Buena Esperanza Stream. All four can be characterized by having steep gradients and relatively small drainage areas, Similar to the watersheds in Puerto Williams, watersheds in Ushuaia represent a mix of vegetation zones including mixed *Nothofagus* forests, peat bogs and high Andean formations. Unlike Puerto Williams, there exists a relatively high level of urbanization of these watersheds just before emptying into the sea. The area receives approximately 520 mm of precipitation per year in the form of rain and snow (Iturraspa & Uriciuolo 2000). A Ramsar site is located within the Arroyo Grande watershed, due to the presence of extensive peat lands dominated by *Sphagnum* mosses and *Carex* grasses (see www.ramsar.org). Grande Stream also is a primary water source for the city and for these characteristics it is a high-priority watershed for protection. A majority of the Pipo River's watershed is protected as national park as well as Buena Esperanza's upper watershed, which also provides a primary drinking source for Ushuaia (Iturraspa et al. 2009). Olivia River, which runs along the western border of the city limits, is paralleled by a scenic route into mountain ranges providing numerous vistas of minimally impacted bogs, forests and glacial formations. All upper watersheds contained networks of trails and recreation opportunities to take advantage of their scenic beauty.

Specific potential threats to these watersheds have been identified as peat extraction, touristic and residential development, deforestation, over irrigation for agriculture and greenhouses, overgrazing from livestock, water contamination from the presence of slaughter houses (Urciuolo & Iturraspa 2005), and climate change causing the potential for alteration of normal ecosystem functioning (Iturraspa 2010).

Punta Arenas

Punta Arenas is the northernmost study site and the least isolated, located on continental South America. The city can be considered the most urban of all three sites with the largest population and highest population density of all three sites. On the other hand, Punta Arenas has the lowest population growth rate of the three and hence represents a relatively established population (Table 1.3). Punta Arenas lies on the Magellan Strait directly across from Tierra del Fuego and is the capital of the Magallanes and Chilean Antarctic Region. The well developed shipping port, international airport and vehicle accessibility connect the city to domestic and global markets better than both Ushuaia and Puerto Williams. Principle industries in Punta Arenas include: natural gas exploitation, petroleum, and methanol; tourism (Vera Giusti 2008); and fishing, of which over 50% of exports are aquaculture salmon and trout (Feliú 2009). Based on the 2002 national census, 5.7% of the total population claimed to be of indigenous descent. A diversity of indigenous groups exist in Punta Arenas with the Mapuche people being the most abundant, even though the region is not considered part of their ancestral range, and their presence in Punta Arenas has occurred from more recent southward migrations. Original indigenous inhabitants in the region included the Alculufe and Tehuelche, which in small part are still present in the region (Holdgate 1961, INE 2011).

The city of Punta Arenas lies within three principle watersheds: Las Minas River, Los Ciervos River, and Tres Puentes River. All three contain predominantly Magellanic steppe or pampa vegetation with ñirre forests and peat bogs. All have a relatively high level of urbanization except Los Ciervos River, which contains mostly private ranch land in the lower watershed. The area has an average annual temperature of 6.7˚C and experiences frequent high winds throughout the year, except winter, and average annual precipitations of 425 mm. Though similar in size to all the other watersheds examined in this study, these rivers differed from Ushuaia and Puerto Williams as headwaters did not begin in the high gradient mountain type terrain; rather these watersheds are principally fed by rain and snow and have their headwaters in a low-lying mountain ridge (Direción General de Aguas 2004).

All three river systems had headwaters protected in the Magallanes National Reserve, but compared to Las Minas with 69% of its watershed within the reserve, the other two watersheds were only minimally protected. Las Minas River is also regularly accessible within the reserve to the public with a network of trails and areas for recreational use. Outside of the park, however, these watersheds are almost entirely covered by private ranchland or residence and have become highly urbanized and even channelized. Because the Strait of Magellan, where Punta Arenas lies, was the principle shipping channel from which ships would pass back and forth between the Pacific and Atlantic Oceans before the construction of the Panama Canal, the city experienced an early economic boom that led to the almost complete deforestation of the region. For this reason, this area which was originally covered by mixed forests of various *Nothofagus* species, presently there is very little native forest cover and in lower portions of these watershed virtually no forest at all.

General Approach

The ecological and social dimensions of sub-Antarctic watersheds were studied near major human settlements in southern Patagonia, using components of the PPD model as an organizing framework in which to situate the research questions, hypotheses and methods (Figure 1.1). Watersheds with a gradient of human population sizes and isolation were chosen as study units because they are geographically defined ecosystems that represent an integration of social and ecological variables (Likens & Bormann 1974, USEPA 1995) and therefore are desirable social-ecological management units. The watersheds and their associated human communities served as the basic study units to answer the following fundamental questions of this thesis:

i) What is the ability of urbanized sub-Antarctic watersheds to provide for high quality ecosystem services?

ii) How do human communities in the sub-Antarctic ecoregion value and perceive local ecosystems and their management?

These questions were addressed through the following chapters:

Chapter 2: I conducted an empirical evaluation of watersheds by assessing stream ecosystem structure and function in Ushuaia to understand the ecology of these urbanized watersheds and their ability to provide for high quality ES. This chapter corresponds to Question/Hypothesis 3 in Figure 1.1. Four study watersheds were chosen, each with reaches in the urban zone and reference sites outside the city. At each, I quantified physical, chemical and biotic measurements, compared them between impacted and reference conditions and observed their changes with increasing urbanization.

Chapter 3: Social surveys (see Appendix 1) were carried out to assess knowledge, values and perceived threats to ES, which corresponds to Question/Hypothesis 4 in Figure 1.1. The survey instrument had a specific emphasis on watershed ES and was applied in Puerto Williams, Ushuaia and Punta Arenas. Responses were compared by t-tests between two general groups: i) a survey of the general population ("community") at each site and ii) authorities, managers and scientists ("specialists"). Non-Metric Multidimensional Scaling (NMDS) process was performed to gain a better understanding of the similarity of the ES value "mindscape" between community and specialist groups. *Chapter 4*: In conclusion, I discuss how social "perception" and biophysical "reality" of local watersheds corresponded and how continuing socio-ecological research in this region can better assess whether local ecosystems are supporting social well-being. In addition, I propose inferences from these findings for future research on the integration of social and ecological variables and make specific recommendations for management and the development of CBEM in the study region.

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Table 1.1. Regional and provincial economic data by sector.

Magallanes & Chilean Antarctic Region		**Tierra del Fuego, South Atlantic Island & Antarctic Province**	
Public sector	29.3%	*Services*	19.0%
Commerce	18.5%	*Manufacturing*	17.2%
Industry	13.3%	*Commerce, restaurants & hotels*	17.0%
Transportation & communications	11.2%	*Education*	11.3%
Agriculture, hunting and fishing	8.7%	*Construction*	7.5%
Construction	7.9%	*Transportation & communications*	6.6%
Financial services	6.6%	*Financial, insurance, real estate and business services*	6.6%
Mining	4.0%	*Social and health services*	5.8%
Electricity, gas and water	0.7%	*Domestic services*	4.9%
		Other	3.8%
		Not specified	0.5%
	100.0%		100.0%

Economic activity for the Magallanes & Chilean Antarctic Region is based on 2005 census data; Economic activity for the Tierra del Fuego Province is based on numbers data from the Department of General Statistics and the 2010 census.

Table 1.2 Regional and provincial area, population and percent of population that is urban.

	Magallanes & Chilean Antarctic Region	**Tierra del Fuego, South Atlantic Island & Antarctic Province**
Area (km^2)	1,382,291	1,002,445
Population	150,826	101,079
Percent Urban (%)	93	97

Data for Chile based on 2002 census (INE 2011); data for Argentina based on 2001 census (INDEC 2010).

Table 1.3. Demographic data per city in Chile and Argentina.

	Puerto Williams (Chile)	**Punta Arenas (Chile)**	**Ushuaia (Argentina)**
Area (km^2)	1.19	39.03	40.58
Population	1,952	116,005	45,430
Population Density (#/km^{-2})	1,600	2,970	1119.5
Growth rate (# yr^{-1})	40.2	233.9	2028.4
Percent Increase (%)	25%	2%	56%
Indigenous (%)	8.5%	5.7%	No Information

Data from INE (2011) and INDEC (2010) for Chile and Argentina, respectively. Growth rate calculated over 10 years from 1991-2001 in Ushuaia and 1992-2002 in Punta Arenas and Puerto Williams. Urban area for Ushuaia is based on a measurements of urban boundary data conducted in Google Earth.

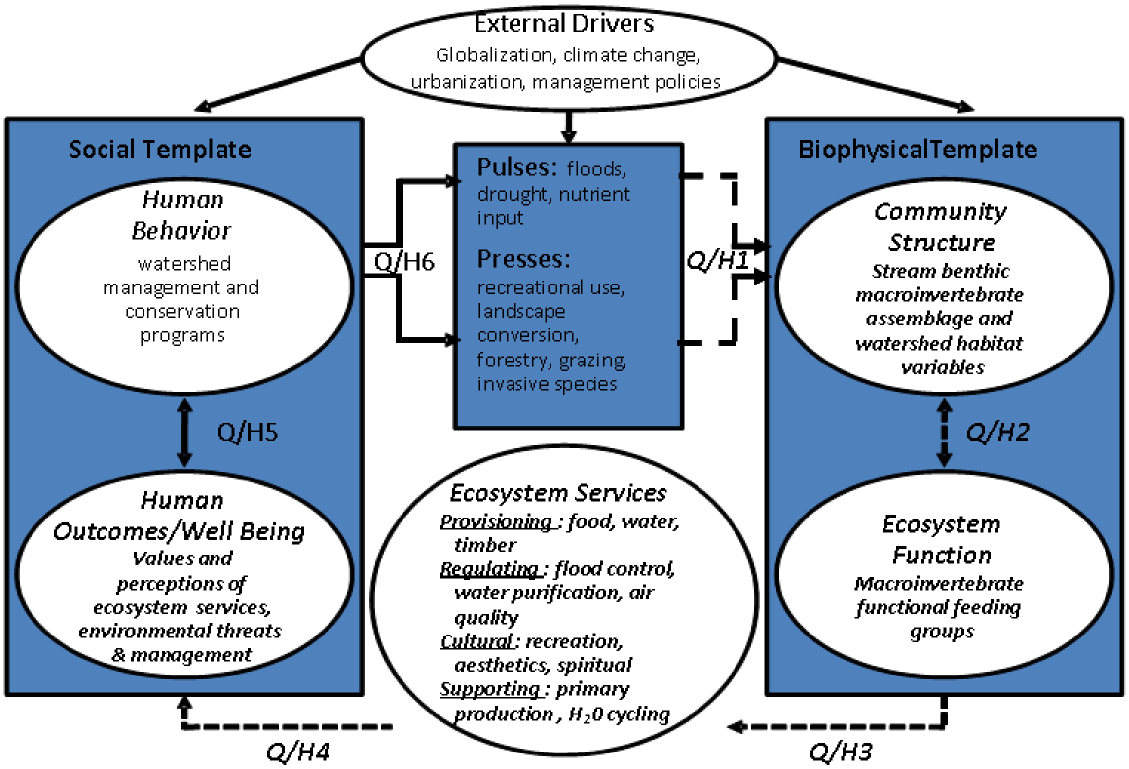

Figure 1.1. The Pulse-Press Dynamics framework adapted from Collins et al. 2011. Questions/Hypotheses with dashed lines (- - - -) and model components in ***bold italics*** are the specific areas addressed in this thesis.

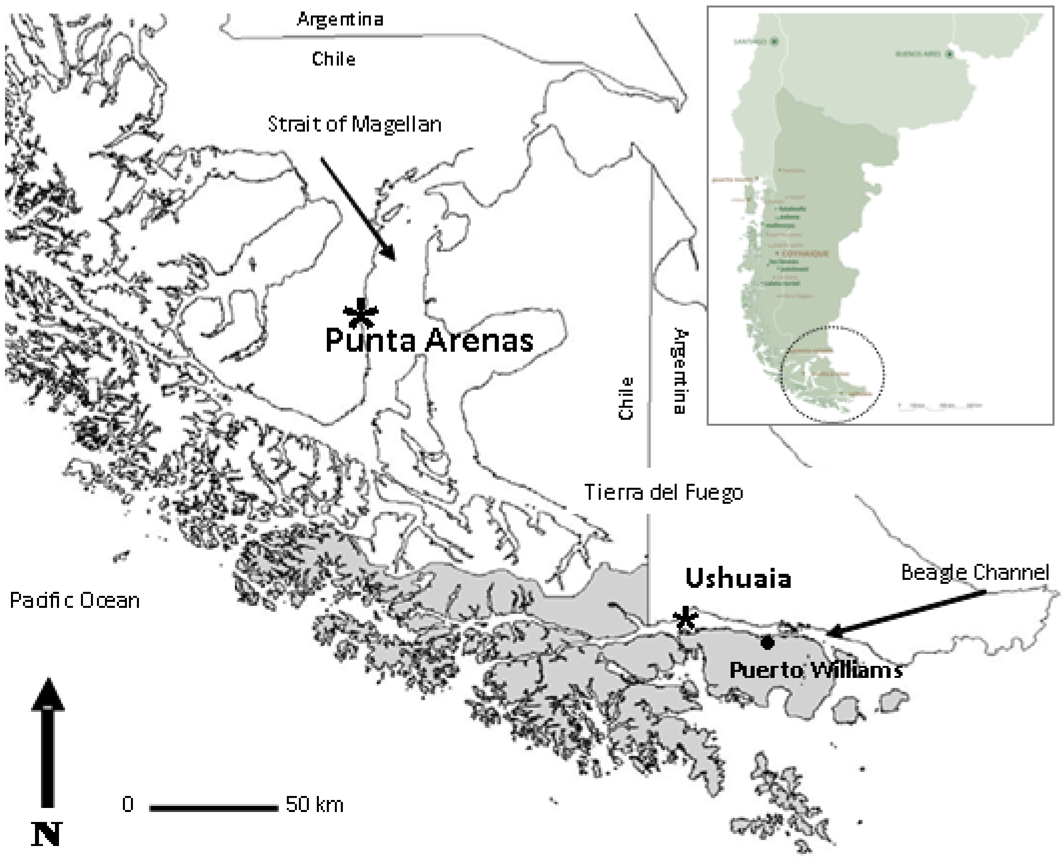

Figure 1.2. Map of the austral extreme of South America. Study sites were located in Puerto Williams (Chile), Punta Arenas (Chile) and Ushuaia (Argentina). Tierra del Fuego Island is divided between Chile and Argentina, while the remaining portion of the archipelago to the south of the Strait of Magellan is under Chilean sovereignty.

CHAPTER 2

BIOPHYSICAL ASSESSMENT OF SUB-ANTARCTIC WATERSHEDS

Introduction

Increasingly, the ecosystem goods and services (ES) concept is being put forward by the scientific community as a practical tool for authorities to develop effective environmental management strategies that better support human well-being (MEA…., Luck et al. 2009). However, much less attention has been paid to the study of the ecological underpinnings of ES, which is a necessary first step for their proper implementation and use in decision-making (Kremen 2005, Kremen & Ostfeld 2005, Townsend et al. 2011). Explaining the underlying ecological structure and processes of specific ES ultimately will permit assessments to be made of their quality, resilience to disturbance, and predictions regarding how ES may respond to different management strategies or environmental change scenarios.

As discussed in Chapter 1, ES assessments based solely on economic valuations do not fully encompass all ES parameters, since this approach is dependent on market forces and fluctuations rather than ecological processes (Sagoff 2011). If ecologically- and socially-effective ES management strategies are to be implemented, then it is necessary to know the ability of ecosystems to provide ES, relative to what the expectations and needs are for those services. Therefore, we must understand not only what society expects the ecosystem to provide, but also have an idea of what it is providing and what it is capable of providing.

A large body of work on environmental assessments exists, such as watershed studies that show how the impacts of urbanization can affect stream ecosystem structure and function (Klein 1979, Booth & Jackson 1997, Wang et al. 2001, Morley & Karr 2002, Allan 2004, Walsh et al. 2005). For example, increasing impervious surface of the watershed increases flood discharge, reduces groundwater recharge, and increases erosion in the stream, resulting in a complete alteration of stream hydrology and geomorphology (Paul & Meyer 2001). Similarly, in-stream temperature may increase with the removal of riparian vegetation in the watershed, and contaminants and nutrients may be introduced to the stream directly from effluent or indirectly through overland run-off (Walsh et al. 2005). In turn, the modification of physical or habitat conditions ultimately influences stream biota. Paul and Meyer (2001) summarized a number of studies that all showed increasing urban land use decreased invertebrate diversity with an especially evident reduction in "sensitive" orders (i.e. Ephemeroptera, Plecoptera, and Trichoptera [EPT]). In another review, Walsh et al. (2005) demonstrated that on a global scale macroinvertebrate communities in urban ecosystems are represented by species-poor assemblages and are constituted by taxa described as being "tolerant" to pollution, such as oligochaetes.

Alterations in macroinvertebrate community structure ultimately affect ecosystem processes, via the disruption of trophic dynamics that influence such things as organic matter decomposition and cycling (Cummins 1973). Compin and Céréghino (2007), furthermore, showed that the impacts of urbanization on macroinvertebrate functional feeding groups (FFGs) was greater than what the influence of natural upstream-downstream gradients of physical variables would have predicted. It is, therefore, well supported that macroinvertebrate communities serve as excellent bioindicators of watershed ecosystem condition, and consequently they are a good tool for the assessment of the quality of many watershed ES (Kremen 2005, Barbour & Paul 2009, Feld et al. 2010).

Based on the previous research regarding the impacts of urbanization on physical habitat variables and macroinvertebrate communities, I explored the underlying ecological dynamics of stream ecosystems in urbanized sub-Antarctic watersheds in the Tierra del Fuego Archipelago. Furthermore, urban watersheds were selected due to the fact they represent the principal ecological interaction that humans have with watersheds in this area, since 98% of the population resides in cities (INDEC 2010), and similarly this same pattern is observed for all of southern Patagonia (e.g., 93% of the Magallanes and Chilean Antarctic Region, INE 2010). To determine the ecological condition of these human-inhabited watersheds, I compared stream physical, chemical and biotic variables in urban and reference sites and analyzed how these variables change as a function of increasing urbanization in four watersheds that pass through Ushuaia, Argentina.

In this chapter, I i) establish baseline data to assess watershed ecosystem quality in the sub-Antarctic ecoregion; ii) examine habitat variables through physico-chemical parameters(temperature, dissolved oxygen [DO], conductivity, pH, turbidity) and a rapid visual assessment protocol-RVAP (Barbour et al. 1999); iii) evaluate macroinvertebrate community structure and function (density, richness, Shannon-Weiner diversity [H’], %EPT and FFGs; and iv) test three biotic indices for their applicability in sub-Antarctic streams (Barbour et al. 1999 - Rapid Bioassessment Protocols–RBP; Miserendino & Pizzolón 1999 -Biotic Monitoring Patagonian Streams –BMPS; Figueroa et al. 2003 - Family Biotic Index –FBI). This approach allowed me to determine how well sub-Antarctic watersheds perform in an urban landscape, providing a first step in the goal of evaluating the ability of these watershed ecosystems to provide for ES such as the regulation of water purification, the provisioning of drinking water, and other related services.

Materials and Methods

Study Area

This study focused on the four principle watersheds that flow through the city of Ushuaia in the Argentine Province of Tierra del Fuego, Antarctica and South Atlantic Islands (see Chapter 1 for greater site details). These watersheds comprise a total area of 50,931 ha with annual flow rates ranging from 0.37 $m^3 s^{-1}$ to 504 $m^3 s^{-1}$. The Olivia River represents the watershed with the largest drainage area; Buena Esperanza Stream is the smallest; and Grande Stream and Pipo River at similar sizes are middle-sized watersheds relative to the others (see Table 2.1).

Data Collection

For each stream, I studied a total of three 100 m stream reaches. Reaches one and two were in the urban zone, and reach three represented the reference site, outside of the city's boundary. The first reach (urban) was established approximately 150 m upstream from the mouth of the watershed into the Beagle Channel. This allowed the exclusion of any direct marine influence from tidal activity. The second reach was established approximately midway between the point where the stream entered the urban boundary and its mouth. The third reach (reference) was at least 200 m above the urban boundary and outside any noticeable or significant anthropogenic impacts. Points where streams entered the urban boundary were determined with GIS using shape files provided by the province's Ministry of Social Development that identified the urban boundary and overlaid onto spatial information from Google Earth digital maps (Figure 2.1). Each reach was divided into three transects at the nearest riffle/run habitat closest to 0, 50, and 100 m.

At each reach, a Rapid Visual Habitat Assessment (RVAP) was conducted, based on Barbour et al. (1999) standards. Physico-chemical habitat variables were measured at transects one (downstream) and three (upstream) in each reach, including temperature (°C), conductivity (µS), dissolved oxygen (%DO and mg L^{-1} DO), salinity (parts per trillion –ppt), and pH. All measures were taken with a YSI 556, and water samples were collected with 20 ml plastic vials and analyzed in the lab for turbidity levels with an Oakton T-1 turbidity meter.

The macroinvertebrate assemblage at each reach was assessed with one sample each of the three transects per reach, using a Surber sampler (0.1 m^2). Benthic samples were transported in 70% ethanol to the laboratory, where macroinvertebrates were separated from detritus and identified to the lowest possible taxonomic level (usually genus), using Merritt and Cummins (1996), Heckman (2010), Pérez (2008), Fernández and Dominguez (2001), McLellan and Zwick (2007), and Peters and Edmunds (1972).

Each taxon was also classified per its purported FFG according to Miserendino and Pizzolón (2000) and Anderson and Rosemond (2007). A sensitivity value was then assigned to each taxon using three guides: RBP (Barbour et al. 1999), BMPS (Miserendino & Pizzol**ó**n 1999) and FBI (Figueroa et al. 2003). The scale for the BMPS (based on level of tolerance) was entered inversely to be directly comparable to the other two indices (based on level of sensitivity). In the limited cases where no sensitivity value had previously been noted for an identified family, a new value was assigned based on similar taxa.

Data Analysis

Mean values were obtained for habitat and biotic variables and compared between reaches 1 (most urban) and 3 (reference) for each stream, using an independent t-test. Stream macroinvertebrate community structure and composition were evaluated as invertebrate density (# m^{-2}), taxonomic richness (taxa m^{-2}) and Shannon-Weiner diversity (H'). Effects on benthic community function were assessed with %EPT taxa and the relative abundance (%) of all FFGs. To determine which family-level biotic indices most closely reflected empirical measurements of taxonomic diversity, regression analysis was conducted for each biotic indicator versus taxonomic richness (s), H' and EPT richness. To understand how habitat and biotic variables changed with increasing urbanization, percent urbanization was calculated for each of the two urban reaches for each stream by determining the length of stream upstream from each reach location that was within the urban boundary using Google Earth ® . This length was then divided by the total length of stream to arrive at a level of urbanization for each reach sampled. Stream macroinvertebrate community structure and composition were calculated as with the urban/reference comparison described above. I then carried out linear regressions for all habitat and biotic variables with respect to percent urbanization. All statistical analyses were conducted in JMP 9.0 (SAS 2009).

Results

Habitat Conditions

Overall, these streams were found to be cool, clear and highly oxygenated. No significant differences were found to exist in any of the physical habitat variables when comparing the most urban reaches with the reference sites, but there was, as expected, a trend of increasing temperature, conductivity and turbidity and of decreasing DO in urban sites, compared to reference conditions. At the same time, RVAP results were significantly lower in urban sites than in reference sites (Table 2.2).

Biotic Community

Of the 27 taxa recorded in the study, 16.1% were identified to the species level, 61.3% to genus and 19.4% to family/sub-family/tribe and 3.2% to order (Appendix 2.1). These benthic macroinvertebrates included a total of 4,802 individuals with taxa ranging from insects and crustaceans to annelids and mollusks. More taxa of insects were identified than any other group (taxa = 34), while oligocheates were the most abundant taxon.

Taxonomic richness (p=0.007) and EPT (p=0.01) were significantly lower in urban sites than reference sites, but on the other hand, H' (p=0.26) and density (p=0.23) did not show a significant change (Table 2.3). FFG composition likewise did not show significant alterations between urban and reference sites (Table 2.4). In both habitats, collector-gatherers (CGs) were dominant (55.0 ±6.2% and 75.0 ±13.0% respectively in reference and urban sites) followed by scrapers (Sc) (24.0 ±10.4% and 24.0 ±13.4%, respectively) (Table 2.4). As with habitat variables described above, these compositional differences were not significant, but did follow expected trends of an increase in the importance of CG in urbanized sites.

Family biotic indices all show a highly significant decrease in sensitivity scores in urban sites compared to reference sites (EPT: p<0.001; BMPS: p<0.001; FBI: p<0.001) (Table 2.3, Figure 2.2). Lastly, the BMPS family biotic index best correlated with diversity indices and EPT, compared to the other indices (R^2= 0.97, p<0.001).

Effects of Increasing Urbanization

The percent of watershed urbanization of each site ranged from 3.4% to 67.7% (Table 2.1). Increasing urbanization was significantly related to decreasing DO (p=0.0006), taxonomic richness (p=0.01), % EPT (p=0.008) and EPT richness (p=0.009). Decreases in H' were only marginally related to increases in urbanization (p=0.06). On the other hand, increasing urbanization significantly increased turbidity (p=0.001), conductivity (p<0.0001) and salinity (p<0.0001) (Table 2.5).

Discussion

Watershed Ecosystem Service Quality, as Experienced by Human Communities

The use of bioindicators is often preferred over assessments of physico-chemical measurements to determine ecosystem quality for technical/scientific reasons, as the biological communities encompass a variety of long-term perturbations that might occur in a watershed and therefore integrate spatial and temporal drivers to ecological change (Karr & Chu 1999). In this study, the overall negative impact of urbanization on taxonomic diversity paralleled a decrease in biotic quality indices that can be used as proxies for watershed and ES quality (in this case specifically the provisioning of clean water). In a similar study in northern Patagonia, Miserendino et al. (2008) also found that species richness, EPT, the Shannon–Weiner diversity index, % EPT density, and the BMPS index were lower at urban sites and percent of CGs increased. Therefore, by confirming the utility of the BMPS as a bioindicator for sub-Antarctic streams, they can now be used a useful proxy for water quality by local management institutions. Such macroinverbrate indicators in this biome are more appropriate than fish, which are very species poor (Moorman et al. 2009) and algae or chemical conditions, which require more specialized equipment to conduct assessments.

At the same time, bioindicators like the BMPS are not only ecologically meaningful and more easily applied in the field and laboratory, but they can also be integrated into citizen science approaches (Penrose & Call 1995). Therefore, in the future, it is recommendable that management institutions seek to incorporate these integrative biotic indexes as measurements of watershed quality to existing approaches as a way to engage the local community and thereby enhance their understanding of the link between watersheds and their daily lives. This enhancement of using biophysical data in the management and communication of watersheds may help protect the diversity of these freshwater biological communities and preserve their ability to support local human communities.

Previous studies have shown that anthropogenic activities, especially those associated with urban landscapes, can negatively affect biological community structure and composition (see Introduction above). The results presented here indicate that although there are apparently relatively low levels of impact occurring in urban sub-Antarctic watersheds, there is still a clear negative response in taxonomic diversity of macroinvertebrate communities and other indicators of watersheds quality. These negative impacts also can have severe implications for the ability of these ecosystems to continue to provide quality services. Zavaleta et al. (2010), for example, showed that minimum levels of biological richness were required to provide multiple levels of ecosystem function. As richness decreased so did functionality of ecosystems. Furthermore, since ecosystem goods and services result from multiple ecosystem functions (Costanza et al. 1997), the reduction in diversity that was shown here may over time result in decreased ES quality and quantity, thereby negatively impacting the social well-fare of these communities interacting with these ecosystems.

Enhancing our Understanding Sub-Antarctic Stream Structure and Function: the Inclusion of Urban Systems

To date, all stream ecology research reported for southern Patagonia has been based on watersheds with little impact from urbanization (see Moorman et al. 2006, 2009, Anderson & Rosemond 2007, 2010). In addition, this region is often highlighted for its "pristine" and "wilderness" status (Mittermeier et al. 2003, Rozzi et al. 2012) in spite of the fact it faces a host of environmental threats (see Chapter 1). In addition, the region's human population is highly urban (>90%), indicating that the predominant experience that society has with watersheds is in cities and towns. In this context, these results indicate that the current level of urbanization of the study streams is having an effect on in-stream habitat variables. At the same time, the effects on community functional composition, as measured by FFGs, suggests that the food web may be less impacted; in all cases CGs dominate sub-Antarctic streams, whether they are natural sites, beaver ponds or urban zones (see also Anderson & Rosemond 2007, 2010). The fact that these streams are naturally dominated by CGs could mean that anthropogenic impacts to streams associated with increases of fine particulate organic material (i.e. increased erosion) is mitigated to some level since these streams are inhabited by taxa that feed on fine particulate organic matter (Cummins 1973).

Some of the variability found in our results, particularly those from the *t*-tests, comparing in-stream habitat conditions in reference and urban sites, can be partially explained by understanding differences in the watersheds. First, the Pipo and Olivia

Rivers and Grande Stream are relatively large watersheds, compared to the Buena Esperanza Stream. A majority of the three former watersheds also lie outside of the urban boundary (Table 2.1). In addition, the main channels of the Pipo and Olivia Rivers run through the city only on its western and eastern edge, whereas Grande and Buena Esperanza Streams run right through the middle of the city, where urbanization is more likely to have a significant impact on stream ecosystems. Therefore, urban sites in the Pipo and Olivia Rivers are not as "urban" as the Grande Stream's urban site and much less so than the Buena Esperanza Stream urban site. This line of argument is also supported by the fact that when we regressed each site with the percent of the watershed upstream that was within the urban area, we obtained significant results, showing that increasing urbanization did produce the same impacts here as elsewhere. In essence, these results demonstrate that not all watersheds in Ushuaia are significantly urbanized, but that increasing urbanization does negatively impact streams.

Conclusions

In summary, urbanized sub-Antarctic streams are few, but those that exist are significantly impacted by human-activities. This negative influence on the watersheds that >90% of the human population depends on for crucial ES, including provisioning, regulating, cultural and supporting services, is important for managers to consider when not only evaluating watershed ES but also engaging the public in the understanding and conservation of this component of their socio-ecological landscape. Therefore, based on these results, I propose that future development planning take into account factors, such as increasing impervious surface, deforestation of riparian areas and presence of harmful effluent from residential and commercial sectors, which negatively impact local aquatic ecosystems and their biological communities, ultimately affecting the well-being of the human communities that depend on them. This is especially important when considering the high rate of population growth that is occurring in Ushuaia ( ), increasing the likelihood of an expansion of the urban coverage of these watersheds. Additionally, I recommend the use of the results produced here as a baseline for developing biomonitoring protocols for Ushuaia's natural resource management agencies to monitor the condition of its watersheds and as a tool to engage community residents in this process as well to develop a better understanding within the community of how human behavior and activities play a role in local ecosystem processes.

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Table 2.1 Principle watersheds of Ushuaia, Tierra del Fuego (Argentina) with watershed total area, mean annual flow, river length from headwaters to mouth, total percentage of river length that runs through the urban boundary and percent of upstream urbanization at study reaches 1 and 2. All reference sites were 0% urban upstream.

Watershed	**Area* (ha)**	**Flow* ($m^3 s^{-1}$)**	**Length (km)**	**Total Urban (%)**	**Reach 1 Urban (%)**	**Reach 2 Urban (%)**
Buena Esperanza Stream	1,656	0.37	6.97	67.7%	65.6%	23.7%
Grande Stream	12,538	3.20	18.31	18.0%	17.1%	9.0%
Pipo River	15,813	4.01	36.35	21.2%	20.8%	9.7%
Olivia River	20,924	5.40	41.59	6.7%	6.3%	3.4%

*Iturraspe et al. 2009. Number of years annual flow is based on is not stated.

Table 2.2. Mean (± s.e.) physical and chemical habitat variables for Reference and Urban reaches of sub-Antarctic streams in Tierra del Fuego. T-tests indicated significant differences between sites in bold ($p<0.05$).

	Reference	**Urban**	***t***	**d.f.**	***P***
Turbidity (utm)	2.5 ±1.5	10.2 ±5.2	-1.2	3	0.24
Temperature (°C)	5.4 ±0.5	6.9 ±1.0	-1.4	4	0.24
Conductivity (μS)	57.3 ±8.2	135.3 ±74.1	-1.1	3	0.37
Dissolved oxygen (%)	96.0 ±0.5	94.0 ±8.2	0.2	3	0.82
Dissolved oxygen (mg L^{-1})	12.2 ±0.1	11.5 ±1.1	0.6	3	0.59
pH	7.7	7.8	-0.7	5	0.52
RVAP	188.7 ±3.3	113.0 ±8.3	8.5	4	**0.001**

For pH only medians are reported; RVAP= Rapid Visual Assessment Protocol.

Table 2.5. Linear regressions of habitat and biotic variables as a function of

Table 1.3. Mean (±s.e.) benthic macroinverbrate community variables for Reference and Urban reaches of sub-Antarctic streams in Tierra del Fuego. T-tests indicated significant differences between sites in bold ($p<0.05$).

	Reference	**Urban**	***t***	**d.f.**	***p***
Density (# m^{-2})	2399.0 ± 1233.5	552.0 ±321.5	1.45	3.41	0.18
Richness (# taxa m^{-2})	9.9 ±0.6	3.7 ±0.3	5.62	3.48	**0.0005**
Diversity (H')	1.2 ±0.3	0.8 ±0.2	2.24	5.23	0.07
EPT richness (# EPT m^{-2})	4.1 ±0.6	1.2 ±0.3	4.48	4.73	**0.0074**
EPT (%)	42.3 ±2.5	30.3 ±10.0	1.11	4.46	0.32
BMPS	50.1 ±1.9	15.6 ±1.6	14.09	5.82	**<0.0001**
FBI	39.7 ±2.1	16.8 ±1.1	9.46	4.57	**0.0004**
RBP	37.1 ±2.1	14.5 ±1.8	8.14	5.87	**0.0002**

EPT = Ephemeroptera, Plecoptera, Trichoptera; BMPS = Biotic Monitoring Patagonian Streams; FBI = Family Biotic Index; RBP = Rapid Bioassessment Protocols.

Table 2.4. Mean (±s.e.) relative abundance of functional feeding groups (FFG) at Reference and Urban reaches. T-tests indicated significant differences between sites in bold ($p<0.05$).

	Reference	**Urban**	***t***	**d.f.**	***p***
Collector-gatherer	55.0 ±6.2%	75.0 ±13.0%	1.35	4.31	0.24
Scraper	25.0 ±10.4%	24.0 ± 13.4%	0.1	5.63	0.92
Predator	8.5 ±6.4%	1.3 +0.9%	1.1	3.12	0.35
Collector-filterer	8.2 ±6.8%	0.8 +0.8%	1.09	3.07	0.36
Shredder	2.8 ±1.2%	0.2 ±0.2%	1.72	3	0.18
Parasite	0	0	0	0	0

percent urbanization (U), showing the equation of each model, R^2 and p values denoting significant relationships in bold ($p<0.05$).

Variable	**Model**	$\mathbf{r^2}$	***p***
Habitat			
Turbidity (utm)	1.86 +30.82 x U	0.67	**0.001**
Temperature (°C)	1.18 -1.39 x %U	0.22	0.12
Conductivity (µS)	34.90 +456.77 x U	0.89	**<0.0001**
Salinity (ppt)	0.02 +0.21 x U	0.87	**<0.0001**
Dissolved oxygen (%)	100.53 -37.468 x U	0.70	**0.0006**
Dissolved oxygen (mg L^{-1})	12.60 -5.71 x U	0.70	**0.0006**
pH	7.75 +0.37 x U	0.14	0.22
HVAP	171.16 -96.34 x U	0.25	0.10
Biotic			
Density (# m^{-2})	1859.83 -3284.21 x U	0.13	0.24
Richness (taxa m^{-2})	8.03 -12.003 x U	0.46	**0.01**
Diversity (H’)	1.18 -1.39 x U	0.31	0.06
EPT (%)	0.43 -0.66 x U	0.52	**0.008**
EPT (taxa m^{-2})	3.40 -6.50 x U	0.51	**0.009**

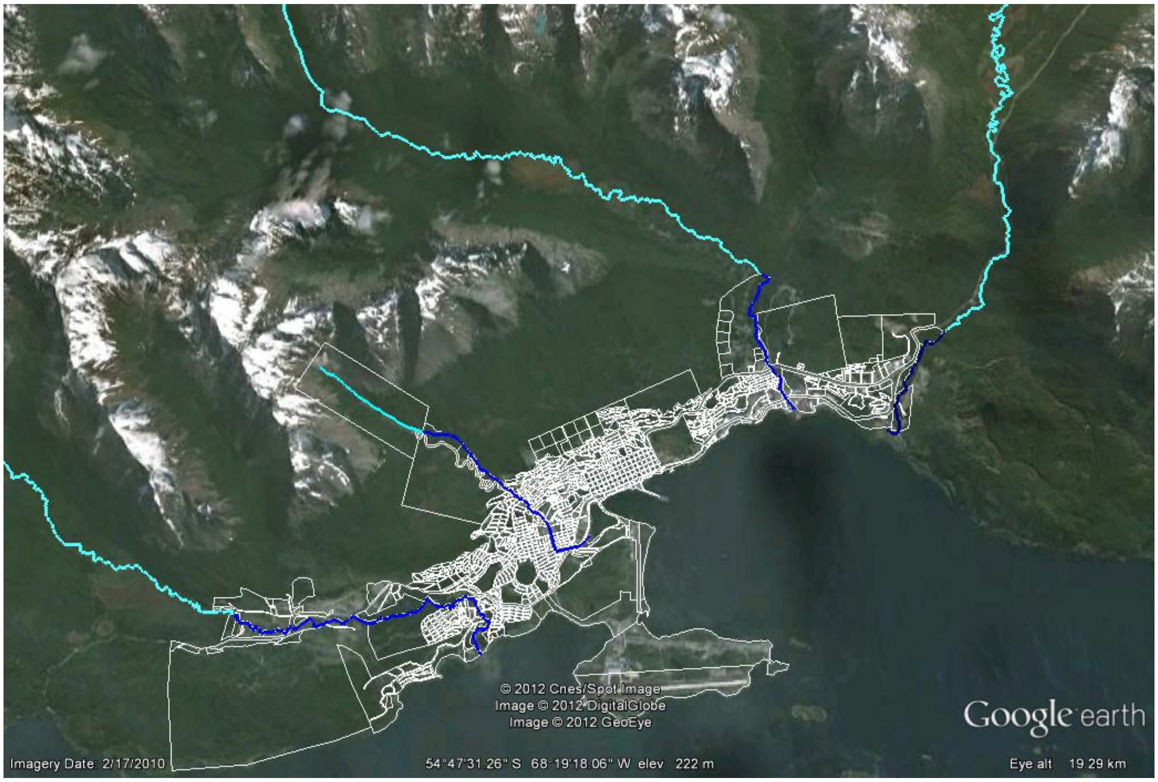

Figure 2.1. Map of all rivers and streams sampled. White lines represent city blocks and denote the urban zone (Google Maps).

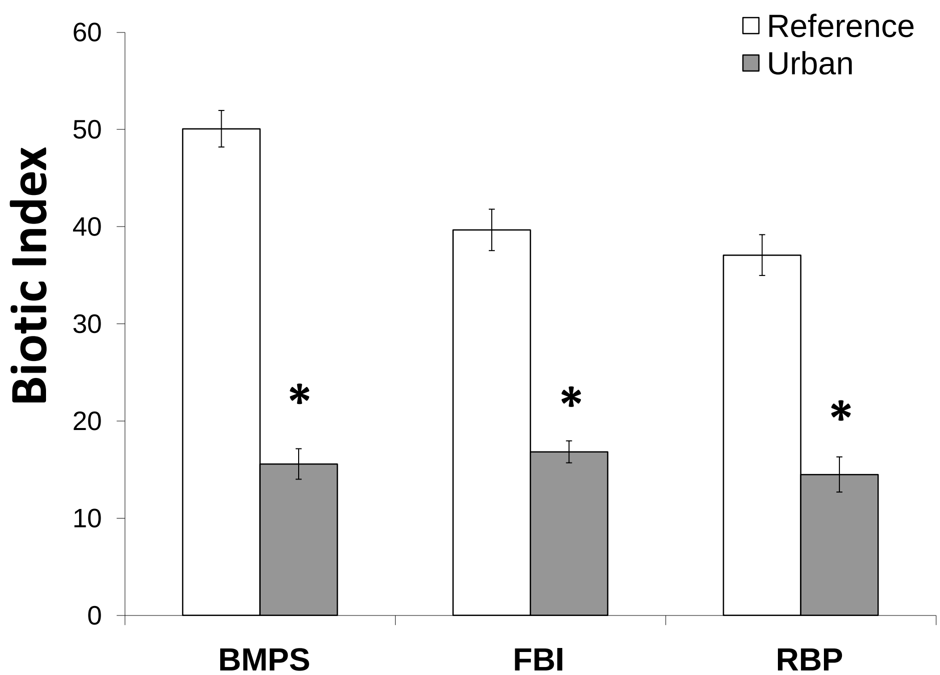

Figure 2.2. Family biotic index scores for urban and reference sites. A higher score signifies greater quantities of sensitive taxa. BMPS: Biotic Monitoring Patagonian Streams; FBI: Family Biotic Index; RBP: Rapid Bioassessment Protocol.

APPENDIX

Appendix 2. 1 Total list of all taxa described during the course of the study in reference (R) and urban (U) sites. FFG = functional feeding group: cg = collector-gatherer, pr = predator, cf = collector-filterer, om = omnivore, sc = scraper.

Class	Order	Family	Subfamily-Tribe	Genus	Species	FFG	R	U
Annelida								
	Oligochaeta					cg	x	x
Crustacea								
	Amphipoda	Hyalellidae		*Hyalella*	spp.	cg	x	x
Entognath	Collembola	Entemobryomorp				cg	x	x
Insecta								
	Coleoptera							
		Elmidae		*Luchoelmis*	sp.		x	x
		Scirtidae					x	
	Diptera							
		Blephecaridae		*Edwarsina*	sc.			
		Ceratopogoniidae				pr	x	
		Chironomidae	Aphroteniinae	*Aphroteniel*	sp.	cg		x
			Chironominae-			cg	x	
			Chironominae-			cf		
			Orthocladiinae			cg	x	x
			Tanypodinae	*Coelotanyp*	sp.	pr	x	x
		Empididae		*Hemerodro*	sp.	pr	x	x
		Limoniidae		*Ormosia*	sp.	om	x	
				Limnophila	sp.	pr	x	x

		Simuliidae	*Gigantodox*	spp.	cf	x	x
		Tipulidae	*Hexatoma*	sp.	pr	x	
			Tipula	sp.	cg	x	x
	Ephemeropte						
		Leptophlebiidae	*Meridialari*	spp.	sc	x	x
			Marssartel	irarrazavali	sc	x	
		Baetidae	*Metamoniu*	ardua Lugo &	sc	x	x
			Andesiops	torrens Lugo &	sc	x	x
	Plecoptera						
		Gripopterygidae	*Aubertoperl*	sp.	sc	x	x
			Antarctoper	sp.	sh	x	x
			Notoperla	sp.	sc	x	
			Rithroperla	*rossi* Froelich	cg	x	x
		Notonemouridae	*Udamocerc*	sp.	sc	x	
	Trichoptera						
		Hydrobiosidae	*Rheochore*	*magellanicum* Flint	pr	x	x
		Limnephilidae	*Monocosm*	*hyadesi* Mabille	sh	x	x
Mollusca							
	Gastropoda	Lymnaeidae	*Lymnaea*	sp.	sc	x	

CHAPTER 3

VALUING SUB-ANTARCTIC WATERSHEDS AND THEIR ASSOCIATED ECOSYSTEM SERVICES

Introduction

Environmental management and conservation strategies are often driven by political and economic priorities or are informed by "expert" opinion, rooted in scientific and technical knowledge (Norton 2005, Fleeger & Becker 2008). Therefore, particular value-systems derived from these disciplines become the basis of decision-making processes, while the potential values from the broader community that is most affected by the outcomes of such decisions are often excluded (Lynam et al. 2007). As a result, environmental and natural resource management strategies frequently force a value system on communities that is foreign to them, and therefore, such plans may often meet with local resistance and in many cases result in a failure to support local social well-being (Menzel & Teng 2010).

Community-based ecosystem management (CBEM) attempts to integrate the values of diverse stakeholders into management structures, thereby avoiding these failures, and construct an administrative system that is compatible with local needs and interests. In this context, CBEM goes beyond public input for the implementation of predesigned programs or simply seeking a one-way dialogue of outreach from an established institution implementing its own priorities; rather it seeks to integrate stakeholder involvement in the development stages of the management structure itself. It has been posited that if diverse stakeholder values are built into the management system, then a reciprocal dialogue between specialists and the broader community becomes a natural process, and indeed several studies have shown that the most successful forms of public engagement in conservation or management are achieved at the planning stages (Duram & Brown 1999, Reed 2008, Menzel & Teng 2010).

Like CBEM, the ecosystem services (ES) approach to research and management, as applied by the Millennium Ecosystem Assessment (MEA 2005), also attempts to incorporate a broader set of values embodied in ecosystems (Raymond et al. 2009) by considering ecosystem goods and services as constituents of social well-being. Nevertheless, this concept is heavily rooted in economic terms and language and thereby has often focused on the monetary values of these ecosystem processes over the previous two decades (de Groot et al. 2002, Brauman et al 2007, Brander et al. 2007, Petrocillo et al. 2010, de Groot et al. 2010). For example, the first major global assessment of ES was conducted by Costanza et al. (1997), who estimated their annual global monetary value at roughly US $33 trillion. Though it is important that society address market failures and include ecosystems' monetary worth into economic models, it is equally important to consider the diversity of ways that we value ecosystems when making environmental decisions, since social well-being is not derived solely from economic valuation (Clayton & Myers 2010).

In this context, I set out here to study basic local ecological understanding, expectations and perceptions of current environmental management in the sub-Antarctic ecoregion, focusing on watershed ecosystems and their associated ES. I assess how ES are valued and perceptions of potential threats. To determine the implications of these factors on management, I studied how the general population (i.e. “community”) and natural resource managers and scientists (i.e. “specialists”) may view these factors differently. In this chapter, I specifically address the following questions:

1. Do respondent groups believe they have the ability to affect current ecosystem management processes through access to ecological information and the ability to communicate with the specialists who determine the management of natural resources?
2. Do respondent groups know the source of their drinking water?
3. Do respondent groups value ecosystem services and perceive potential threats differently?

I hypothesized that community respondents would believe they have less access to scientific information and decision making than specialists, based on the fact that institutions in these communities are not currently implementing public participatory processes in the confection of their environmental management strategies (see Chapter 1). I also anticipated that the general public will have less overall knowledge of watersheds, including information on the origin of their drinking water, compared to the specialists. Previous research on ES has shown that specialists often more highly value particular ES categories known as regulating and supporting services compared to the general public, which places more value on provisioning and cultural services (Raymond et al. 2009). Finally, given these potentially different relationships and views of nature, I expected that the community will also be concerned about different threats to ecosystems than specialists. Such differences would also be consistent with an overall lack of dialogue between communities and specialists, regardless of the specific socio-economic and political factors of specific sites (see Chapter 1). In summary, understanding community perceptions of ES and threats is intended to establish a baseline for quantitatively evaluating whether current natural resource management and conservation strategies meet local needs and expectations, while the assessment of perceptions and values also provides information for the development of CBEM-style strategies that integrate the broader community into ecosystem management and outcomes.

Materials and Methods

Study sites

This research was done in the sub-Antarctic biome of southern South America (Chile and Argentina), which provided an ideal location to perform an assessment of the social dimensions of ecosystem services. Paradoxically, this region is considered to be one of the most pristine in the world and at the same time is experiencing increasing pressures from development and global ecological change. All of these factors have implications for environmental management strategies. The present study was focused on three human urban centers: Puerto Williams (Chile), Punta Arenas (Chile), and Ushuaia (Argentina) (see Chapter 1 for greater detail). All three sites show some cultural similarities, such as all being colonized by Euro-centric, national governments after independence from Spain. Additionally, Spanish is the dominant language at all sites. There also exists, however, a number of cultural and demographic features that differentiate these settlements. Particularly, total population and population growth rates vary between sites (see Table 1.3).

Determining ecosystem service values and threats

Research questions were tested through the application of a quantitative and qualitative survey instrument (Appendix 3.1). Before survey application, I spent a period of approximately two months engaging in participant observation, which allowed me i) to develop an appropriate survey to address my questions, ii) test the survey with regional residents, and iii) make any cultural adjustments to the survey based on responses from trials. This process allowed me to identify basic explanations that were integrated into all questions such that every survey was consistent and would not require additional explanation from the surveyor, which would influence the application method. For the purposes of this study, two social groups were defined *a priori* based on the interests of the research questions: "specialists" were scientists and academics related to the biological and ecological sciences and decision-makers in natural resource management institutions; and all other survey participants were defined as the "community" population.

The survey was applied to these two social groups and was divided into five main sections: 1. general demographic information from the participant (e.g., age, home town, place of birth, education level, gender and profession); 2. ability to access scientific information and decision-makers; 3. level of knowledge of watersheds; 4. perceived values and status of ES; and 5. perceived threats to ES. For the ES portion of the survey (section 4), the total list of services was based on the MEA (2005) typology. For each ES and threat, participants were asked to assign a value between 1 and 10. In addition, for each ES, the participants were asked if it was deteriorating, improving, or maintaining its status. For potential threats, the existing literature was reviewed for the region to generate a list of activities that pose some sort of potential risk to the quality of ES. Space was also given to add additional threats the participant may have perceived as existing. For all questions, space was provided for comments on any particular topic or to explain their response more fully. All survey tools and protocols were approved by the University of North Texas Institutional Review Board (IRB #11175).

To obtain completed surveys from the general community, a number of different methods were used. Most surveys in Punta Arenas and Ushuaia were obtained through convenience sampling by selecting a variety of public spaces including hospitals, clinics, local businesses, schools, shopping malls, city parks and in waiting areas for municipal, state or national public services and approaching any available person willing to conduct a survey. This methodology was deemed to be sufficient for obtaining a representative sample of the population, since all surveys were obtained in areas where a broad suite of social sectors come together. In Puerto Williams surveys were applied using a systematic sampling design through resident door-to-door interviews to ensure a representative sample of a relatively small, but heterogeneous community. All streets in the community were numbered and using a random number generator one street each day of sampling was selected where the first 4 houses on each street were approached for an interview between 5 p.m. and 9 p.m. (i.e. when most members of the household were most likely to be available). This sample design was necessary for Puerto Williams, since the majority of the residents on the island do not congregate in any one area, due to the fact that it is a small community with very few public spaces. To sample the specialist population, I used a mix purposive and chain-referral sampling methodology, where participants at research and natural resource management institutions were recruited through mail, email, by phone or in person. First, institutional directors were contacted to seek permission and assistance to subsequently apply the survey to those professionals and staff under their supervision. Additionally, while surveying the general community, any participant who self-identified as a scientist/academic related to ecology, biological or natural resource management or employee of a natural resource management institution and held a graduate level of degree was treated as a specialist. No minors were surveyed in this study.

Data analyses

Only surveys that answered at least sections 1 and 2 were entered into the unified database and then cross-checked for accuracy. No individual identifying information was recorded that could be linked directly to the respondent. Age and years of residency were used to calculate percent residence time in each participant and whether each participant could be considered "native" (i.e. born in the region even if not the same city) or "non-native" (born outside the region). The average value for each ES category (provisioning, regulating, cultural and supporting) and total ES mean were calculated per survey. In addition, the social groups predefined by the survey were further sub-divided into authority, scientist, public sector employee, private sector employee, house wife, student and other.

The first four questions of the survey had binary responses (yes/no). These related to basic information on watersheds (knowing the definition of watershed and knowing source of drinking water) and also perceptions regarding information and decision-making (access to information and ability to communicate with decision makers). These results were analyzed with a logistic regression (X^2 test). Next, differences between the mean value of each ES, each ES category, and each threat were determined using independent t-tests, comparing “community” versus “specialist”. Logistic regression was also used to determine differences in the percentages of respondents selecting whether each ES was perceived as degrading, improving or staying the same within each ES category. Finally, the top three threats identified by each group were ranked in the order they appeared in terms of frequency as being categorized “top 3” by each survey respondent. All previously described analyses were conducted in JMP 9.0 (SAS Institute 2009) statistical software.

To have a better understanding of the overall similarity of the ES value “mindscape” between the community and specialists groups, a Non-Metric Multidimensional Scaling (NMDS) process was performed, using PC-Ord version 3.4 (McCune & Grace 2002). This analysis allowed the determination of whether the entire suite of values expressed in each survey for community and specialist respondents were clustered as per the pre-defined groups. The NMDS uses a Bray-Curtis Index to compare the similarity of assemblages, in this case ES values, between categories. Since this analysis requires no blank data cells, to conduct this procedure, only surveys that answered at least 80% of the questions were included. Upon removal of the remaining surveys, we also excluded the ES that were reported in less than 90% of surveys, which left us with a dataset that conformed to the analysis requirements.

Results

Survey data demographics

A total of 312 completed or partially completed surveys from all three communities and both study populations were obtained and used in the analyses. Total surveys for each site were 7, 18, and 10 specialists and 39, 114 and 124 community members from Puerto Williams, Ushuaia, and Punta Arenas, respectively. Slightly over half of all participants completing surveys at each site were male (Table 3.1).

Access to information and decision-making and watershed knowledge

There was no difference between the community and specialist groups regarding perceptions of access to information (p=0.50) and access to decisions-makers (p=0.81). Both the community members and specialists perceived that the general public had little access to scientific information about local ecosystems and their management or to decision-makers (Table 3.2, Figure 3.1). Only 32% of the community and 38% of specialists perceived that sufficient access to information existed and 51% and 53%, respectively, believed sufficient access to authorities existed. Significant differences, however, did exist between the community and specialist populations with regards to familiarity with the term watershed (community = 60% yes, specialists = 100% yes, X^2 = 32.28, p<0.0001) and whether or not participants knew from which watershed their drinking water came (community = 64% correct, specialists = 88% correct; X^2 = 9.11, p=0.003) (Table 3.2, Figure 3.1).

Perceptions of ecosystem services values

Among the ES categories, only provisioning services were valued differently between the community and specialists (t = 2.46, p = 0.012), whereby the community on average valued these services more. For all other categories no significant differences existed, but an overall trend emerged of the general community valuing regulating and cultural services more highly than specialists, who in turn reported higher values for supporting services (Table 3.3, Figure 3.2).

For individual services, the community reported higher valuation than specialist respondents for the provisioning of food (p=0.009), fiber products (i.e. firewood, p=0.03) medicinal/pharmaceutical products (p=0.005), ornamental products (i.e. artisanal crafts, p=0.03), and geological resources (p=0.03) and the regulation of air quality (p=0.01) (Table 3.4). On the other hand, the specialists more highly valued the regulation of water (p=0.04), recreational cultural services (p=0.0003) and the ability to generateknowledge systems greater as well, but only marginally significant (p=0.06) (Table 3.4). No significant differences existed in how community and specialist participants valued supporting services.

The percentage of community participants who understood ES categories was lowest for supporting services (73%) and regulating services (73.4%). Cultural services were the most understood by the community (86.9%), while provisioning services were in between (79%). The least understood specific services by the community were: 1. the provisioning of genetic resources (49.8%); 2. the supporting service of soil formation (56.3%); and 3. the provisioning of medicinal/pharmaceutical resources (58.6%). The regulation of erosion (59.8%) and of air quality (59.8%) also had relatively low levels of comprehension by community respondents (Table 3.4).

Regarding the ranking of the top three ES, both groups showed the same prioritization for the ES in the provisioning category, but had slightly different rankings for regulating, cultural and supporting services. Overall, the community most often prioritized water cycling and photosynthesis supporting services. Aesthetic, inspirational and provisioning of water services occupied second place, and intrinsic/bequest type services were at third. Specialists on the other hand prioritized recreational services first, provisioning of water second and aesthetic services third (Table 3.5).

Perceptions of status and threats to ES

The community was apparently more optimistic regarding the status (degrading, improving or the same) of ES than the specialists. It was discovered that while almost half of both groups felt that ES conditions were static (i.e. maintaining the same) (t = -

0.67; d.f. = 51.46; p = 0.51), the specialists had a significantly greater proportion who believed that ES were degrading (t = 2.54; d.f. = 43.90; p = 0.02) and the community believed more often than specialists that some ES were improving (t = -2.70; d.f. = 60.64; p = 0.01) (Figure 3.3).

Furthermore, the community perceived most threats in a similar manner to specialists, but two threats had a significantly higher level for the community than for specialists. These were deforestation (p=0.003) and the ozone hole (p=0.002), while specialists perceived the threat from livestock grazing higher than the community (p=0.007, Table 3.6, Figure 3.4). The ranking for these threats were: climate change, deforestation and the ozone for community respondents, and urban development, introduced species and deforestation for the specialist population (Table 3.7).

Overall "mindscape" similarity of ES values between participant groups

NMDS results showed a high degree of overlap regarding the overall "mindscape" for both study groups. These results also indicated that a greater diversity (wider spread of data points) was found for the values that were held by the community, compared to specialists, which were more homogeneous. However, in general while there were particular differences between the two groups, the NMDS illustrated that overall the value systems of these two groups have a great deal in common (Figure 3.5).

Discussion

Science-society dialogue

Public participation in environmental management is being sought out as an alternative to traditional command-and-control strategies that fail to consider the local ecological and social context of where management is being implemented (Tuler & Webler 2010). Though both Argentina and Chile recognize the need to integrate public participation into environmental management processes (see Chapter 1), it is clear that community members feel they lack the ability to affect decision-making regarding the management of local ecosystems. However, the fact that the specialist community, made up of scientists and decision-makers, reflects the same view is surprising, considering the fact that it is precisely these individuals who are charged with engaging the community. It is also troubling that a large portion of the general community does not have a basic understanding of common ecological terms, such as the watershed, a basic knowledge of local natural resources, such as the source of one's drinking water, nor a perception of the benefits that local ecosystems provide to humans and which are often vital for life. For example, the provisioning of genetic diversity was an ES poorly understood by community members. When participants were presented with this service in the survey a brief general description was given showing that genetic resources were closely tied to biodiversity (see Appendix 3.1) as described by the MEA (2005).Therefore, a portion of the benefits provided by biodiversity are poorly understood by community members. When considering the great deal of concern that exists among the scientific community about the loss of biodiversity (Brooks et al. 2002, Hooper et al. 2005, Boris et al. 2006), more efforts need to be taken to communicate such information to the general public if it is expected that people will change the behaviors that negatively affect biodiversity and

ES. This is further emphasized by the fact that perceptions of ES status and potential threats to ecosystems, which usually play a major role in influencing the decisions managers make, differed greatly between community members and specialists. Clearly, improved dialogue between these two social sectors is necessary and this would be best achieved if it is developed as a foundational process at the institutional level.

Dialogue, on the other hand, can not occur if it is only unidirectional. Even if outreach education is considered as a product of science-based and political institutions, it is highly unlikely that groups of people, which contain informal ecological knowledge obtained through cultural tradition, a profession related to natural resources or simply through spending time as an outdoor recreationist, will be able to contribute to the overall knowledge-base of local ecosystems. Such local (LEK) and traditional (TEK) types of ecological knowledge can greatly enhance the adaptability and long-term resilience of management strategies, while promoting the cultural diversity of a region and thus creating reservoirs for diverse knowledge systems (Berkes et al. 2000, Lertzman 2009). For example, Olsson and Folke (2001) found that local ecosystem knowledge of crayfish in a Swedish watershed built ecological resilience into the watershed and created an adaptive capacity to manage them. Further, they suggested that scientific-based management strategies could greatly benefit from using community-based and collaborative approaches to fully take advantage of diverse knowledge types. Although this study did not specifically seek to investigate different types of LEK and/or TEK that may exist in the region, during the survey period of this research, there were many occasions where such knowledge surfaced through conversation with community participants and could therefore be an area for future research.

Overall, this study showed that poor dialogue currently exists between science and society at the southern tip of the Americas. This has even greater implications when one considers that there are some value differences for local ecosystems between those who influence their management and those who depend on them. Many of the provisioning services that were valued significantly greater by community members than specialists were those that can be manufactured into local tangible products, such as Patagonian lamb, the calafate berry (*Berberis microphylla*), and marsh grasses which are used to make regional crafts and jewelry. Indeed, the people surveyed in this study were proud of their locally produced products and such values should be considered in the management of these ecosystems.

Considering both value diversity and similarity for adaptive ecosystem management

It was often those services which are difficult to put into monetary terms (e.g., intrinsic/bequest values, regulation of air quality) that were highly valued in this study. This has important implications for future environmental management that employs the ES as a central unit. As the discussion of ES valuation continues, it is crucial that these value types are considered in the discussion, and not only those that can be easily expressed in monetary terms, if we as a society are to address the ecological constituents that support overall human well-being. Lockwood (1999) discusses the difficulty of capturing these types of values in economic terms, as well as concerns among social sciences and psychologists on economists using stated preference techniques. The methodology used in this study relied on ranking and relative differences in an arbitrary scale to interpret overall valuation, rather than simply placing it into a monetary scale.

Perhaps the lack of dialogue and participatory processes in management would be of less concern if all people valued ecosystems the same, but that is clearly not the case here. Even if the differences are not exceptional, the fact that there is a greater diversity of values among the community than among specialists shows that specialists, who are more likely to have the ability to insert their values into management strategies, are less likely to capture the broad diversity of values from the community, which includes social sectors that are less likely to have the same ability. It is a positive sign, however, that because many values of ecosystems are shared between the community and specialists a foundation exists for transitioning to more collaborative processes for managing ecosystems. On the other hand, because both populations recognize a general deficiency in such participatory processes, it would be important to analyze the institutional obstacles that are currently preventing such society-science integration. Furthermore, it would be important to determine the values that have developed institutions and policies that regulate and manage natural resources and to what extent they differ from the diversity of values expressed by the community and specialists themselves.

Conclusions

As environmental management institutions increasingly align themselves with the ES paradigm and efforts to create community-based administrative and research plans, it is essential that ES research seeks to understand the range of values that exist in the communities where management is taking place. If a goal of environmental management, and society as a whole, is to support the well-being of current and future generations, then values and knowledge systems represented within a society must be considered in management decisions. Lockwood (1999) warns against the biased decision-making that can occur when values are only attempted to be expressed indirectly through normal political processes and influenced by privileged stakeholders. Therefore, it is highly recommended that community-based and public participatory processes be integrated into management institutions to initiate such dialogue for future adaptive management strategies in the sub-Antarctic ecoregion. The results of this study have shown that a diversity of values exists for local ecosystems and that values may differ between those who influence the management of ecosystems and the rest of the community. At the same time, the study population had a solid foundation of shared values that provide a starting point for the construction of a dialogue between science and society.

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Table 3.3. Mean values (± s.e.) for categories of ecosystem services (ES) for Community and Specialist populations and results of independent t-tests, showing significant differences in **bold** ($p<0.05$).

ES Category	Community	Specialists	*t*	d.f.	*p*
Provisioning	7.4 ±0.1	6.6 ±0.3	2.46	40.78	**0.012**
Regulating	7.3 ±0.1	7.1 ±0.4	0.41	41.82	0.69
Cultural	7.9 ±0.1	7.7 ±0.3	0.54	42.90	0.59
Supporting	8.0 ±0.1	8.2 ±0.3	0.36	45.96	0.72

Table 3.1. Total numbers of completed surveys for each city by Community & Specialist and Male & Female categories.

Groups	Total	Puerto Williams	Ushuaia	Punta Arenas
Community	277	39	114	124
Specialist	35	7	18	10
Male	56%	51%	56%	56%
Female	44%	47%	43%	44%
Total N	**312**	**46**	**132**	**134**

Table 3.2. Percentage of respondents who answered either yes or correctly to questions 7-10 in survey (see Appendix 3.1). Logistic regression results are provided for each question, comparing social groups; *p* values in **bold** show significant differences ($p<0.05$).

Survey Questions	Community	Specialist	X^2	d.f.	*p*
Information Access	32.5%	38.2%	0.45	1.0	0.50
Communication with Managers	50.6%	52.9%	0.07	1.0	0.79
Definition of Watershed	59.8%	100.0%	32.28	1.0	**<0.0001**
Knowledge of Water Source	64.2%	88.2%	9.11	1.0	**0.003**

Table 3.4. Mean values (± s.e.) for all ecosystem services included in the survey shown for Community and Specialist populations. Results of independent t-tests are given and significant differences are highlighted in **bold** ($p<0.05$). The percentage of Community respondents that understood each service and average for each category are given as well.

Ecosystem Service	Community	Specialists	*t*	d.f.	*p*	Percent understood
Provisioning						**79.0%**
food	7.9 ±0.2	6.4 ±0.5	2.74	38.51	**0.009**	98.5%
water	8.5 ±0.1	9.0 ±0.4	1.41	44.09	0.08	98.1%
fiber	7.5 ±0.2	6.3 ±0.5	2.23	35.42	**0.03**	94.3%
medicinal	6.0 ±0.2	4.1 ±0.6	3.03	26.98	**0.005**	58.6%
genetic	6.9 ±0.2	6.7 ±0.5	0.28	37.22	0.78	49.8%
ornamental	7.1 ±0.2	5.7 ±0.6	2.23	33.49	**0.03**	93.1%
geological	7.0 ±0.2	5.7 ±0.5	2.31	33.94	**0.03**	80.1%
Regulating						**73.4%**
climate	7.1 ±0.2	7.7 ±0.5	1.27	41.23	0.21	65.5%
disease	7.2 ±0.2	7.0 ±0.5	0.34	25.87	0.73	73.6%
water	7.4 ±0.2	8.5 ±0.5	2.08	38.36	**0.04**	88.1%
H_20 purification	7.1 ±0.2	7.8 ±0.5	1.40	37.73	0.09	78.9%
pollination	7.0 ±0.2	6.4 ±0.6	0.95	31.35	0.35	59.8%
air quality	8.1 ±0.2	6.4 ±0.6	2.74	33.99	**0.01**	82.8%
erosion	7.0 ±0.2	7.3 ±0.5	0.52	43.41	0.61	59.8%
pests	7.6 ±0.2	6.8 ±0.6	1.30	24.29	0.2	68.6%
natural disasters	7.4 ±0.2	7.8 ±0.4	1.00	26.71	0.32	83.1%
Cultural						**86.9%**
spiritual	7.4 ±0.19	6.7 ±0.67	1.01	26.71	0.32	80.1%
recreation	8.2 ±0.14	9.2 ±0.19	3.82	73.11	**0.0003**	91.2%
aesthetics	8.5 ±0.14	8.8 ±0.25	1.12	54.79	0.27	93.5%
inspiration	8.5 ±0.15	7.7 ±0.42	1.72	40.35	0.09	92.0%
education	7.1 ±0.17	7.8 ±0.46	1.36	42.09	0.18	89.3%
sense of place	8.0 ±0.16	7.2 ±0.45	1.56	40.97	0.13	85.8%
cultural heritage	7.8 ±0.15	7.3 ±0.46	1.07	37.67	0.29	83.9%
knowledge systems	7.2 ±0.2	8.0 ±0.4	1.92	43.2	0.06	76.6%
social relations	8.2 ±0.2	7.5 ±0.4	1.72	41.29	0.09	91.2%
cultural diversity	7.7 ±0.2	7.4 ±0.5	0.57	30.15	0.57	85.8%
intrinsic or bequest	8.4 ±0.1	7.7 ±0.5	1.40	35.08	0.17	87.0%
Supporting						**73.0%**
soil formation	7.2 ±0.2	7.8 ±0.4	1.34	41.39	0.19	56.3%
nutrient cycling	7.9 ±0.2	8.4 ±0.4	1.36	50.55	0.18	65.9%
primary production	7.7 ±0.2	7.5 ±0.4	0.50	39.70	0.62	78.2%

photosynthesis	8.6 ±0.1	8.0 ±0.4	1.27	39.75	0.21	79.3%
H_20 cycling	8.6 ±0.1	8.7 ±0.3	0.18	47.61	0.86	85.1%

Table 3.5. Ecosystem services with the highest mean average value per Community and Specialist groups were ranked for the top three services per category.

Ecosystem Service Category		**Community**	**Specialist**
Provisioning			
	1	water	water
	2	food	food
	3	fiber	fiber
Regulating			
	1	air quality	water flow
	2	pest control	natural disaster
	3	water flow	H_20 purification
Cultural			
	1	aesthetics	recreation
	2	inspiration	aesthetics
	3	intrinsic or bequest	knowledge systems
Supporting			
	1	H_2O cycling	H_2O cycling
	2	photosynthesis	nutrient cycling
	3	nutrient cycling	photosynthesis

Table 3.6. Mean (+ s.e.) for each perceived threat to ecosystem services (ES) were determined for each social group. Statistical differences were determined with t-tests, and significant results ($p<0.05$) are in **bold**.

Threats to ES	Community	Specialists	*t*	d.f.	*p*
climate change	8.1 ± 0.2	7.5 ± 0.4	-1.53	46.83	0.13
industrial pollution	7.1 ± 0.2	6.4 ± 0.5	-1.25	47.22	0.22
deforestation	7.8 ± 0.2	6.2 ± 0.5	-3.2	41.22	**0.003**
introduced species	7.1 ± 0.2	7.7 ± 0.4	1.28	47.18	0.21
ozone hole	8.2 ± 0.2	6.5 ± 0.5	-3.30	37.2	**0.002**
peat extraction	6.2 ± 0.2	6.6 ± 0.5	0.68	43.14	0.5
tourism	5.0 ± 0.2	5.7 ± 0.4	1.81	57.60	0.08
urban development	6.7 ± 0.2	7.3 ± 0.4	1.45	49.82	0.15
livestock grazing	4.3 ± 0.2	5.8 ± 0.5	2.86	44.33	**0.007**

Table 3.7. The ranking of each threat per social group. Percentages are based on the number of respondents who identified each as a "top 3" threat. Bold indicate the top 3 within each social group.

Threat	Community	Specialist
climate change	**1 (65.8%)**	4 (35.3%)
industrial pollution	4 (39.9%)	3 (38.2%)
deforestation	**2 (51.8%)**	**2 (41.2%)**
introduced species	6 (22.8%)	**2 (41.2%)**
ozone hole	**3 (48.2%)**	7 (11.8%)
peat extraction	7 (8.8%)	6 (17.7%)
tourism	8 (8.3%)	8 (8.8%)
urban development	5 (24.9%)	**1 (52.9%)**
livestock grazing	9 (6.2%)	5 (20.6%)

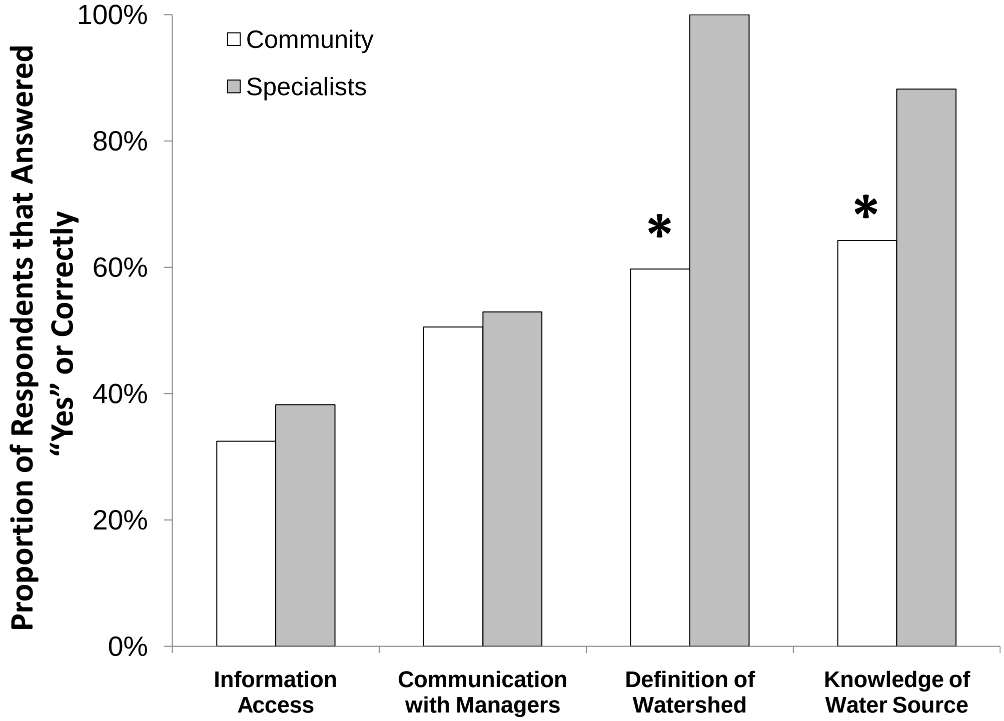

Figure 3.1 Proportion (%) of respondents (Community versus Specialists) who answered in the affirmative or correctly to binary questions regarding overall levels of information and access to information about watersheds. Stars indicate questions with signicant diffrences between social groups with a X^2 test ($p<0.05$).

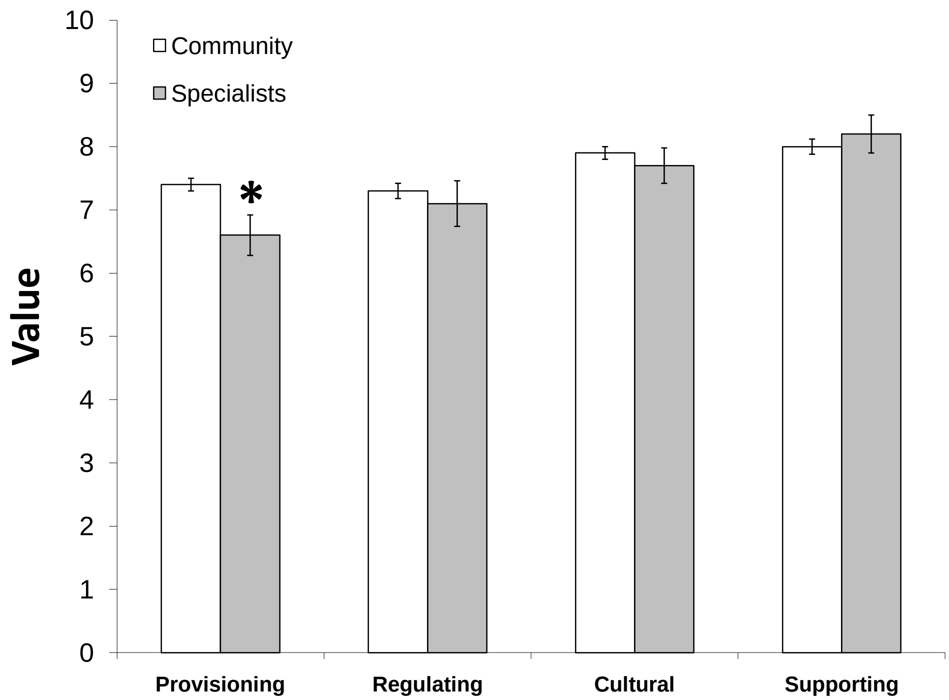

Figure 3.2 Mean value (± s.e.) of each ecosystem service category measured by respondent social status (Community versus Specialists). Stars indicate questions with significant differences between social groups with a t-test (p<0.05).

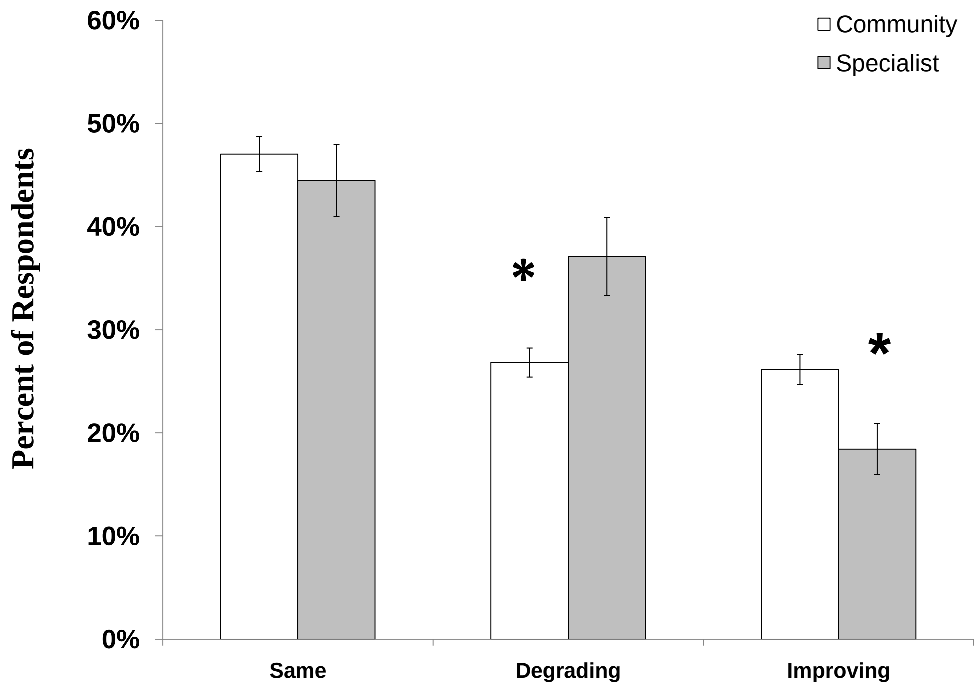

Figure 3.3 Proportion (%) of ecosystem services believed by respondents (Community versus Specialists) to be staying the same, increasing or decreasing. Stars indicate significant differences between social groups with a X^2 test (p<0.05).

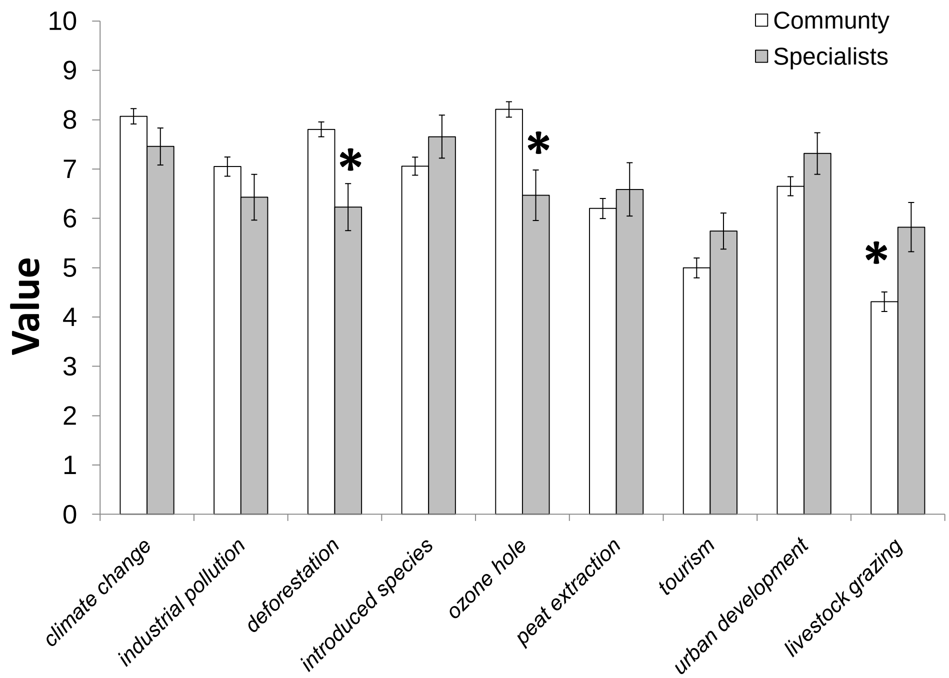

Figure 3.4 Mean value (± s.e.) given to potential threats to ecosystem services by respondents (Community versus Specialists). Stars indicate significant differences between social groups with a t-test (p<0.05).

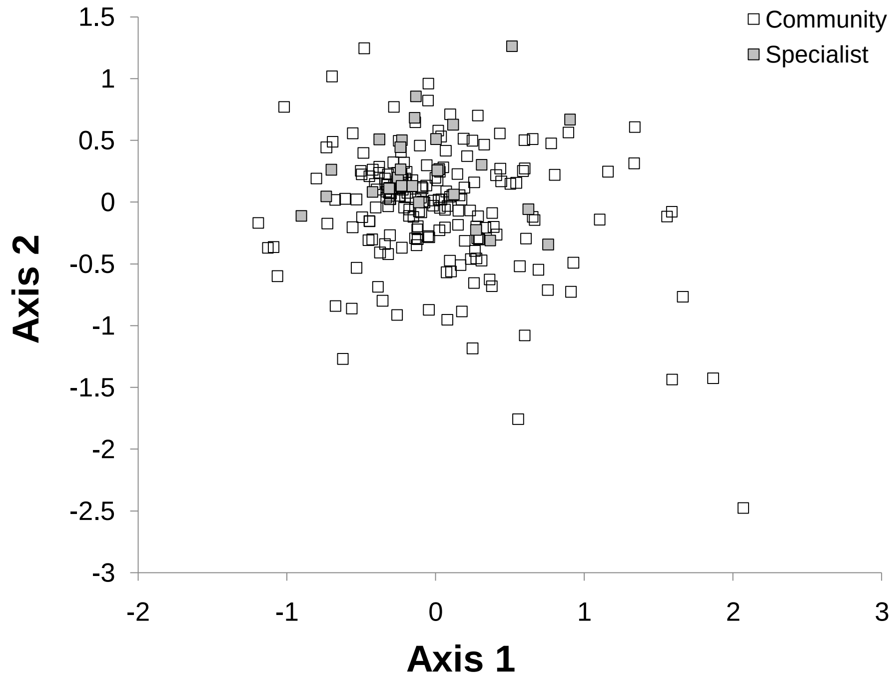

Figure 3.5 Graphic representation using Non-metric Multi-dimensional Scaling (NMDS) of the similarity (Bray-Curtis) for the entire survey responses of ecosystem service values between social groups (Community and Specialists).

APPENDIX

Appendix 3.1 English version of the survey applied to all participants at all sites. The version received by participants was translated to Spanish and contained basic explanations to ecosystem services based on observations during the participatory research period.

General Information

Age ____ Hometown: ___________ ( ) male ( ) female

1. **Number of years you have been resident or periodic resident in the community? ____________________**
2. **Name the neighborhood or district you live in?**

   ____

3. **Do you identify yourself most as (mark one): ( ) scientist/academic ( ) natural resource manager ( ) politician or government worker ( ) long-time resident ( ) military officer ( ) student ( ) teacher**

4. **Identify your profession or job.**

   ____

5. **Education Level: ( ) high school ( ) university ( ) masters or above**

Watershed Information (*a watershed is the region draining into a river, river system, or other body of water; a river and its valley*):

6. **Are you familiar with this term ____? Do you have another way of defining this term?**

7. **Do you feel the general public in your community has sufficient access to scientific information concerning regional watersheds and rivers? Explain?**

8. **Do you feel the general public in your community has sufficient ability to communicate with regional scientists and natural resource managers? Explain?**

9. Specific place-based watershed information:

Watersheds in Puerto Williams	Identify the river that provides your drinking water	Rank in order from highest valued to least valued	Annual frequency of visits to the river or its tributaries	General location of where you visit the river or its tributaries	Comments
Río Róbalo					
Río Ukika					
Other:					
Other:					
Do not know					

Watersheds in Punta Arenas	Identify the river that provides your drinking water	Rank in order from highest valued to least valued	Annual frequency of visits to the river or its tributaries	General location of where you visit the river or its tributaries	Comments
Río Las Minas					
Río de los Ciervos					
Río Tres Puentes					
Other:					
Do not know					

Watersheds in Ushuaia	Identify the river that provides your drinking water	Rank in order from highest valued to least valued	Annual frequency of visits to the river or its tributaries	General location of where you visit the river or its tributaries	Comments
Río Pipo					
Río Olivia					
Arroyo Grande					
Arroyo de Buena Esperanza					
Other:					
Do not know					

	Ecosystem Services	Value from 1 (low) to 10 (high) for the service you believe to be present. Mark 0 if it does not exist or skip if it is not understood	Is the service *deteriorating (d)*, *improving (i)*, or *maintaining (m)*	*Comments*
Provisioning	**Food** (crops, livestock, wild food, fisheries)			
	Freshwater			
	Fiber (timber, plant material, fuel wood)			
	Biochemicals, natural medicines, pharmaceuticals			
	Genetic resources (biodiversity; genetic mat'l of current or future value; sources of unique biological products)			
	Ornamental (ex. artisan crafts)			
	Geological resources (ex. minerals)			
Regulation	**Climate regulation** (ex regulation of extreme changes in climate)			
	Disease regulation (value that ecosystems/nature regulates the birth of diseases)			
	Water regulation (which affects water flow in rivers)			
	Water purification and waste treatment (natural purification and regulation)			

	Pollination (of plants)			
	Air quality regulation			
	Erosion regulation (ex. stream bank erosion)			
	Pest regulation (natural pest resistance)			
	Natural hazard regulation (ex. natural flood regulation)			

10. Ecosystem Services Information (continued).

	Ecosystem Services	Value from 1 (low) to 10 (high) for the service you believe to be present.	Is the service *deteriorating* (*d*), *improving* (*i*), or *maintaining* (*m*)	Comments
Cultural	**Spiritual and religious** (related to local environment; ex. meditation along side a river)			
	Recreation and ecotourism			
	Aesthetic (ex. beauty of the landscape)			
	Inspirational (that the local environment inspires you)			
	Educational (on local ecosystems and biodiversity)			
	Sense of place			
	Cultural heritage (that the local environment permits growing of cultural roots now or historically)			
	Knowledge systems (ex. a system to identify local plants or animals)			
	Social relations (ex. the ability to enjoy a river with family over a barbecue)			
	Cultural diversity (ex. a variety of cultures can access local ecosystems and share their knowledge of them)			
	Bequest, intrinsic, existence (ex. the value that plants and animals have their own right to live)			
Sup	**Soil formation**			
	Nutrient cycling (ex. the movement of			

	nutrients between plants, insects, carnivores, detritivores; cycle of life)			
	Primary production (`the growth of plants			
	Photosynthesis (*oxygen production*)			
	Water cycling (ex. clouds-rain-plants-ground-river-ocean-cluds)			

11. Place a number from 1 (low) to 10 (high) for the potential level of threat that exists to local ecosystems and biodiversity and rank the top three threats for your local watersheds.

Potential Threats	**Severity of Threat (1-10)**	**Rank Top 3 Threats**
1. Climate change (ex. global warming)		
2. Industrial contamination		
3. Deforestation and logging		
4. Exotic species		
5. Ozone hole		
6. Peat extraction		
7. Tourism		
8. Urban development		
9. Ranching		
10.Other: ___________________		
11.Other: ___________________		
12.Other: ___________________		

12. Do you have any general or additional comments regarding the services provided by watersheds in your community or threats that they face?

CHAPTER 4

CONCLUSIONS, IMPLICATIONS AND SUGGESTIONS FOR THE FUTURE

Significance of this Research

Southern South America's Patagonian and Sub-Antarctic Ecoregions are conformed by some of the most pristine ecosystems left on the planet. Furthermore, this area conveys a grand sense of scenic beauty and a feeling of "naturalness" that is highly desired for both conservation and ecotourism. Yet, ironically, these ecosystems are not devoid of anthropogenic influences since the first human inhabitants arriving several thousand years ago. Today, urban centers exist and are growing; development and infrastructure are increasing; and exposure to global and localized environmental threats is becoming more apparent (Chapter 1). As a result, it is imperative that researchers seek to understand these ecosystems and managers attempt to rationalize their use and conservation. Both of these endeavors (i.e. research and management) require a fundamental understanding of these systems' ecological, social and socio-ecological attributes.

The growing global realization among academics and decision makers of the link between the environment and humans has created a burgeoning body of literature that establishes a plethora of tools and approaches (e.g., the Pulse-Press Dynamics (PPD) framework [Collins et al. 2011]), to facilitate our understanding of the dynamics of coupled social-ecological systems. Nonetheless, most of these tools have yet to be fully employed and tested in real-world scenarios. By using the PPD framework as a model that links social and ecological domains of ecosystems via the ecosystem services (ES) concept, this thesis initiates a necessary process in a region where, to date, very few integrated socio-ecological assessments have occurred and where national priorities of both Chile and Argentina have stated as a goal such integrated management, but without achieving effective implementation. Therefore, in this thesis, I have contributed to this process by surveying biophysical conditions that underpin watersheds (Chapter 2), as well as evaluating the community's social values/perceptions of those ecosystems (Chapter 3) to propose concrete actions in management and research (final section below).

To date, comprehensive assessments of watershed biophysical quality or ES quality do not exist for Tierra del Fuego. Aquatic macroinvertebrate communities in these ecosystems provided a useful tool that is extensively studied elsewhere and could be conveniently and effectively implemented as one proxy to help understand overall ES quality provided by watersheds to human communities. In this way, the data generated from this study provides a baseline to implement long-term monitoring to continue to evaluate those impacts to stream ecosystems. In addition, the process of collecting and identifying macroinvertebrates for use in bioindication of ecosystem quality is relatively inexpensive and simple. It also has been shown to be a useful tool to engage the public in research and management activities related to watersheds.

Chapter Two, therefore, showed that in sub-Antarctic urban watersheds, biotic communities are being negatively impacted by urbanization, and therefore the ecosystems that they inhabit may be hindered in their ability to provide for quality ES.

On the other hand, trophic relationships were not as severely impacted (as measured by Functional Feeding Groups-FFGs), which may reflect some level of resilience or buffering capacity of these ecosystems against urban influence. Anderson and Rosemond (2010) have previously indicated that sub-Antarctic streams also may be resilient to beaver invasion, since the alterations caused by beavers serve to enhance pre-existing conditions, such as favoring collector-gather FFG taxa. Similarly, the fact that urban sites also favor these taxa means that the overall impact of urbanization may be attenuated by the baseline conditions of these streams. Yet, at a more fine scale analysis (e.g., species assemblage, etc.), there were important changes as a result of urbanization. At the same time, these results indicate that special attention should be given to both watershed ecosystem structure and function as the region continues its current trend of rapid urban development and how that impacts the overall ability to support social well-being in sub-Antarctic human communities through ES.

Chapter Three showed that both similarities and differences existed in the way communities and specialists perceived and valued ES and extant management strategies. This exemplifies previous investigations that have emphasized the diversity of environmental values that may exist in the region (Schuettler et al. 2011). However, it also importantly demonstrates that there are core values that are shared between decision makers and the general community, which bodes well for attempts to promote community-based ecosystem management (CBEM) schemes. The results from Chapter Three, therefore, showed that stakeholder involvement in the management of ecosystems is feasible and that community cares about the ES watersheds provide. However, their viewpoints and priorities must be considered. For instance, community members valued such ES as air quality and inspiration more highly than specialists. Natural resource management institutions, therefore, could formulate policies and regulations that assure the protection of these services as a way to engage the public. This may translate to replanting and forest protection against deforestation (a top perceived threat by community members) of watersheds for air purification and oxygen production and to the creation and/or enhancement of public urban parks that give people access to the inspirational traits of local ecosystems. Such policies in turn will garner support from the local community since, as this thesis has shown, these are highly valued ES, which may not be sufficiently considered in current strategies. In addition, riparian enhancement may not only serve to improve these ecosystem services that community members value but also improve the overall ecological conditions shown to have degraded in Chapter Two.

However, current management strategies are not structured to effectively include multiple values in their implementation, and this result is recognized by both community members and specialists. This fact is even true within recent natural resource management policy in both Chile and Argentina, though institutions do not have the know-how to implement such policy. Further research can explicitly seek to understand the values that are currently shaping environmental policy and management institution structure and compare those to the values found to exist among community and specialist populations in this study. This will facilitate a better understanding of where current management strategies are failing to meet the needs of these communities.

Participatory Research

This thesis was designed to include public participation in its implementation as a way to enhance the science-society dialogue. While being in constant contact with community members and simultaneously with natural resource managers, I was able to directly communicate various forms of information and knowledge between these science-based institutions and the greater community. For example, during my social field work in Puerto Williams I learned through general discussions in relations to the topics being covered in the surveys that the community saw deforestation and poor forest management as a severe threat to their livelihood since the residents of Puerto Williams rely on wood fired stoves to heat their homes through the long and often harsh winters. In addition to the provisioning of firewood, their exists a number of additional valued ES that are produced by the island's forests (i.e. scenic beauty and ornamental materials), therefore these forested ecosystems are very important. On a number of occasions, I was told there were no reforestation plans in place on the island by community members. At the same time and in the same manner, I learned from the local office of the national forest service (*CONAF*) that a management plan was in place, reforestation efforts have been and are being implemented and that the long-term sustainability of these forests were guaranteed, at least for the provisioning of firewood. Indeed their existed a gap in communication about this island's crucial resource which supported the well-being of the inhabitants.

Taking a participatory approach to this research allowed me to actively communicate this information between these two groups to reduce fears of the community and inform the *CONAF* of those fears so that they can develop and implement programs and/or materials about the reality of some of the ecosystem services that the island is able to produce. Based on examples like these, I highly recommend that future ecosystem research actively engage the public, if not in its implementation at least at some level of the design to not only communicate knowledge being generated, but also to understand people's relationships to the ecosystems being studied.

During my time in Puerto Williams, I also was engaged in community processes. For example, I assisted with environmental education courses being conducted in the local public school with a grant supported by the Explora Program, the national Chilean initiative to enhance science education. These were elective courses which focused on the local flora and fauna of the Tierra del Fuego Archipelago. Furthermore, I mentored two high-school children from the same school in developing a stream bioassessment study, which was entered into the regional science fair. These experiences allowed me to build trust between me and many of my survey participants, who were often parents of school children I was assisting. This experience also facilitated my own gaining of greater understanding of social relationships to local ecosystems in Puerto Williams and allowed me to better assess gaps of communication occurring between specialists and community members there based on first-hand experience.

Community-based ecosystem management

This thesis has taken a "community-based" approach as opposed to a "stakeholder" approach because, as shown by the MEA, all people are dependent on ecosystems to some extent, some more directly than others, and therefore any environmental management strategy which impacts an ecosystem will impact the people dependent on that ecosystem. On the other hand, certain groups of people within a community may be more predisposed to engage themselves directly in management, which are otherwise neglected, than others. These people, often called stakeholders, may be key individuals to initiate a dialogue in establishing community based strategies to ecosystem management. Though, as warned by others (see Chapter 1), care should be taken so as not to over-empower a potentially oppressive group and to guarantee an equal distribution of benefits. In any case, stakeholders may not only have a direct stake in management actions they may have important local and/or traditional ecological knowledge which can be coupled with traditional scientific knowledge to develop locally relevant and adaptive strategies and actions (see Chapter Three).

The secondary goal of this study was to improve the overall understanding of socio-ecological systems so that institutions ultimately could develop adaptive management strategies that fit within the context of their surroundings. Key components to creating such strategies are i) the understanding of community perceptions and ii) increasing the communication that occurs between the community and the institutions developing the management plans. To be adaptive, it is not enough to integrate these diverse values that have been presented here, but also to bring into the process those people who are doing the valuing into strategy development. Indeed, integrating values alone is insufficient; to be adaptive, the people and civic institutions themselves need to be integrated. Elucidating the basic values that underlying community and specialist worldviews provides the baseline for developing goals of management, but participation ought to be central to CBEM strategies to be adaptive, since perceptions and behavior can change over time just as ecosystems do. It should not be assumed, then, that any new strategy will be successful by itself.

Therefore, by including stakeholders in the management structure, the impact of new strategies can be continually evaluated and re-evaluated. In a review of stakeholder participation in environmental management, Reed (2008) found that for a participatory-based management strategy to be successful, participation occurs as a process rather than as a collection of tools. The tool-based model is best exemplified by the act of "outreach," the distribution of information generated by institutions outwardly to the public. It is in essence a last ditch effort to include society or weakly satisfy the requirements of an institutional decree. This method, as shown by Reed (2008), often fails because it represents uni-directional communication and is not dialogue, and therefore prohibits a real understanding of social-ecological dynamics. In order for environmental research, management and conservation to actively dialogue with society to develop adaptive management strategies, a process of community engagement needs to occur as the foundation of the management structure.

Assessing the Ecosystem Services Paradigm

The ES concept was employed in this research for two principle reasons:

1. ES link social and ecological systems providing for a useful tool to understand social-ecological dynamics (Collins et al. 2011), and

2. Given the recent surge of global and place-based ES research and assessments (de Groot et al. 2010), it is inevitable that the ES concept will become a central theme in the development of new environmental management strategies.

In fact, the importance of ES for managers was evident in the field. While conducting surveys in Chile, I was invited by a national environmental management agency to attend a conference to discuss the development of a new strategy based on regional ES. Regional and national government institutions had been asked to attend the conference to identify services they considered high priority for protection and conservation. Obviously, such individuals are responsible for developing expertise in natural resource sustainability and ecosystem processes, but since ES are also the benefits that whole societies receive from ecosystems, not only those that specialize in the study of ecosystem processes, it should have been of high priority to include non-specialist members of the community into the conversation. It is clear from my research that their opinions, concerns and priorities should have also been expressed. But how might this be achieved? Based on my results, I suggest that institutions look to the larger body of work conducted on CBEM processes for specific examples on implementation of these processes (e.g., Brosius 1998, Rhoades 1998, Berkes 2004, Chazel 2008, Fleeger & Becker 2008, Reed 2008, Menzel & Teng 2009, Raymond et al. 2009). Furthermore, community groups may currently exist within each region that have a clear and direct stake in local natural resources as discussed above (e.g., fisherman or farming-coops and conservation groups). If these existing organized groups were to be included and legitimized in a formal process, they could form the basis of a broader and more effective community approach. Including representatives or “liaisons” from such community groups into the discussion of the development ES management strategies can begin the process of building more locally relevant and adaptive frameworks. Caution should be taken, though, with the development and implementation of any new process or strategy so as to avoid potential pitfalls of CBEM and discussed thoroughly in the works mentioned above. For future CBEM and conservation, Berkes (2004) suggested that whether or not CBEM works is an inappropriate question, and we should instead focus on the drivers and influences that cause its relative success or failure.

Lastly, as academic and government institutions rally behind the ES concept as a way to manage ecosystems, it is important to analyze the implications of such a construct. It is clear that ecosystems themselves function regardless of how humans perceive them, but humans may determine how they function nonetheless. Ecosystems in reality do not exist to serve us, but we benefit greatly from them. We would not be able to survive without them, and as emphasized throughout this thesis, social systems are intertwined with biophysical ones and many ecosystems would not exist without us. It may then be useful to conceptualize these relationships as services in that it not only allows us a way to term certain social-ecological relationships, it broadens the definition of ecosystems for society so that we can more clearly see our dependency on underlying ecological processes. In fact, during the interviews that were conducted for this research most participants, if not all, accepted the ES term as a positive one. On a number of occasions, I received comments such as “I have never thought of our environment like that, but it really makes it obvious how much we as humans depend on the environment.” Such statements lead me to believe that perhaps the ES concept is a good one that may initiate a greater desire to support and connect with local ecosystems.

On the other hand, there are other potential implications for shifting our perception to perceiving ecosystems as factories for goods and services. For example, instead of sustainably managing whole ecosystems, employing the ES concept could potentially lead to only managing for very specific, anthropocentric ES, leading to extreme degradation of others. It may also, as mentioned above, reinforce the idea that ecosystems exist to serve humans, promoting the human dominion view of nature which many scholars have warned us about (e.g. Leopold 1949, Odum 1958, White 1967). In any case, it is clear that many portions of contemporary Western and globalized society are consolidating behind the ES paradigm. Because this thesis does not directly analyze the implications for the broader human-nature relationship, it is not possible to determine here whether it is valid that the ES concept ought to be universally accepted, but I do suggest that future research on philosophical grounds needs to be considered in this area.

Conclusions and Suggestions for Future Management and Research

This thesis initiates the process of putting in practice a social-ecological method for understanding ecosystems. The results have emphasized the need to integrate a community based approach into regional environmental management processes. Such an approach encourages a science-society dialogue and promotes the development of place-based adaptive management systems that are better aimed to deal with future ecosystem change. Lastly, specific suggestions for future research and management based on this thesis include the following:

1. develop a long-term watershed monitoring program, which includes public-participatory processes or citizen science, based on the results and discussion from Chapter Two to continue impacts assessment of ecosystem services quality;
2. take into account the potential impacts to aquatic ecosystems from urbanization discussed in Chapter Two for future urban planning as the expansion of urban centers in the sub-Antarctic ecoregion continues;
3. utilize the survey of values obtained and analyzed in Chapter Three to develop management strategies that better support the social well-being of community members and to initiate the development of community-based management processes in each of these research sites;
4. compare the diversity of values obtained from community members with those used in the development of current environmental policy and management institutions in the Magallanes and Chilean Antarctic Region (Chile) and the Tierra del Fuego, South Atlantic Island and Antarctic Province (Argentina);
5. integrate the results of Chapter Two and Chapter Three into socio-ecological frameworks to gain a better understanding of the social-ecological dynamics of the region understudy and to assess whether biophysical conditions allow ecosystems to meet the needs and expectations of the community;
6. conduct more in-depth research on the conceptual, ethical and practical implications of implementing the ES concept.

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