

INFLUENCE OF LANDSCAPE CHANGE ON THE NEARSHORE FISHERIES IN
SOUTHERN CHILE

By

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To Sofia and Rodrigo

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Abstract of Dissertation Presented to the Graduate School
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INFLUENCE OF LANDSCAPE CHANGE ON THE NEARSHORE FISHERIES IN
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Coastal systems provide livelihoods and food to over half of the world's population. Land cover/land use change (LCLUC) is one of the most significant global changes affecting aquatic systems. Human activities on the land deposit nutrients and sediments in the rivers that discharge into the nearshore environment and as a result coastal systems are becoming eutrophic and organisms are susceptible to parasites. This study examined the relationship between LCLUC, especially forest-plantation development, changes in nearshore chlorophyll-a patterns, marine-food webs, and the health of the *loco* (*Concholepas concholepas*) shellfish in southern Chile. I also examined how fishers, who are restricted to harvest *loco* shellfish only in management areas, have adapted or are vulnerable to these environmental changes. I used space-for-time substitution and worked across 13 watersheds (250 km of coastline) with over 30 fishing organizations and 41 management areas to provide a unique, geographical understanding of environmental change, vulnerability, and adaptation to change. Plantations increased 1,992 km² from 1985 to 2001. The photosynthetic biomass from 1998 to 2005 across thirteen watersheds is higher, 3.2 mg/m³ average chlorophyll-a concentration values, in

nearshore regions that are influenced by forest-plantations whereas native-forest influenced areas have 2.0 mg/m³ values. The *loco* shellfish harvested from management areas influenced by forest-plantations have approximately 30% more parasites on their shells when compared to *locos* from areas influenced by native-forest land cover. Fishers who harvested shellfish from the degraded areas lost \$1 for each 10% increase of parasites on the *loco* shell. Fisher knowledge and technology did not help fishers adapt to the environmental change. Instead fishers are moving to offshore fisheries such as *congrío* (*Genypterus* sp.) where their knowledge and technology can help fishers succeed and the environmental influences of landscape change are reduced.

CHAPTER 1 INTRODUCTION

This dissertation consists of four independent papers (Chapters 2-5), each of which is a paper written for submission to a journal for publication. This dissertation is about land cover/land use change (LCLUC) in southern Chile, the associated changes in chlorophyll-a concentration levels in the nearshore marine ecosystem, the effect on the *loco* (*Concholepas concholepas*) shellfish health, and how fishers adapt to these environmental changes.

The second chapter will be submitted to *The Geographical Journal* and addresses the social and ecological vulnerabilities that stem from landscape change over the past 15 years in southern Chile and specifically asks:

- What are the patterns of landscape change over the past 15 years in southern Chile?
- What coastal areas are vulnerable to influences of landscape change over the past 15 years in southern Chile?
- Have people migrated out of rural areas where forest plantations have been established in the past fifteen years?

I identified whether plantation development resulted from afforestation of grasslands or agriculture or substitution of native forest. I then used principal-components analysis to understand regional development patterns. Peasant agriculture has shifted to plantation forests and some remaining tracts of one of the world's few temperate rain forests have been lost. Substitution of native forest by forest plantations accounted for 43% of the land converted to plantations. Afforestation accounted for 38% of the conversion-- agriculture accounted for 27% and cleared land accounted for 11% of the conversion.

Landscape change stems from subsidies of plantation development. Most native-forest that has been converted is at the foothills of the mountains and therefore is likely not pristine forest. The nearshore environment in the Valdivian region likely receives nutrient inputs from forest plantations and these fishers are vulnerable to the effects of the environmental changes on the landscape. People living in the rural areas where forest plantations were established have migrated out.

The third chapter will be submitted to *Marine Ecology Progress Series* and addresses how the nearshore environment is influenced by landscape change and specifically addresses the following questions:

- Are nearshore chlorophyll-a patterns related to landscape-change patterns or are they related to upwelling?
- Are nearshore chlorophyll-a concentration values at the watershed and zonal scale higher near plantation-influenced watersheds?
- Are terrestrial derived nitrogen and carbon sources incorporated into the marine food web?

I found high nearshore ocean chlorophyll-a values (>10 mg/m³) near watersheds containing forest plantations that comprised up to 30% of their total land area. Low chlorophyll-a values (<0.6 mg/m³) were found in the coastal areas near watersheds with high percentages ($>80\%$) of native forest land cover. *Loco* tissue in nearshore areas near plantation watersheds had enriched carbon and nitrogen ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) values, which indicate that terrestrial nitrogen entered the coastal waters and increased primary productivity which then increased atmospheric carbon fixation.

Chapter 4 will be submitted to *Ecological Applications*. I address how *loco* health was influenced by landscape change and associated changes in the coastal system. I answered the following questions:

- Do *locos* located in management areas influenced by forest plantations have more epibionts and shell-boring organisms on their shells?
- Do *locos* located in management areas influenced by forest plantations have lower lipid content in their muscle tissue?
- Do *locos* located in management areas influenced by forest plantations weigh less than *locos* from other regions?

I analyzed 1260 *locos* across 41 fisheries management areas. I used cluster analysis to group *locos* according to their height, meat weight, length, as well as the percent of phoronids, polychaetes, shell boring bivalves, and barnacles found on *loco* shells. I then used a discriminant analysis on the groups of the cluster analysis to identify the relationship between groups of *locos* and LCLUC. The discriminant analysis characterized 70% of the *loco* groups by percent forest plantation development from 1985-2001 and chlorophyll-a values in the nearshore. Canonical correlations found relationships between LCLUC and *loco* characteristics. The first canonical correlates LOCO1, representing *loco* parasites, and LAND1, representing a eutrophic system, showed a strong correlation 0.88, $p=0.00$. *Loce* shells from the northern Valdivia region, a region with many forest plantations upland and high chlorophyll-a values in the nearshore, were infested with shell-boring phoronids and barnacle epibionts and had low weight. *Locos* from the Osorno region, a predominantly pristine area, had shell-boring bivalves and were heavier. Further examination of the social and ecological conditions in

sites that had *locos* with better or worse health than expected given the local conditions offered clues to how fishers can mitigate the influences of upland land use on their *loco* fisheries.

In Chapter 5, to be submitted to *Human Organization*, I address how nearshore fishers on the coast of Chile adapt to environmental change. Specifically I answer the following questions:

- What factors (knowledge, technology, and environment) contribute to fisher success?
- Do fishers use the same strategies to adapt for success in the *loco* (closed-access) and *congrío* (open-access) fishery?

Data includes reports by 279 fishers on the price they received for various resources, as well as on their knowledge of each resource, on the location of fisheries, on boat availability, and on their age. Data also includes satellite images (to measure plantation development and the productivity of marine phytoplankton) and GIS output (to characterize spatial relationships of management areas). Finally, 360 specimens of *locos* were surveyed for shell-parasite load and other health characteristics. Environmental characteristics explained the most variance in price for the *locos*. Specifically, shell parasites and chlorophyll-a patterns accounted for the most price variance for *locos*, a restricted access shellfish. Intensified technology (more boats) was detrimental to fisher success. Traditional ecological knowledge explained a smaller fraction of price variation. Fishers working in nearshore systems were heavily influenced by local environmental conditions: they benefit when the environmental quality is good and suffer losses from environmental change in their management areas. Fishers could use knowledge and

technology to receive higher prices for the *congrío* (open-access) fishery where the environmental variables explained a lower fraction of success. Fishers in eutrophic environments were more successful offshore, and those in non-eutrophic environments were more successful in the closed-access *loco* fishery.

CHAPTER 2
LAND COVER/LAND USE CHANGE AND FOREST PLANTATION
DEVELOPMENT PATTERNS IN A COASTAL-TEMPERATE FOREST OF
SOUTHERN CHILE AND ASSOCIATED VULNERABILITIES

Introduction

Coastal Systems and Land Cover/ Land Use Change

The land-sea interface-- the coastal system—is a rich environment for people and nature. Over half of the world’s population lives in coastal systems (Cohen et al. 1997) and the livelihoods of the world’s 13.1 million artisanal fishers depend on the coastal environment (FAO 2002). Landscape change and coastal development alter hydrological patterns, sediment and nutrient composition, and biodiversity of rivers and the nearshore environment (Milliman 1991; Diaz & Rosenberg. 1995; Smith et al. 1999; Bounoiua et al. 2002). People living in the coastal environment are affected by environmental change in the nearshore that alters photosynthetic biomass (Van Holt b in prep) the trophic dynamics of marine resources (Kemp et al. 2005), resource quality (Van Holt c in prep), and therefore fishing strategies and fisher success (Van Holt d in prep). Those people living in rural areas on the land where change is occurring are also affected by new development and some people relocate to urban areas (Kay 2006). By understanding development patterns and identifying areas where people’s livelihoods are likely to change, we can better understand the critical pathways of change (Turner & Robbins 2008) and this can lead to a better understanding of adaptation and vulnerability to environmental change, which could help us develop a more sustainable future (Turner & Robbins 2008). This paper addresses the social and ecological vulnerabilities that stem from landscape change over the past 15 years in southern Chile. The specific research questions are:

- What are the patterns of landscape change over the past 15 years in southern Chile?
- What coastal areas are vulnerable to influences of landscape change over the past 15 years in southern Chile?
- Have people migrated out of rural areas where forest plantations have been established in the past fifteen years?

Latin American Land Cover Change Patterns

Across Latin America globalization, local policies, subsidies, and population growth drive deforestation and afforestation (Grau & Aide 2008). Tropical forests are becoming deforested for cattle ranching and agriculture, especially across the Amazon (Houghton et al. 1991). The global soybean market leads to deforestation of dry forests in Brazil, Bolivia, Paraguay, and Argentina by transforming forested areas into soybean fields (Dros 2004). Grasslands in Argentina and Uruguay are becoming afforested with plantations to support the global pulp industry (Farley et al. 2005). The foothills of mountains that were once used for agriculture are being abandoned as people move to the cities (Kay 2006) and these abandoned areas have regrown to forests (Southworth & Tucker 2001). In southern Chile, where forest plantations account for almost 10% of the country's exports (INFOR 2006); forest plantations for the global pulp market have replaced native forest and agricultural lands. Understanding the patterns of landscape change and its effects on the nearshore environment is particularly important in Chile, a coastal country where near shore fisheries provide a livelihood to over half a million people (Bernal et al. 1999).

Globalization, subsidies, and local policies as landscape change drivers.

Pine (*Pinus radiata*) was introduced in the 1940's to protect degraded riparian areas (Lara & Veblen 1993; Clapp 1998; Toro & Gessel 1999). Plantation development exploded with the "Decreto Ley 701" law of 1974 when the Pinochet administration subsidized 75% of the cost of plantation establishment and eucalyptus (*Eucalyptus globulus* and *Eucalyptus nitens*) became an important pulp species (Lara & Veblen 1993). To bring Chile into the world market economy and to make the country less vulnerable to the fluctuations in the copper market (Auty 1993, Gwynne 1996), the government subsidized in-demand, non-traditional agricultural exports such as pine trees. In this process, pine trees are converted to wood chips and are exported for the global pulp market. In some cases, pulp mills were built in Chile. The United Nations fostered commercial forestry by helping to establish the Instituto Forestal (Husch 1982), a research institute that provides technical support for plantation development. By 1992, Chile was the world's sixth most important wood pulp exporting country (Sedjo 1999). In 2005, plantations comprised 2.1 million hectares or 13.4% of the forest cover in Chile (INFOR 2006). Subsidies also led Brazil, Chile, China, India, and Russia to become important forest-plantation regions (Sedjo 1999; Barr & Cossalter 2004; Bull et al. 2006; Zhang & Song 2006) and these subsidies are a major driver of land cover/land use change (LCLUC) (Nagashima et al. 2001).

Forest Plantation Development Effects

Identifying the location and extent of forest plantations, the geographical features of the landscape that have developed to plantations, and, whether plantations resulted from afforestation, i.e., replacement of agricultural lands, ranchlands, grasslands, or shrublands (Blaschke et al. 1992; Barlow & Cocklin 2003; Farley & Kelly 2004) or

substitution, i.e., replacement of native forest (Lara & Veblen 1993; Ewers et al. 2006), helps to understand the effects of plantation development on the people and the environment and identify the vulnerable areas and people.

In terms of ecological effects, researchers have identified that, at times, the effects of plantations on biodiversity, nutrient cycling, hydrology, and carbon sequestration, are distinct in afforested and substituted lands, while other effects may depend on the area converted and not the historical land cover. Birds (Carnus et al 2006; Vergara & Simonetti 2004) as well as mammals (Munoz et al. 1987; Saavendra & Simonetti 2005) have been negatively affected by substituted forests. Biodiversity can increase or remain the same in afforested systems (Carnus et al. 2006). Lower diversity and abundance of macroinvertebrates were found in streams where upland plantations were present (Tierney et al. 1998). Nutrients from plantations, for example nitrogen, are leached into streams (Binkley & Resh 1999). Nitrogen leaching and sedimentation is high at the onset of plantation establishment (Oyarzun & Pena 1995; Farley & Kelly 2005; Oyarzun et al 2007) and nitrogen leaching has been identified after the plantation has been established as well (Stevens et al. 1994). Parfitt et al. (2003) discovered that nitrate leaching was of a higher magnitude when native forests were first converted to agriculture and then to forest plantations. Plantations affect the hydrology of watersheds by increasing evapotranspiration and decreasing the amount of water that is supplied to streams (Fahey & Jackson 1997; Gyenge 2003; He et al. 2003; Farley et al. 2005). Huber et al. (2007) showed that afforested lands altered hydrology more than substituted lands, because less water was transpired by agricultural plants when compared with native forests. Plantations can decrease (Fearnside 1995; Byrne 2006; Glenday 2006; Nosetto 2006;

Betts et al. 2007) or increase (Binford et al. 2006) carbon sequestration, depending of the characteristics of the native forest that they are compared to. Carbon sequestration can increase in afforested areas (Christie & Scholes 1995).

With respect to the social effects of plantations, development patterns and geography can help to identify affected people. In other regions of Chile, peasant farmers living on sloped mountains and using small-scale agriculture, domestic animals, and occasional seasonal work to survive, eventually sold their land to plantation companies and moved to urban areas (Clapp 1995; 1998; 2001). These marginal agricultural areas are located on sloped mountainsides as in other parts of the world (Posner & MacPherson 1980). If marginal agricultural areas that may include forested landscapes are sold to plantation companies, localized rural to urban migration (Clapp 1998) might be observed. Fishers working in rivers and the nearshore areas can also have their livelihoods disrupted as plantation development has been shown to alter downstream aquatic systems (Iroume et al. 2006; Oyarzun et al. 2007) in Chile. In cases of extreme changes in the nearshore environment, key species may be lost and people face negative-socioeconomic consequences (Mee 1992; Kemp et al. 2005; Van Holt d in prep).

Schlatter (1977) predicts where plantations should establish in the southern Chile based on the soil characteristics. Plantations are suited for type IV -VI soils, which are soils that have a medium to moderate slope, cannot be plowed due to erosion risk, and have low draining; type VII soils, which are moderate to high sloped, can also be used for plantations, though there is a high risk of erosion and the best use of these areas is to preserve the natural forest. Type I-III soils, which drain easily, are best suited for agriculture. Wilson et al. (2005) predicted future plantation development patterns in

southern Chile. They modeled future development patterns based on an analysis of a map that estimated forest cover prior to European settlement, which was derived from expert opinion and slope and elevation characteristics, and a recent land cover map, which was based on aerial photography from 1995-1996. The study presented here is the first analysis in the region that measures the past with remotely sensed satellite images. The accuracy and quality of the satellite images are comparable in the past and present and offer a new perspective on regional-development patterns.

Objectives

This study 1) characterizes LCLUC in the past 20 years across administrative region X of Chile in terms of area and percent of the watersheds converted, 2) identifies whether forest plantations are a result of afforestation or substitution, 3) examines whether rural migration out of rural areas is associated with plantation establishment, and 4) identifies communities and areas vulnerable to recent land-cover/land-use change (LCLUC).

Methods and data sources

Study Site

The northern half of region X, an administrative region of Chile, contains three large watersheds with roughly one large watershed in each province (Figure 2-1). The names of watersheds on Fig. 2-1 are derived from the main river in the watershed: Valdivia (watershed # 3), Bueno (5), and Maullín (13), and ten small watersheds-- Lingue (1), Bonifacio (2), Chaihuín (4), Quilhue (6), Contaco (7), Hueyelhue (8), Cholguaco (9) San Luis (10), Llico (11) and Putratrán (12). High annual precipitation (2,000-4,000 mm) and a mean annual temperature of 12.5°C (Eldridge & Pacheco 1987) give rise to a temperate rainforest ecosystem, which prior to European settlement spanned across the

entire study site; today the remaining portion of the forest are along the coastal and Andes mountains (Figure 2-2). Principal economic activities include forestry, fisheries, agriculture, and cattle ranching. Agriculture and ranching expanded in the valleys of the temperate rainforest ecosystem beginning in the late 1800's (Figure 2-2). Today, agriculture and ranching continue to be dominant land uses, although pine and eucalyptus plantations represent the most significant percentage of LCLUC in recent times (INFOR 2006). In 1997 farms covered approximately 290,000 ha in the valley with most of the land producing fodder crops (64%) and cereals (17%) such as wheat, oats, and barley (INE 1997). The region also is an important dairy producer accounting for almost 70% of the country's dairy production. In 1997 (the latest figure), there were more than 1.5 million cows in the region, most of which were raised on natural grasses and on small-scale farms (INE 1997). Very few industrialized operations are present and fewer than one million people live in the region (INE 2002). Urban and commercial activities are not considered significant in terms of coastal systems, with the exception of the Celulosa Arauco (CELCO) pulp mill that began operating in 2003 and is located in the northern part of the study site that began operations in February 2004 and can process 680,000 tons/year (Oinonen 2005). The temperate rainforest offered available land and little competition for forest plantation development. Over the past fifteen years (1985 to 2001), plantations have encroached on the temperate rainforest, at times replacing both native forest and agricultural areas (Clapp 1998; Wilson et al. 2005).

There are three main provinces in the region. The Valdivian province has extensive forest plantations and agriculture (Figure 2-1). The Osorno province has extensive native forest cover, agriculture activities, and a less extensive, but increasing, number of

plantations. The Llanquihue province has extensive agriculture and ranching, as well as *matorral* (new growth or shrubby forest) land cover and few plantations. Chile is an export-based economy where native forest and agricultural cover are relatively stable (no huge areas of deforestation or agricultural expansion is occurring) and therefore is a model for countries with similar landscape and economic characteristics.

Image Preprocessing and Analysis

An October 5, 1985 Landsat 5 TM and a November 29, 2001 Landsat 7 ETM+ scene (WRS II path 233, row 87-89) were selected to correspond to the spring season when rains subside; these were the only available scenes with minimal clouds. The 1985 scene represents the region 13 years after the 1972 forestry law that subsidized plantations (Lara & Veblen 1993) and the 2001 image is from the time after Chile became an established, global-level pulp producer (Sedjo 1999). A land cover map (*catastro*) generated from aerial photographs in 1995 and 1996 (CONAF et al. 1997) was used to further understand specific land was used for training samples. I georectified the 2001 image by using training points from digital road maps from Chile's Ministerio de Obras Publicas, which have accuracy that corresponds to both the Instituto Geographica Militar topographic maps and the *catastro* (CONAF et al. 1997) which both have a minimum mapped unit of 6.25 ha (and a 1:50,000 scale) and using the nearest-neighbor sampling algorithm. I then rectified the 1985 image to the 2001 image. The root mean square errors for each image was less than 15 m. I then atmospherically corrected images using the Center for the Study of Institutions, Populations, and Environmental Change (CIPEC) protocol that includes converting radiance values to surface reflectance values and dark object subtraction (Markham & Barker 1986; Teillet & Fedosejeus 1995). The low-gain portion of band 6, the thermal band, was converted to temperature values. I

then topographically corrected all scenes using the Minnaert Correction, a modified cosine correction that helps determine the extent to which a pixel is Lambertian (Minnaert 1941). Teillet et al. (1982) recommended modifying the cosine correction with a constant (k) that is derived in this case by regressing selected points in the native forest class of varying illuminations and slopes to determine to the extent the surface is Lambertian. I generated points for the regression of band k by selecting points in the native forest class of all illumination types. I then created additional layers by transforming the atmospherically and topographically corrected image with the tasseled-cap transformation that converted bands to six new axes that represent brightness, greenness, wetness, fourth, fifth, and sixth layers (Kauth & Thomas 1976). I also created a normalized differential vegetation index layer (NDVI) (Rouse et al. 1974). Finally I ran a texture analysis on band 5 and created three new layers: a range, mean, and standard deviation texture layer. I used band 5 because it was most useful in separating forest plantations from native forest in trial tests. For the supervised classification I created multiple layers that included all previously mentioned bands plus the Shuttle Radar Topography Mission (SRTM) Finished 3 arc-second (90 m) raster elevation dataset and the derived slope image.

Land Cover Change Analysis

I used the Maximum Likelihood supervised classification method to create nine classes (1) native forest, (2) plantation, (3) *matorral*, (4) agriculture, (5) cleared land, (6) urban, (7) wetland, (8) water, and (9) snow classes (ITT 2008). I used the Chilean vegetation map and my knowledge of the spectral signatures when necessary to select training points (i.e. cases where an agricultural region was identified but wasn't characterized in terms of cleared land or active agriculture). I collected 109 accuracy

samples from July to August in 2004. I grew the locations of the accuracy samples to approximately 10 pixels using the spectral signatures to capture the overall signature in the training sample area and retained these samples for accuracy assessment of the 1985 and 2001 image. For the accuracy samples of each forest class, with the assistance of a Chilean forest engineer, I listed the main tree species present, percent ground cover (measured by taking a visual inspection of approximately a 10 x 10m plot and estimating the amount of ground cover), and canopy closure (measured by visually inspecting approximately a 30 x 30 m² area and estimating the percentage of light that will go through the entire area); I also estimated the age of the forest plantations (measured by counting the rings of the stumps, using a reference of growth of approximately 4 cm each year at breast height for pine and 2 cm each year for eucalyptus (Torralba et al. 2005; Munoz et al. 2005) and knowledge of land use in the region. I then conducted a second accuracy assessment by generating 30 random points in each land cover class to capture the accuracy of area that may not be easily accessible. In this case I used the national vegetation map (CONAF et al. 1997) and personal knowledge of the satellite image to assess accuracy (i.e. I could distinguish cleared land and agricultural areas on a 4-5-3 composite image; plantations were determined using the national vegetation map and visually inspecting a 4-5-3 composite of the satellite image).

The forest plantations were visually obvious on the image, but difficult to separate by solely spectral means. It was essential to restrict the forest-plantation analysis because of spectral confusion with disturbed native forest and because the study site was large (35,853 km²). To restrict the location of forest plantations I created a vector layer that included a 1-km buffer around plantation polygons from the national vegetation map

(CONAF et al. 1997) which is based on aerial photos and visually obvious plantation regions that I identified. The one-km buffer best accounted for expansion of plantations and eliminated the spectral confusion with native forest areas located in the middle of the extensive native forests of the Andes. I used the RuleGen extension in ENVI (ITT 2008) that was created by Loh and Shih (1997) and found that spatially reducing the area where plantations could be found, combined with the Maximum Likelihood classifier, provided better results as entire plantation areas were selected instead of just a few pixels within the plantation area.

I used the preliminary classification of 1985 and 2001 to further refine the classification. For example, I double checked regions that had cleared land in 1985 and native forest in 2001. Although plantation regions were accurately identified, some pixels within a plantation area were classified as native forest. I reclassified those plantation pixels (usually those pixels were inside areas already classified as plantations) and left the correct native forest pixels. I also sieved the urban class and made a minimum urban class consist of 10 pixels using an 8-neighbor rule; this eliminated confusion between cleared land and urban areas.

After the supervised classification, area (km^2) and percent of each land cover/use class (km^2 of LCLU/ total watershed area km^2) in 1985 and 2001 were calculated in each of the thirteen watersheds (Figure 2-1). Then, the total area (km^2) and percentage of each class that converted from the 1985 class to the 2001 class was calculated for each watershed. I then calculated the Euclidean distance from the edge of lakes and rivers to the edge of each of the major land uses in 2001.

Analysis of Landscape Change Patterns and Associated Migration

Watersheds were the unit of analysis to understand the ecological effects of landscape change because they are physical areas that drain the land into the rivers. I ran principal components analyses on the percent of native forest, agriculture, plantations, and cleared land classes per watershed in 1985 and on the percent of each land-cover/use class per watershed in 2001. Biplots (Gabriel 1971; Gower & Hand 1996) of the first two principal components were used to identify watershed characteristics that were subsequently used to order watersheds and to understand regional patterns in land cover/use. I characterized percent of land cover/use for each year because the area is an absolute quantity that can vary because of watershed size while proportion brings all the areas of the watersheds into the same value (100%). Bivariate plots of percent cover with arrows indicating change from 1985 to 2001 were used to illustrate land cover/use composition change.

To understand how plantations may be related to rural to urban migration, I calculated the changes in rural populations per county. I calculated the change in rural population from 1994 and 2002 per county using the Chilean Census Data (INE 1994; INE 2002) and compared these values to the landscape change data from 1985 to 2001 to evaluate whether rural people left regions where agriculture and native forest was converted to forest plantations and forest plantations were abundant. County-level analysis is standard for understanding changes in population structure because they are important administrative boundaries in the region.

Results and discussion

Landscape Change in Southern Chile

Land-cover classifications and accuracy assessments

Figure 2-3 shows the land-cover classifications for both 1985 and 2001. The 2001 classification had an overall accuracy of 88.25%, a kappa coefficient of 0.86, and no individual classes were less accurate than 75% (Table 2-1). The 1985 classification had an overall accuracy of 91%, a kappa coefficient of 0.90, and the accuracy of no individual classes was lower than 75%. I had high accuracy in detecting differences between native forest and forest plantations; the 2001 image had 87% producer's and 93% user's accuracy; native forest had an 85% producer's and 83% user's accuracy. The accuracy assessment with 30 randomly generated points of each land cover class was similar. The 2001 classification had an overall accuracy of 92% with a kappa coefficient of 0.91 and the 1985 classification had an overall accuracy of 90% with a 0.89 kappa coefficient; no individual classes were below 70% (Table 2-1).

Major LCLUC patterns

Plantations have become a more dominant part of the northern half of the Xth region of Chile. From 1985 to 2001 plantations and agriculture increased on average by 124 km²/yr and 53.4 km²/yr, respectively (see Figure 2-3, Table 2-2). Native forest and cleared land decreased by 81.1 km²/yr and 43.4 km²/yr, respectively. More subtle changes in the landscape include increases *matorral* and urban land cover (3.7 km²/yr, and 1.9 km²/yr), and wetlands decreases 1.7 km²/yr.

A biplot of the PCA scores of the land cover fraction data show the 95% and 86% of the variability in the land-cover fraction could be explained by two components in 1985 and 2001, respectively (Figure 2-4; Table 2-3). The main distinction between 2001

and 1985 PCAs is that plantations become an additional component on PCA2 in 2001. Native forest is the most influential land cover variable in PCA1, which explains the largest proportion of the data, 78.9% in 1985 and 70% in 2001. Watersheds 4,8,6,9, and 10 group together because these watersheds have high amounts of native forest; watersheds 1,3,5, 11, and 13 group together because they have low native forest. Watersheds 2, 7, and 12 have median amounts. Once watersheds are ordinated according to native forest cover, PCA2 explains an additional 16.5 % (1985) and 16 % (2001). Plantations covary with agriculture and cleared land in both years and they are opposite of native forest cover; so watersheds that are high on native forest are low on agriculture, plantations, and cleared land. The watersheds group in similar patterns in 1985 and 2001 demonstrating that plantations have a small influence in the overall ordination of watersheds.

Bivariate plots (Figure 2-5) of percent cover identify three distinct groups of watersheds. From 1985 to 2001, plantation watersheds (1, 3, 5, 7, and 11) gained a large to moderate increase in plantation fraction (3% to 35%) covering the watershed (watershed 5 is large so the fraction is relatively small). Also, in 2001, these watersheds had low native forest fraction (70% or less) and high agriculture fraction (10-35%) with moderate loss in fraction of native forest (3-13% loss, except watershed 5) from 1985 to 2001. Plantation watersheds have low percentage of native forest, high percentage of agriculture, and some fraction of native forest loss.

Native forest watersheds (4, 6, 8, 9 and 10) started with a very high (>80%) fraction of native forest, which they maintained (>78%) in 2001. They had low (<5%) fractions of cleared land in 1985 and shifted to low to moderate (6%-15%) fractions of

cleared land (watersheds 4 & 10 had moderate shifts) in 2001. Agriculture fractions ranged from 1% to 4% in 2001. Watersheds 4 & 10 had moderate shifts in native forest, however. Watershed 4 lost 14% of its native forest (110 km²), and watershed 10 lost 13% native forest (97 km²). Of the native forest lost from 1985 to 2001 in watershed 4, 72% was converted to clear and 21 % to plantation. In watershed 10, 98% of the native forest converted transitioned to cleared land.

In the mixed watersheds (2, 12 and 13) the forest remained stable from 1985 to 2001. In 2001 the watersheds had moderate (60%) fractions of native forest; watershed 13 had only 24% native forest but also had 6% *mattoral*, which is similar to native forest. From 1985 to 2001, there was a low to moderate (2-11%) increase in the fraction of cleared land. Agriculture moderately increased and in 2001 7-20% of the watershed was covered in agriculture. Little to no plantations was present in either year.

Substitution was the predominant method of transformation to plantations closely followed by afforestation (Figure 2-6; Figure 2-7). Substitution accounted for 43% or 984 km² of the areas converted to forest plantations from 1985 to 2001. Most substituted forests were probably degraded native forest before conversion. These areas were degraded because these forests were located at the foothills of mountains and in fragmented areas or at the edges of large tracts of native forest where people graze cattle, plant small agricultural plots, and log the forest for firewood and other timber. Few areas in the coastal area or Andes mountains, where the forest is less disturbed, were converted (except for watershed 4).

Agricultural/ranching areas accounted for 603.7 km² or 26.6% of the area converted to plantations from 1985 to 2001 and cleared land explained 10.7% of the

conversion (462.9 km²)—in total 37.3% of the plantations were afforested. Watershed 1 lost the most agriculture (13.1% or 69.2 km²) mostly to plantations. Watersheds 3 and 5 lost the most cleared land 3.4% (345.7 km²) and 4.5% (688.6 km²), respectively, again with the majority converting to plantations.

Watersheds 1, 3, 4, and 10 lost the most native forest, 17.1% (89.9 km²), 6.6% (677.3 km²), 14.4 % (109.6 km²) and 12.7% (96.6 km²), respectively (Figure 2-7). Most of the native forest lost in watershed 4 converted to cleared land and loss in watersheds 1 and 3 converted mainly to plantations. Watershed 5 had the most native forest that converted to agriculture.

Plantation regions were closer to rivers (43 m) than were native forest regions (256 m) (Table 2-4) and therefore nutrient inputs into the system from plantation systems have a more direct influence on the aquatic system.

Rural Migration Patterns

The livelihoods of farmers and fishers face vulnerabilities since regional development patterns have been altered. People living in counties with an increase in forest plantations have lost rural populations (Figure 2-8; Figure 2-9). In the northernmost Mariquina County in 2001, plantations covered 300 km². Since 1985 native forest and agricultural areas were converted to pine plantations. The rural population also decreased by 20% from 1994 to 2002 (INE 1994; INE 2002). La Union and Los Lagos counties follow similar patterns, losing rural inhabitants as agriculture and native forest was lost in favor of plantations. Other counties associated with plantations, including, Mafil, Paillaco, Corral, and San Juan de la Costa, also lost subsistence farmers. Not all plantation counties lose rural people, however, the Valdivia County, which has a large amount of plantation activity, has had an increase in the rural population. Futrono and

Llanquihe have little plantation activity, but lost around 30% of the rural inhabitants so other factors can also influence rural migration. In total 11 plantation counties lost rural people; 8 non-plantation counties lost people; and 3 plantation counties remained the same or gained inhabitants (two of which are major metropolitan areas of the region—Valdivia and Osorno).

Past and future development patterns

Most of the forest conversion was from substituted native forest that was likely degraded prior to conversion. Using the Chilean land-cover map as a guide, substitution of native forest was still an important component of plantation development, even after 1995-1996. For the total of the 983 km² of native forest converted in all of Region X between 1985 and 2001, 308 km² of native forest and 48 km² of agriculture and cleared land was converted since 1995-1996 whereas and 562 km² of native forest already was plantations in 1995-1996; other transitional phases account for 64 km². Relatively undisturbed native forest was substituted mainly in watershed 4. Since most of the substituted forest is located either in fragments (usually near agricultural lands) or at the edge of the native forest, it is likely that these forests were degraded before substitution occurred because forest edges have been shown to have higher mortality, damage, and turnover rates (Laurance et al. 1998).

Native forests that were converted to plantations were at lower slopes and elevation (mean slope of $10^{\circ} \pm 5^{\circ}$ and $278 \text{ m} \pm 132 \text{ m s.d.}$ elevation) whereas native forest that remained native forest were at higher slopes and elevations ($13^{\circ} \pm 9^{\circ}$ slope and mean elevation of $562 \text{ m} \pm 353 \text{ s.d. m.}$).

Conversion of agricultural and cleared land areas in the past 15 years reflects the development patterns in region IX (Clapp 1995; 1998; 2001). I infer that in region X, as it

became more difficult to substitute forest, plantation companies capitalized on unsuccessful agricultural lands with limited yield and associated native forest as they did in the IXth region (Clapp 1998). Areas converted from agriculture to forest plantations had an average slope of $8^{\circ}\pm 5^{\circ}$ and elevation of $228\text{ m}\pm 114\text{ m}$ whereas areas in sustained agricultural land covers were flatter and at lower elevations (average slope of $3^{\circ}\pm 4^{\circ}$ and elevation of $152\text{ m}\pm 98\text{ m}$). Based on the satellite image analysis, agriculture in the valleys remains stable most likely from the strong agricultural export market (Gwynne, 1996), reliable transportation (based on digital road maps from Chile's Ministerio de Obras Publicas and experience travelling in the region) and arable soil (Schlatter 1977). According to the soil-use map (CIREN & CORFO 1983; Figure 2-10; Table 2-5) very little land useful for agriculture (Classes II and III), $11,170\text{ km}^2$ or 5% of the total plantation cover, was converted to plantations, in 2001.

In the 2001 Landsat image, large agricultural areas in watershed 5 on the eastern slope of the coastal mountains, had already been cleared and is a possible location for new plantations. These cleared soils range from type IV to type VII. Native forest that was degraded and agricultural lands on median slopes will probably continue to be locations for future plantation development.

According to my analysis, the areas that experienced the most plantation development between 1985 and 2001 are located on the western portion of watersheds 3 and 5, which corresponds to the eastern mountain slopes of the coastal mountains and not along the western portion of the coastal forest (Figure 2-6). This contrasts with Wilson et al's (2005) prediction of future development patterns. However, Wilson's prediction depends on road establishment and roads been developed only recently (2005) in the

coastal mountains and Wilson et al's (2005) prediction may hold true in the future. Regions where coastal roads will be built could convert from native forest to plantations if undisturbed native forest is directly converted to plantations. More likely, however, is that the native forest will become disturbed through coastal development and then plantations can become established. Bueno (5), San Luis (9), and Maullin (13) watersheds are possibly areas of future concern because I observed the government paving roads in the region in 2008 and if substitution of pristine forest occurs or the forests are degraded, then the Wilson et al (2005) patterns may hold true.

Schlatter's (1977) assessment of plantation establishment for pines agrees with the current trends. The least desirable soils (class VII) are mainly used for forest plantations, showing that available land that is best for plantations, type IV-VI, is limited. Soil class VII accounts (Table 2-5) for most of the forest plantations in 2001 (63%) and 1986 (69%), respectively, followed by class IV, V, and VI, which accounted for (31%) of the plantations in 2001 and 24% of the plantations in 1986 (Table 2-5). Figure 2-10 shows that the soil class IV, V, and VI are important in the Osorno region where this soil type corresponds to dairy farming. Plantations established on class VII soil mainly represents the Coastal and Andes Forest where plantations occur usually at the edges, probably because these areas have less steep slopes and are located closest to roads.

The native-forest cover in the coastal forest was very stable, at least from a regional perspective, over the past fifteen years. CONAF limits on substitution, the geography of these watersheds, and the lack of connection to road networks probably reduced deforestation. Additionally, large areas of the coastal native forest watersheds are located on the westward side of the coastal mountains, and the metamorphic soils are not ideal

for pine plantations because they are nutrient-limited and have low potential depth for roots (Schlatter & Gerding 1995; Schlatter et al. 1995). Furthermore, the watersheds have little or no connection to road networks making plantations or agriculture even less attractive. The native forests in the Andes mountains, which are located in the eastern portion of Valdivia (3) and Bueno (5), remain in high-altitude and sloped terrain that are either not feasible for plantation use due to the rugged terrain, or isolated and not connected to roads.

Deforestation in Chaihuín (4) and San Luis (10), represent two different development patterns. Prior to 1990 a company in the Chaihuín watershed obtained approval to substitute *Eucalyptus* plantations for native forest. A portion of the land was substituted, another portion was clear cut, and a final portion remained native forest. According to local informants, the company abandoned the project because of financial problems that developed in part from legal battles over substitution of native forest. Today a consortium of conservation organizations own the land--clear cutting ceased and the native forest will be restored. San Luis, located in the heart of the alerce (*Fitzroya cupressoides*) coastal forests (CONAF et al. 1997), was deforested, most likely from illegal fires (Lara 1999). Dead alerce can be legally harvested, but local authorities cannot easily distinguish between a recently burned alerce and one that died years ago. The most serious threat to the native forest watersheds in the alerce region is fire (Lara 1999); a fire could convert native forest watersheds to a mixed watershed and ultimately lead to conversion to plantations.

Coastal management: predicting vulnerable sites and future management

In general, region X has three development zones (Figure 2-1) The Valdivia zone (watersheds 1-4) is has changed from a system dominated by agriculture and to a lesser

extent native forest to a region where plantations dominate and people living in this area are most vulnerable to the influences of plantation development (Figure 2-8). The nearshore region may have increased nutrients, lower oxygen levels, and increased sedimentation affecting fisheries (Smith et al. 1999; Bounoua et al. 2002; Kemp et al. 2005, Van Holt c, d, in prep) (Figure 2-9). In many plantation counties the small-scale farmers on the sloped mountains likely migrated to urban areas since forestry companies buy out small-scale farmers and replace their land with forest plantations. The Osorno zone (5-9), which contains most of the small coastal native forest watersheds, remains relatively similar with extensive native forest and is the least affected. The Bueno watershed (watershed 5 in Figure 2-1) in the Osorno zone is an exception, with an extensive conversion to plantation and cleared land; however, the large size of the watershed and the surrounding native forest may buffer some of the effects. The Llanquihue zone (10-13) is in a state of transition with some native forest, *matorral*, plantation, and agriculture, and potentially some ecological and social effects, but no clear indication as to what the future landscape pattern will be. According to Schlatter (1977), most of the region in watershed 13, the area that is mainly *matorral* cover, is not suitable for pine plantations because the ñadi soils have poor drainage and in the summer they become extremely dry; these thin soils are on flat lands and derived from volcanic ashes.

In terms of the coastal region, the water resources along the rivers and coasts of areas near plantations need to be examined in more detail as future research hypotheses. The landscape analysis of this study can serve as a basis to design studies about nutrient dynamics and conduct a more detailed analysis that includes history and extent of

conversion and possibly plantation age to further understand nutrient dynamics in plantation systems in southern Chile

The relationship between loss of rural people and increase in plantations leads to future research hypotheses that address how rural livelihoods are shifting. I hypothesize that those who do remain in areas dominated by plantations adapt to a new rural life. Rural farmers who remain near plantations likely have fragmented social networks because their neighbors are gone--a rural farmer in the region reported that “no one was left, just the plantations.” Plantation companies buy out one family after another after another until whole communities disappear (Clapp 1998). Cattle ranching systems are also likely changing as forest plantations replace small-scale dairy farms located on marginal agricultural lands—those plantation areas are located in IV, V, and VI soil types (pink areas in Figure 2-10). Some evidence of outmigration show that indeed changes are happening; Purranque, Rio Negro, Fresia and San Juan de la Costa, all ranching counties, are losing rural people (between 9 and 22%) (INE 1994; INE 2002) and the loss of people can influence dairy production for Chile.

Because Chile is a leader in plantation exports worldwide and has relatively stable native forest and agricultural areas, plantation development patterns can serve as a model for this type of development in other areas of the world that have similar land constraints. Chile’s relatively small size help make it a model country to identify effects of plantations on the ecosystem and peasant and fisher livelihoods.

Table 2-1. Accuracy assessment for the 2001 & 1985 image using the 109 accuracy-assessment training points and 30 randomly selected points.

Class Name	Training points				Reference Totals	30 random points		
	Producers Accuracy pixels	User Accuracy Pixels	Producer Accuracy %	User Accuracy %		Classified Totals	Producer Accuracy %	User Accuracy %
2001 Image								
Plantations	315/362	315/337	87	94	30	31	93	90
Native Forest	242/286	242/292	85	83	30	27	80	89
Mattoral	207/266	207/217	78	95	30	35	97	83
Agriculture	159/159	159/188	100	85	30	27	87	96
Cleared land	191/210	191/226	91	85	30	23	70	91
Water	50/50	50/50	100	100	30	32	100	94
Urban	272/292	272/272	93	100	30	32	100	94
Snow	46/46	46/46	100	100	30	30	100	100
Wetland	50/65	50/50	77	100	30	33	100	91
1985 Image								
Plantations	311/384	311/311	81	100	30	28	93	100
Native Forest	256/256	256/318	100	81	30	26	80	92
Mattoral	190/238	190/191	80	99	30	36	93	78
Agriculture	234/234	234/293	100	80	30	29	87	90
Cleared land	228/230	228/266	99	86	30	28	70	75
Water	242/246	242/250	98	97	30	30	100	100
Urban	76/97	76/76	78	100	30	30	97	97
Snow	253/261	253/256	97	99	30	30	100	100
Wetland	181/223	181/184	81	98	30	33	90	82

Table 2-2. Area and percent of change and 2001 land use/cover of plantation, native forest, *matorral*, agriculture, and clear land class. Area change was determined by calculating the difference in area between respective land cover class in the November 29, 2001 image (Landsat ETM, path 233, rows 87-89) and the October 5, 1985 image (Landsat TM, path 233, rows 87-89) for each class and each watershed. Area in any land-cover type for 1986 can be calculated by subtracting the change from the value for 2001. Percent change was calculated by dividing the area change by the total watershed area.

	Plantation		Native Forest		Matorral		Agriculture		Cleared Land	
	Change	2001	Change	2001	Change	2001	Change	2001	Change	2001
Area (km ²)										
1	151.0	181.9	-89.9	169.2	0.1	2.0	-69.2	76.6	10.0	90.0
2	0.4	2.5	-20.4	140.8	0.0	0.1	-4.6	27.4	25.4	43.6
3	1264.0	1425.0	-677.3	4483.5	-7.5	73.4	61.0	2172.5	-345.7	1365.5
4	27.1	27.1	-109.6	591.0	0.5	0.5	2.0	21.0	78.3	101.3
5	417.2	489.5	56.8	5815.1	-8.7	155.0	836.1	5403.4	-688.6	1855.3
6	0.0	0.0	-14.6	268.1	0.1	0.1	0.9	4.4	13.1	16.7
7	27.0	33.1	-37.4	325.7	0.6	2.1	4.6	54.0	4.0	66.2
8	12.2	12.2	-24.4	313.7	0.9	1.0	-1.6	16.0	11.8	24.4
9	0.0	0.0	-18.6	348.4	0.1	0.1	0.8	3.8	17.1	21.9
10	0.0	0.0	-96.6	629.6	0.1	0.2	1.4	10.2	93.5	110.0
11	84.9	86.3	-45.0	637.1	1.5	4.9	-14.1	313.1	-27.1	152.8
12	0.0	0.0	-28.1	158.1	3.1	4.0	6.9	33.8	18.4	64.6
13	8.0	8.0	-192.4	1141.2	68.5	308.7	30.6	990.9	94.9	634.9
Total	1991.8	2265.6	-1297.5	15021.5	59.3	552.1	854.8	9127.1	-694.9	4547.2
Percent										
1	28.7	34.5	-17.1	32.1	0.0	0.4	-13.1	14.5	1.9	17.1
2	0.2	1.1	-9.0	62.4	0.0	0.0	-2.0	12.1	11.2	19.3
3	12.3	13.9	-6.6	43.7	-0.1	0.7	0.6	21.2	-3.4	13.3
4	3.6	3.6	-14.4	77.7	0.1	0.1	0.3	2.8	10.3	13.3
5	2.7	3.2	0.4	37.9	-0.1	1.0	5.4	35.2	-4.5	12.1
6	0.0	0.0	5.0	91.2	0.0	0.0	0.3	1.5	4.4	5.7
7	5.6	6.8	-7.7	67.1	0.1	0.4	1.0	11.1	0.8	13.6
8	3.3	3.3	-6.6	84.6	0.2	0.3	-0.4	4.3	3.2	6.6
9	0.0	0.0	-4.9	91.9	0.0	0.0	0.2	1.0	4.5	5.8
10	0.0	0.0	-12.7	83.0	0.0	0.0	0.2	1.3	12.3	14.5
11	6.1	6.2	-3.2	45.7	0.1	0.3	-1.0	22.5	-1.9	11.0
12	0.0	0.0	-10.6	59.6	1.2	1.5	2.6	12.7	6.9	24.3
13	0.2	8.0	-4.0	23.8	1.4	6.4	0.6	20.7	2.0	13.3
Total	5.6	6.3	-3.6	41.9	0.2	1.5	2.4	25.5	-1.9	12.7

Table 2-3. Eigenvalues and eigenvectors of PCA1, PCA2, PCA3, and PCA4. Note: Standard deviations are the square root of the eigenvalues. Rotation contains the eigenvectors.

	PC1	PC2	PC3	PC4
2001 proportion data				
Plantation Area	-0.19	-0.92	0.23	-0.25
Native Area	0.91	-0.04	0.17	-0.38
Ag/Ranch Area	-0.36	0.39	0.51	-0.68
Clear Area	-0.09	-0.03	-0.82	-0.57
S.D.	25.51	8.82	5.27	3.75
Eigenvalues	650.76	77.79	27.77	14.06
1985 proportion data				
Plantation Area	-0.02	-0.21	0.18	0.96
Native Area	0.90	-0.40	-0.12	0.09
Ag/Ranch Area	-0.38	-0.59	-0.67	0.26
Clear Area	-0.20	0.67	-0.71	0.02
S.D.	26.85	4.10	3.06	1.16
Eigenvalues	720.92	16.81	9.36	1.35

Table 2-4. Euclidean distance (m) from river or lake to plantation, native forest, agriculture, and cleared land classes.

	Mean	Stdev
Native forest	256	562
Plantation	43	248
Agriculture	139	408
Cleared land	77	336

Table 2-5. Area and percent of forest plantation (1985 and 2001) by soil use classes (CIREN and CORFO 1978). Soil classes I-II are suitable for agriculture and have low slope and high drainage. Soil classes IV-VI are best for plantations, the slope is higher and soils do not drain well. Soil classes VII are not ideal for plantations because the slope is even higher and drainage is poor. Soil class VIII are not suitable for plantations because they are located in rocks, snow, glaciers, dunes, or wetlands.

Soil-use class	2001 plantation area (km ²)	2001 plantation proportion	1985 plantation area (km ²)	1985 plantation proportion
I	46	0	0	0
II	2,157	1	144	1
III	9,013	4	694	3
IV,V,VI	65,492	31	6,508	24
VII	132,126	63	18,438	69
VIII	1,757	1	830	3



Figure 2-1. Study site is the northern portion of Administration Region X of Chile. Thirteen watersheds for LCLUC analysis were delineated using the Dirección General de Aguas (the Chilean Ministry of Water) digital watershed map. In the map the Lingue watershed is represented by (1), Bonifacio (2), Valdivia (3), Chaihuín (4), Bueno (5), Quilhue (6), Contaco (7), Hueyelhue (8), Cholguaco (9) San Luis (10), Llico (11), Putratrán (12) and Maullín (13). The names of the watersheds are derived from the main river in the area or the name of the region. The development patterns extend across three zones: Valdivia zone extends from 39°S to 40°S, the Osorno zone is from 40°S to 41°S and the Llanquihue zone is 41°S to 42°S.

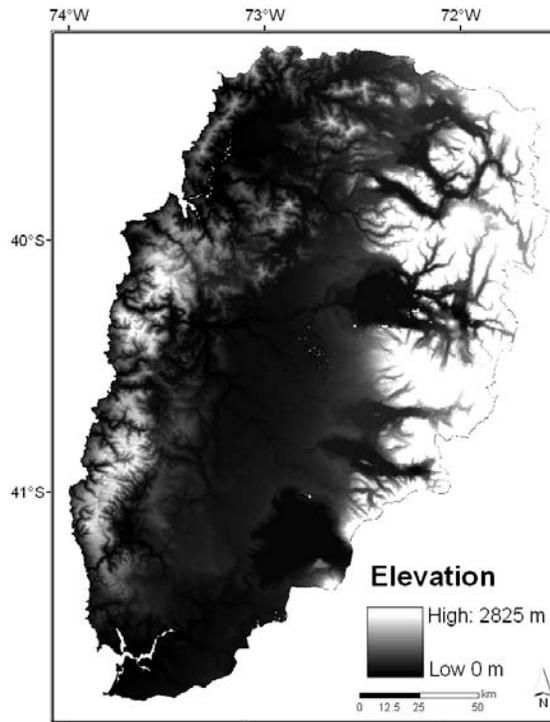


Figure 2-2. Digital elevation model of the study site based on Shuttle Radar Topography Mission (SRTM) Finished 3 arc-second (90 m) raster elevation dataset. The remaining portion of the Coastal Temperate Forest and the Andes Forest is on high elevation areas (shown in white). Agricultural regions occur in the valley between the two mountain ranges.

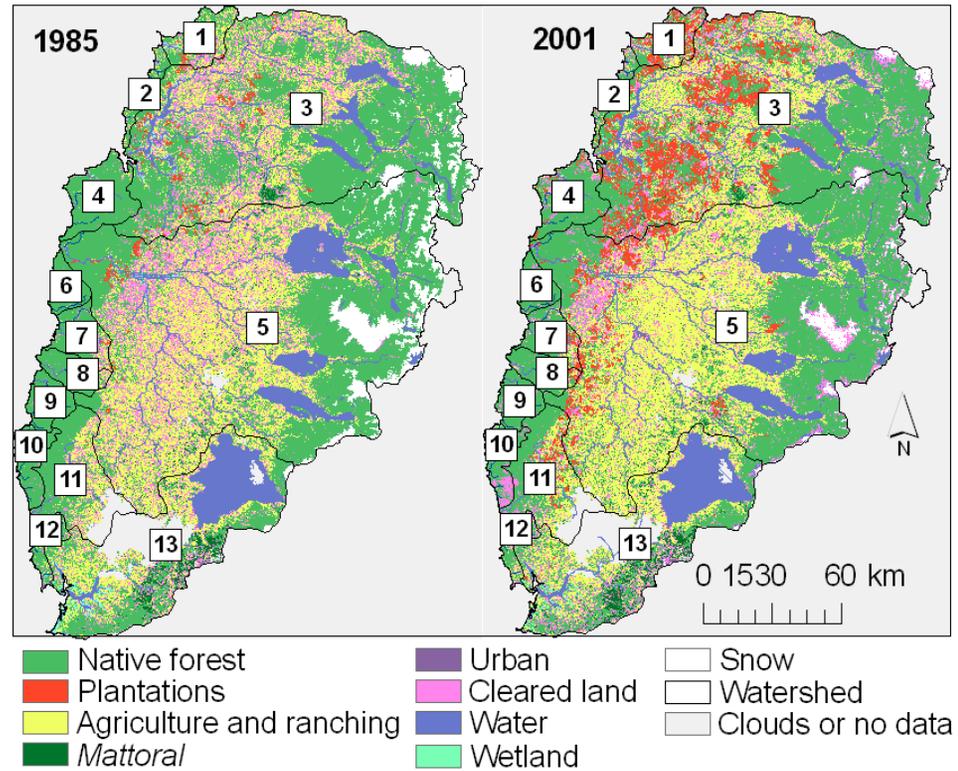
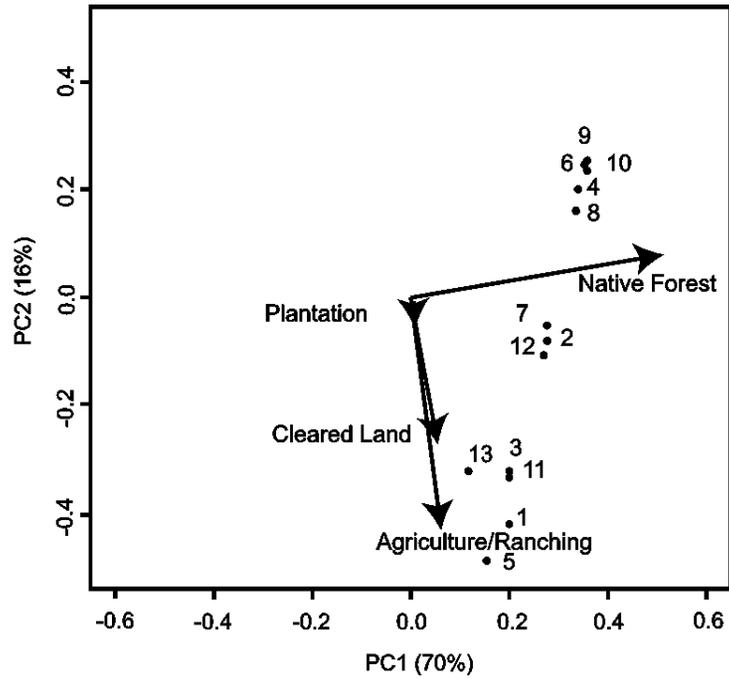
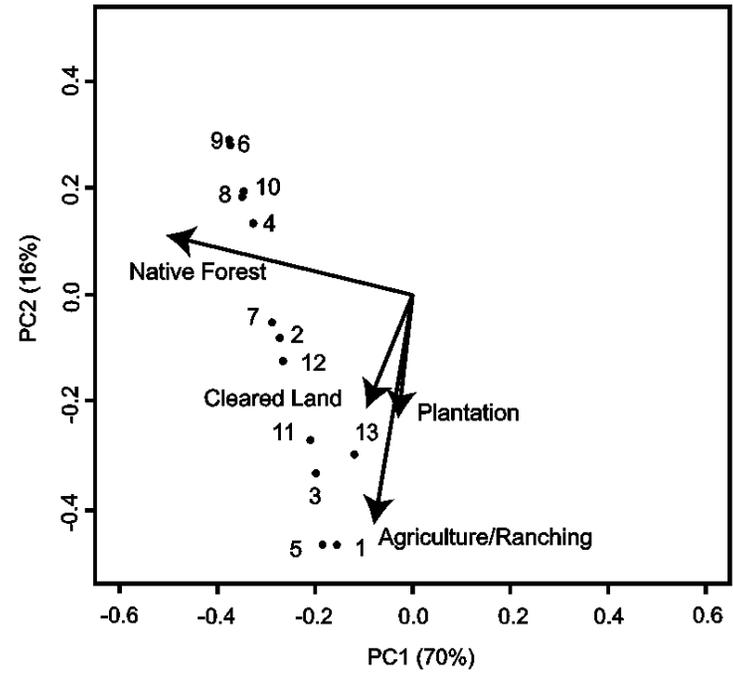


Figure 2-3. Supervised classification of October 5, 1985 (Landsat TM, path 233, rows 87-89) and November 29, 2001 (Landsat ETM, path 233, rows 87-89) images showing native forest, plantation, *matorral*, agriculture, cleared land, sand, water, urban, snow, and wetland land cover/uses. The numbers in white boxes correspond to watersheds in Figure 2-1.

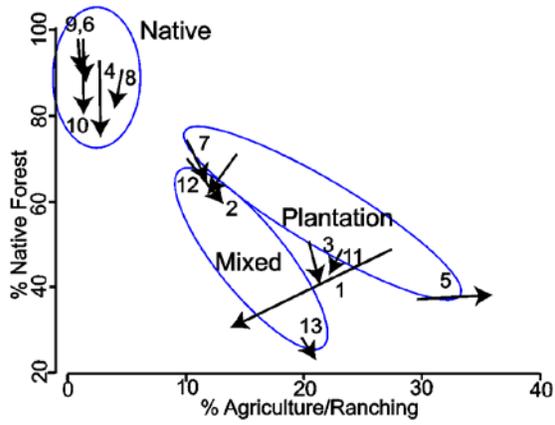


A.

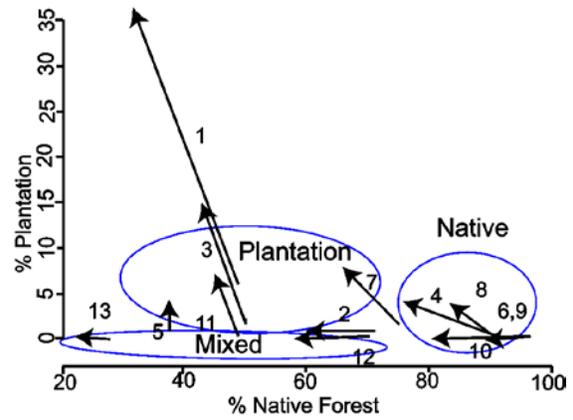


B.

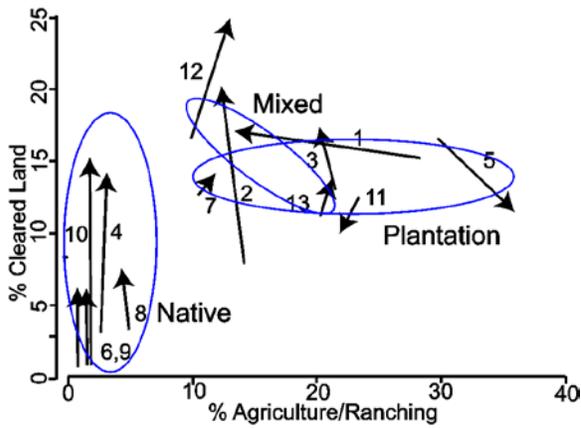
Figure 2-4. Principal components analysis biplot of the (A) 1985 and (B) 2001 land cover fraction variables. The numbers in correspond to watersheds in Figure 2-1 and Figure 2-2.



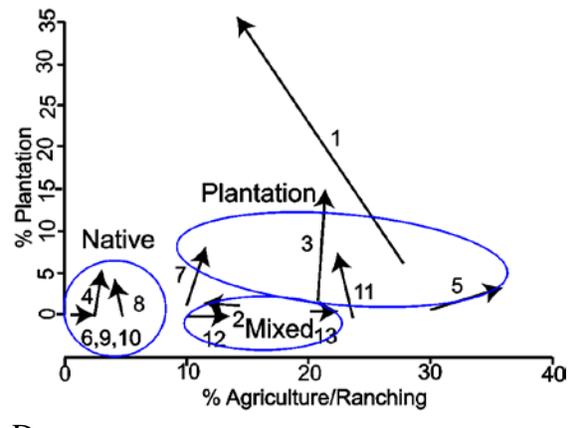
A.



B.



C.



D.

Figure 2.5. Plot of the change from 1985 to 2001 in the relative percent of A, native forest and agriculture/ranching B, plantation and native forest C, cleared land and agriculture/ranching and D, plantation and agriculture/ranching

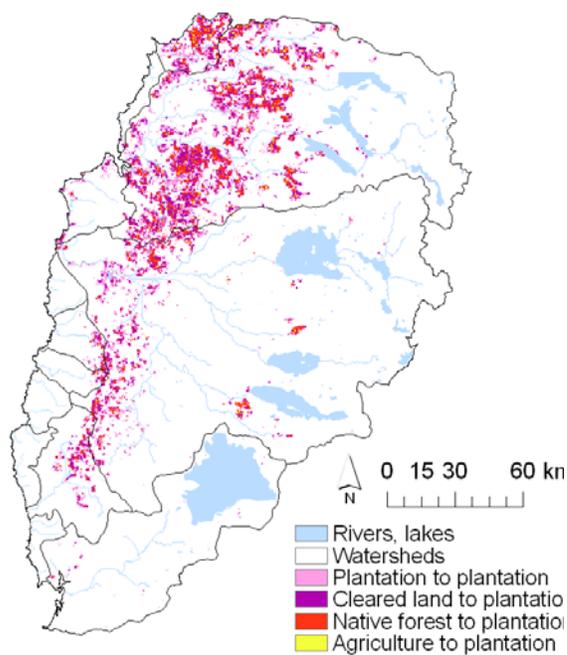


Figure 2-6. Conversion to the plantation class in 2001 from plantations, cleared land, native forest, and agriculture/agronomy in 1985. Based on supervised classification of October 5, 1985 (Landsat 5 TM) and November 29, 2001 (Landsat 7 ETM+), path 233, rows 87-89.

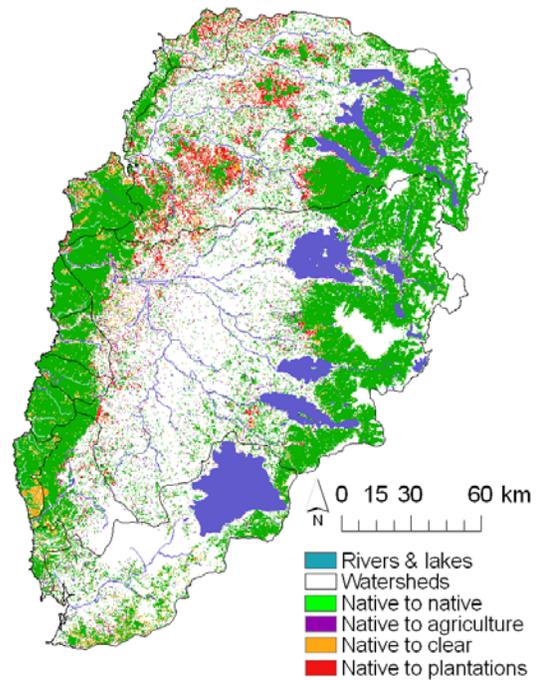


Figure 2-7. Conversion from the native forest class in 1985 to plantations, cleared land, native forest, and agriculture/agronomy in 2001. Based on supervised classification of October 5, 1985 (Landsat TM, path 233, rows 87-89) and November 29, 2001 (Landsat ETM, path 233, rows 87-89).

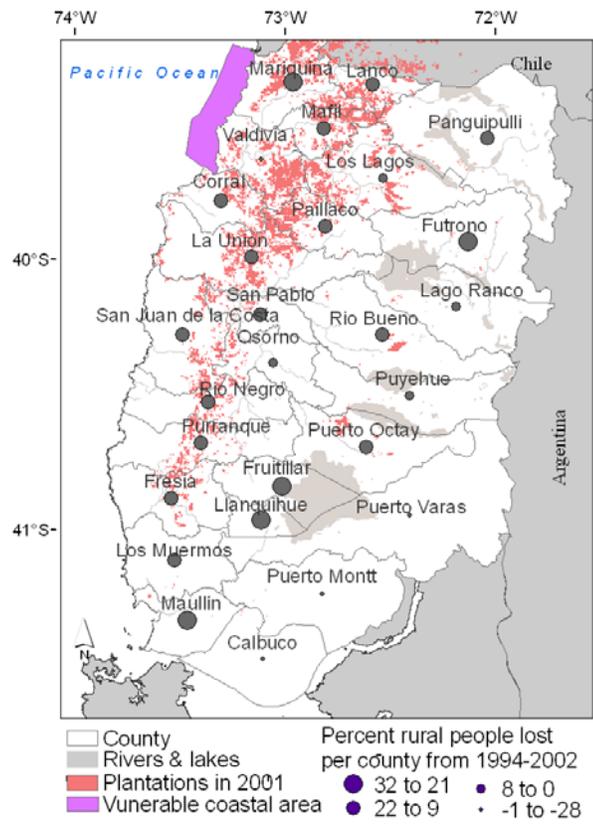


Figure 2-8. Vulnerable sites on land (regions with forest plantations and high loss of rural people in the county and in the nearshore region, in high plantation areas where rivers outlet to the ocean).

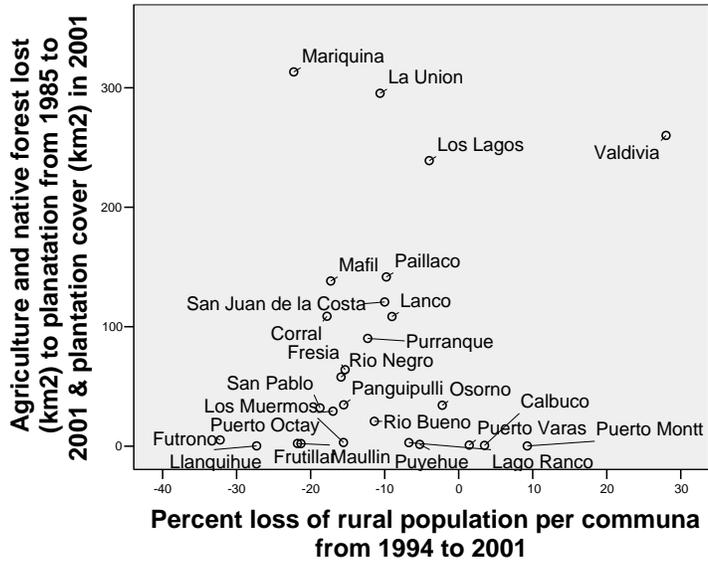


Figure 2-9. Agriculture and native forest lost to forest plantations from 1985 to 2001 and total plantations in 2001 (minus the area of agriculture and native forest converted) by percent loss of rural population per county as per the census data from 1994 to 2002 (INE 1994; INE 2002).

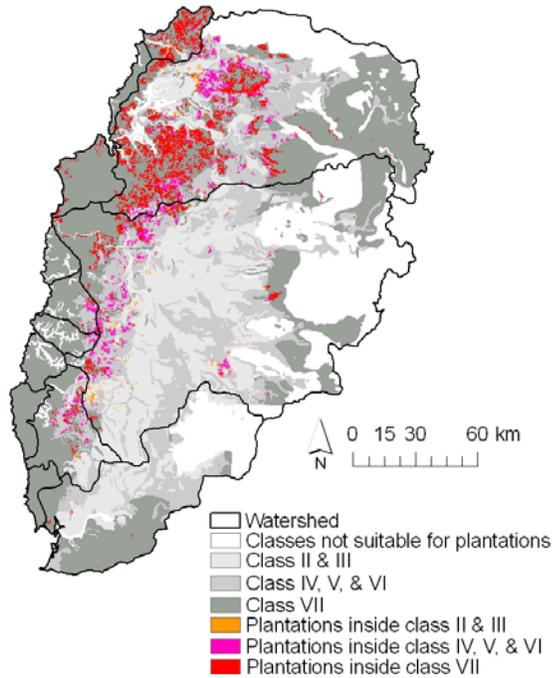


Figure 2-10. Forest plantations in 2001 by soil use maps (CIREN and CORFO 1983) see Table 2-6 for information on soil use classes. Soil classes I-II are suitable for agriculture and have low slope and high drainage. Soil classes IV-VI are best for plantations, the slope is higher and soils do not drain well. Soil classes VII are not ideal for plantations because the slope is even higher and drainage is poor. Soil classes that are not suitable for plantations include rocks, snow, glaciers, dunes, or wetlands.

CHAPTER 3
CHLOROPHYLL-A PATTERNS AND ISOTOPIC SIGNATURES OF *LOCO*
(*CONCHOLEPAS CONCHOLEPAS*) SHELLFISH IN RELATION TO FOREST-
PLANTATION DEVELOPMENT IN SOUTHERN CHILE

Introduction

Landscape Change and Nearshore Systems

I examine here how nearshore coastal waters are influenced by landscape change at the meso-scale. Human activities on land can alter coastal marine systems by affecting changes in hydrologic regimes, rates of nutrient loading, and sediment delivery of the rivers that discharge into the nearshore that, in turn, influence patterns of biological productivity and other key ecological processes (Smith et al. 1999; Bounoua et al. 2002; Kemp et al. 2005). Terrestrial derived nutrients that are delivered to the nearshore environment can have profound influences on primary producers, phytoplankton in particular (Gomes et al. 2000; Shiomoto et al. 2002). Increased nutrient inputs to the nearshore environment can lead to changes in the material-transport pathways and energy flow with consequences for food-web structure and function (see, e.g., Kemp et al. 2005). Extensive changes in the nearshore environment have been attributed to landscape change in the Black Sea, Chesapeake Bay, and Gulf of Mexico (Anderson et al. 2002; Kemp et al. 2005; Diaz & Rosenberg 2008). Nearshore changes can have far-reaching effects influencing organisms that live in the nearshore as well as offshore organisms that spend a part of their life cycle in the nearshore environment (Beck et al. 2001). In cases of extreme changes in the nearshore environment, key species may be lost and people are likely to face negative socioeconomic consequences (Mee 1992; Kemp et al. 2005). This study addresses the following questions:

- Are nearshore chlorophyll-a patterns related to landscape-change patterns or are they related to upwelling?
- Are nearshore chlorophyll-a concentration values at the watershed and zonal scale higher near plantation-influenced watersheds?
- Are terrestrial derived nitrogen and carbon sources incorporated into the marine food web?

The social and environmental influence of landscape change on terrestrial systems has been the focus of much research (Foley et al. 2005). Less research has been carried out on the relationship between landscape change and the associated changes in coastal marine environments because of complexities at the land-sea interface (Talley et al. 2003). Studies that link landscape change to changes in nearshore marine systems tend to be small in scale (tens of kilometers along the coast) and are generally focused on single estuaries with established connections to well-identified watersheds (Camacho-Ibar et al. 2002). Less information is available on how landscape change influences the nearshore environment at larger spatial scales (but see Bonsdorff et al. 1997; Alexander et al. 2000; Anderson 2002; and Matthews et al. 2004) because satellite images were not available until recently and ocean dynamics are complex—i.e. geomorphology can influence species diversity (Fernandez et al. 2000) and large-scale studies need to account for significant geomorphological, abiotic, and biotic differences (Talley et al. 2003). Today, however, satellite images and ancillary data on regional abiotic and biotic factors are available to help design studies across mesoscales i.e., 100's of kilometers of coast.

Meso-scale studies across multiple watersheds allow for a greater understanding of processes that drive regional patterns. For example, a space-for-time substitution method

that compares watersheds with different landscape change patterns can help illustrate the environmental condition that may have existed in a watershed prior to the change (Fukami and Wardle 2005). Also, by comparing multiple watersheds, more evidence may be produced to determine whether environmental differences can be attributed to site-specific upland activities, rather than to broad-scale changes that might occur, for examples, as a consequence of climate change. Once these regional patterns are described, mechanistic studies can be designed at the appropriate scale and location without bias due to accessibility.

Across Latin America, globalization, population growth, and local policies and subsidies drive landscape change (Grau & Aide 2008). In Chile, forest-plantation development exploded with the “Decreto Ley 701” law of 1974 when the Pinochet administration subsidized 75% of the cost of plantation establishment to support the global pulp industry (Lara & Veblen 1993); today pine (*Pinus radiata*) and eucalyptus (*Eucalyptus globulus* and *Eucalyptus nitens*) are the main forest-plantation species. By 1992, Chile was the world’s sixth most important wood-pulp exporting country (Sedjo 1999). In 2005, forest plantations comprised 2.1 million hectares or 13.4% of the Chilean forest cover (INFOR 2006).

Plantations, especially *Eucalyptus*, are fertilized with nitrogen and phosphorus to increase productivity (Guerra et al. 2007). Shlatter’s (1977) study shows that pine plantations do not hold nitrogen well in the soil and therefore also need to be fertilized. Recent studies of waters within the Valdivia watershed show that nitrogen concentrations are elevated relative to historical values and, in some cases, exceed legal limits (UACH 2005). Historical data indicate that nitrogen (N-NO₃) levels in the rivers were low,

ranging from a minimum average of 0.065 mg/l to a maximum of 0.271 mg/l, from 1987 to 1992 (DGA 1992). Oyarzun et al.'s (2007) study of small rivers in Chile showed an increase in nitrogen levels in plantation watersheds when compared with native-forest watersheds. Little et al.'s (2008) study of nitrogen levels in small rivers that had different land-use strategies identified the highest nitrogen level in a watershed covered with forest plantations. Plantation development in Chile over the past 15 years has probably increased the amount of nitrogen being delivered to the nearshore environment via rivers.

Chlorophyll-a as an Indicator of Change

An increase of chlorophyll-a in the nearshore environment can be an important indicator of change in biological and ecological processes. Chlorophyll-a is the primary light-harvesting pigment found in all photosynthetic organisms including phytoplankton, which are generally the main contributors to primary production in the nearshore and oceanic systems. Chlorophyll-a concentration is one of the best predictors of photosynthetic biomass available today (Huot et al. 2007). High chlorophyll-a values indicate an increase in phytoplankton and could indicate that fertilization with nitrogen, phosphorus, or other nutrients, has occurred, and initiated an increase in algal biomass in an otherwise nutrient-limited system. High chlorophyll-a values can also occur as a consequence of upwelling events that bring cool, nutrient-rich water from deep waters to the ocean surface and stimulate photo-plankton production (Ryther 1969). If high chlorophyll-a values in coastal waters are accompanied by cold sea-surface temperatures then upwelling is generally assumed to have contributed to the high chlorophyll-a values (Ryther 1969; Moreno 1979). Spectral information obtained from satellites is often employed to quantify chlorophyll-a levels in nearshore and oceanic waters and time-series data, when available, can be used to identify changes in production characteristics.

If other abiotic and biotic factors are similar, space can substitute for time to understand how future landscape change may influence chlorophyll-a values.

Stable Isotopes: Tracers of Material-Transport Pathways and Food-Web Structure

Loco (*Concholepas concholepas*) is a murcid-mollusk carnivore that preys predominately on filter-feeding tunicates and barnacles (Stotz et al. 2003) and therefore is a good species for stable-isotope analysis to understand material-transport pathways and food-web structures. The isotopic signatures of *locos* can indicate changes in the food web structure and how bottom-up influences (nutrient inputs) can alter the pathways of flow within food webs. Stable-isotope analysis is based on the ratio of light and heavy isotopes of an element; these ratios are compared to a standard and the ratios are either enriched, depleted, or equal to the standard (Fry 1988). Stable-isotope ratios can help trace the origin of carbon and nitrogen because terrestrial, marine, and atmospheric nitrogen and carbon have distinct isotopic ratios (signatures) (Coleman & Fry 1991). *Loco* flesh should be lighter or heavier depending on the source of C and N, and (McKinney et al. 2001; Freyer & Aly 1974; Kreitler et. al. 1978; Cole et al. 2004; Peterson & Fry 1987; Trumbore & Druffel; Coleman & Fry 1991). If terrestrial nitrogen and carbon entered the system, the $\delta^{15}\text{N}$ values should be enriched or depleted slightly (Freyer & Aly 1974; Kreitler et. al. 1978; McKinney et al. 2001) and the $\delta^{13}\text{C}$ values should be depleted (Trumbore & Druffel 1995) because terrestrial $\delta^{13}\text{C}$ values generally range from -32 to -20 (Coleman & Fry 1991). Known enrichments can also occur through the food web, $\delta^{13}\text{C}$ values are typically enriched 1‰ per trophic level and $\delta^{14}\text{N}$ values are typically enriched 3-4‰ per trophic level (Fry and Sherr 1984; Minagawa and Wada 1984). Shifts in the food-web structure, such an increase or decrease in food-web length

(Cabana & Rasmussen 1994), or domination of some organisms (Bade et al. 2005) can also be identified with isotopes.

Fisheries and Landscape Change

The Chilean Fishing and Agriculture General Act of 1991, a Territorial User Rights Fishery (TURF) program, granted groups of artisanal fishers managed exploitation areas for benthic resources (MEABR) in the nearshore. Fishers gain quasi property rights and exclusive rights to benthic resources within these areas (Bernal et al. 1999). The Act has been hailed as an ecological success because *loco*, among other nearshore marine species, have recovered from the effects of overharvest (Defeo and Castilla 2005; Gonzalez et al. 2006). Changes in the nearshore environment; however, can have consequences for those who depend on living-marine resources for their livelihoods if changes in the landscape negatively influence the quality of the resources in the management areas and fishers cannot shift to other regions to harvest resources (Van Holt in prep d). Moreover, employees of Servicio Nacional de Pesca (SERNAPESCA), the Chilean fishery management institution, report that in the near future fishers will be required to pay a fee to retain the MEABRs. As a result, fishers are becoming increasingly concerned that upland activities will affect their livelihoods. Indeed, fishers living close to forest plantations have *locos* with shells infested with parasites (Van Holt in prep c), and these fishers are paid lower prices per kg for the *loco* shellfish and earn a lower monthly income from the MAERBs. Some fishers working in these poor-quality regions have given up on fishing altogether (Van Holt in prep d).

Since Chile has a very long coast in relation to its total land area, the nearshore environment is important to its economy. As of 1992, fisheries provided 516,000 direct and indirect jobs (3.8% of Chile's population in that year). Of those jobs, 86% were in

the artisanal (nearshore) fishery (Bernal et al. 1999). With 41 million fishers worldwide (FAO 2002), and 40% of the world's population living along the coast (Cohen et al. 1997), the relationship between fisheries and landscape change needs to be more adequately addressed.

Our specific objectives were to determine: (1) the spatial and temporal variability of chlorophyll-a in nearshore coastal waters from 1998-2005; (2) if landscape change factors or upwelling, or both, influence high chlorophyll-a values; (3) are upland-landscape characteristics related to the nearshore environment with high chlorophyll-a values; and (4) if terrestrial nutrient inputs are discernable in the marine food web.

Methods and data sources

Study Site

In region X of Chile (Figure 3-1), along the central coast (Fernandez et al. 2000; Camus 2001), uniform wind patterns, topography, and temperature give rise to similar invertebrate and fish communities in the rocky intertidal ecosystem (Moreno et al. 1979; Fernandez et al. 2000; Lancellotti & Vasquez 2000; Camus 2001). Upwelling events are not considered major ecosystem drivers as in other regions of Chile (Hebbeln 2000); however, small, coastal-upwelling events reportedly occur during summer months (January to March) in the northern-Valdivia region (Moreno et al. 1998). According to Hebbeln (2000), the surface-sediment distribution and related photosynthetic biomass is related to either terrigenous inputs or ocean currents. The temperate climate and high rainfall (approximately 2000-4000 mm annually) (Eldridge & Pacheco 1987) enhances erosion, surface-water runoff, and sedimentation, especially in the winter (Fernandez et al. 2000). Additionally, beach sands interspersed throughout the rocky intertidal areas have mainly terrestrial rather than oceanic origins (Hebbeln 2000). Coastal

geomorphology is also similar throughout the region--the continental shelf extends to approximately 6.54 km and to 200 m in depth; there are no fjords in the study area. (Fernandez 2000). The Humboldt Current is the main oceanographic feature that influences the region (Lancellotti & Vasquez 2000; Fernandez et al. 2000; Thiel et al. 2007) and typically flows north.

In comparison to the extreme north and south of Chile, the diversity of fish and benthic-organisms is relatively similar in the north and south (Lancellotti & Vasquez 2000); the extreme north has more diverse fishes and less diverse benthic organisms and the extreme south holds the opposite trend. However, diversity of benthic organisms does exhibit slight variation. In a rapid survey of benthic organisms, the Valdivian zone (Figure 3-1) had a low Shannon Index score for benthic organisms (-0.2); the Osorno zone had the highest diversity score (2); and the Llanquihue zone had a median score (0.7) (Moreno 2001). Important benthic fisheries include the Chilean abalone, *loco*, (*Concholepas concholepas*), mussels (*Mytilus* sp.), tunicates (*Pyura* sp.), limpets (*Fisserella* sp.), and sea urchins (*Loxechinus albus*). Important exploited finfishes include *congrío* (*Genypterus* sp.), *corvina* (*Cilus gilberti*), and *sierra* (*Thyrsites atun*).

The main zones in the study site include the Valdivian zone that has extensive forest plantations and agriculture, the Osorno zone that has extensive native forest cover, agriculture activities, and a less extensive, but an increasing number of plantations, and the Llanquihue zone that has extensive agriculture and ranching, as well as *matorral* (new growth or shrubby forest) land cover (Figure 3-1).

Satellite-Image Analysis of Chlorophyll-a and Sea-Surface Temperature

Spatial and temporal variability in chlorophyll-a concentration pattern was characterized using 9-km resolution Sea-viewing Wide Field-of-view Sensors (SeaWiFS)

chlorophyll-a products. Chlorophyll-a (CHLA) concentration values that are obtained from the SeaWiFS satellite image are derived from an empirically based bio-optical algorithm (O'Reilly et al., 2000) using reflectance values, which are derived from calibrated digital counts that have been atmospherically corrected (Hu et al. 2009). The SeaWiFS images provide monthly chlorophyll-a concentration (mg/m^3) averages from 1998 to 2005; monthly composites include every valid measurement of water-leaving radiance that is spatially and temporally combined within a 9 by 9 km^2 element (referred to as bins) (Thomas & Franz 2005). Sea surface temperature (SST) (4 micron night scales) were obtained at a 9 by 9 km^2 scale using Moderate Resolution Imaging Spectroradiometer (MODIS) images for each month from July 2002 to December 2005 to test whether upwelling influenced chlorophyll-a patterns.

Zone-level analysis

Three zones, i.e., Valdivia (39°S to 40°S and 73°W to 74°W), Osorno, (40°S to 41°S and 73.5°W to 74.5°W), and Llanquihue (41°S to 42°S and 73.5°W to 74.5°W) (Figure 3-1) were compared to assess the influence of landscape change on the nearshore system. I described regional chlorophyll-a patterns tested whether and identified whether upwelling or landscape change influenced chlorophyll-a values. First monthly images from 1998 to 2005 were analyzed for each zone (Valdivia, Osorno, Llanquihue) using the GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni) from NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC). In the zone-level analysis, I generated Hovmoller diagrams to explain the latitudinal and longitudinal variability of chlorophyll-a values. In the latitude-Hovmoller diagrams, I averaged the longitudinal chlorophyll-a values across one degree. In the longitude-Hovmoller diagrams, I averaged the latitudinal chlorophyll-a values across one degree.

For example, to generate the value for December of 1998 at 35S° latitude in the latitude-Hovmoller diagram, I averaged the chlorophyll-a values (9 x 9 km² resolution) across all 35S° pixels from 74W° to 73W° longitude to generate an average one-degree value for 35S°.

To determine if upwelling explained high chlorophyll-a patterns, I compared latitude-Hovmoller diagrams of chlorophyll-a values with latitude-Hovmoller diagrams of MODIS generated sea-surface temperature (SST) values for each month from July 2002 to December 2005. Regional SST values generally range between 12°C to 14°C, whereas cold, upwelling water ranges from 9°C to 10°C (Moreno et al. 1998). If low-temperature values were found in the same areas with high chlorophyll-a values, then upwelling is a likely explanation for the chlorophyll-a patterns. Alternatively, low temperatures are not found with high chlorophyll-a values then landscape change probably contributes to the high chlorophyll-a values. I ran a test of independence between the presence or absence of unusually low SST and 24 high chlorophyll-a patches (>10 mg/m³) to determine if high chlorophyll-a values and low SST temperatures (9°C to 10°C) were dependent on each other. The effects of upwelling related to satellite images is immediate (i.e. cold temperatures immediately correspond to increase in chlorophyll-a values) so I did not quantitatively examine for lag time. I did, however, visually inspect temperature values two months before and after the increase in chlorophyll-a and no cold temperatures were observed.

I also calculated the chlorophyll-a value for each zone by averaging the chlorophyll-a values in 30 pixels (9 by 9 km² each) along the shore and then extending westward across one degree latitude for each zone. I compared mean values for all

months (January to December), summer months (November to February) and winter months (April to July) from 1998 to 2005. I used an ANOVA followed by a Tukey-Kramer Multiple Comparison test to determine if mean chlorophyll-a values for each zone (Valdivia, Osorno, and Llanquihue) were statistically different and to identify which specific zones were distinct. I also conducted an ANOVA with a randomized-block design using year as a block to account for the yearly variation in chlorophyll-a values.

Watershed-level analysis

For the watershed-level analysis, I compared landscape change data in 13 watersheds with chlorophyll-a concentration values at the 9 km pixel closest to the point where the river discharges into the coastal ocean (Figure 3-1). I averaged the SeaWiFS chlorophyll-a data from April, May, June, and July (1998-2005) because these months did not have any reports of upwelling events (Moreno et al. 1998).

Landscape-change data was obtained from an October 5, 1985 Landsat TM and a November 29, 2001 Landsat ETM scene (WRS II path 233, row 87-89). I used the Maximum Likelihood supervised classification method to create nine classes (1) native forest, (2) plantation, (3) *matorral*, (4) agriculture, (5) cleared land, (6) urban, (7) wetland, (8) water, and (9) snow classes (ITT 2008) (Figure 3-2; See Chapter 2 for details). For the analysis with the chlorophyll-a data, I used the 1985 and 2001 land-cover values as well as area and percent change in plantation, native forest, agriculture, cleared land, urban, and *matorral* (i.e. shrubby bushes and small trees).

I then correlated the chlorophyll-a average and landscape change data with a Bonferroni correction to account for statistically significant correlations by chance. Next I ran a regression analysis to see if landscape variables explained the variance in average chlorophyll-a values from 1998 to 2005. I selected three independent variables (percent

plantation change, area plantation change, and percent urban change) based on a scree plot of mean square error and a test of multicollinearity. Watershed 2 was excluded from the analysis because it was an outlier; the high chlorophyll-a values were influenced by the Valdivia watershed (watershed 3). Watershed 2 rivers are small streams that have little input into the nearshore so watershed 3 values were related to chlorophyll-a values near watershed 2; also watershed 2 doesn't have extensive landscape change.

Isotopic Analysis of *Loco* Shellfish

To investigate whether landscape activities are correlated with isotopic signatures of the carnivorous *loco* shellfish, I sampled six *locos* at four fisheries management areas that were influenced by native forest, plantation, and mixed land-cover classes from July to August during the 2003 loco-harvest season in Chile (Figure 3-1). *Locos* were dried, homogenized, and tissue (excluding viscera) was ground at the Mulsow Laboratory at Universidad Austral de Chile. At the University of Florida, the dried samples were loaded into a Micromass VG602 mass spectrometer for analysis of stable carbon and nitrogen isotope ratios. The results were then corrected and expressed in standard delta notation (PDB was the reference standard for carbon and nitrogen in air was the standard for nitrogen) (Fry 1988). I then used a scatterplot to examine the isotopic signatures.

RESULTS

General Chlorophyll-a Trends

Low chlorophyll-a values were found from approximately April through August across all sites and chlorophyll-a values decreased with distance offshore. High chlorophyll-a values occurred from November to March and were located close to shore. Seasonal temperature shifts played a role in seasonal-chlorophyll-a values. Lower SSTs (9.6°C to 12°C) and lower chlorophyll-a values (generally <2.5 mg/m³) were measured

from July to September; higher temperature values (12°C to 16°C) and higher chlorophyll-a values (generally $>2.5 \text{ mg/m}^3$) were recorded from January to April.

Upwelling or Landscape Change?

None of the $>10 \text{ mg/m}^3$ patches of chlorophyll-a from the latitude-Hovmoller diagrams showed evidence of upwelling temperatures. For example, from February to March in 2003, the latitude-Hovmoller diagram (Figure 3-3) shows a large $>10 \text{ mg/m}^3$ patch of chlorophyll-a that spans from 39.40°S to 39.75°S. The corresponding latitude-Hovmoller diagram for SST showed no upwelling range temperatures (9°C to 10°C) at the same location during the same time. The test of independence shows that high chlorophyll-a patches ($>10 \text{ mg/m}^3$) were independent and not related to low-temperature (9°C to 10°C) events ($p= 0.537$) providing no evidence to support that upwelling temperatures are related to chlorophyll-a and suggesting that landscape change could play a role in high chlorophyll-a values.

Zone-Scale

Consistent differences in chlorophyll-a were observed among the three zones (Table 3-1, Figure 3-4, Figure 3-5, and Figure 3-6). The chlorophyll-a values derived from the SeaWiFS satellite images (area averaged) showed distinct patterns across zones from 1998 to 2005. Most notably the Valdivian zone had relatively high chlorophyll-a values that ranged from 1 to 11.5 mg/m^3 , in comparison, the Osorno zone ranged from 0.7 to 6.6 mg/m^3 , and the Llanquihue zone, ranged from 0.7 to 9.2 mg/m^3 (Figure 3-4). In the latitude and longitude-averaged data, the Valdivian zone also had the most months with values above 10 mg/m^3 when compared with the Osorno zone, which had the lowest chlorophyll-a values, and the Llanquihue zone, which had median values (Table 3-1). The average span of high chlorophyll-a values was the largest latitudinally and

longitudinally in the Valdivia zone, while the latitudinal and longitudinal coverage of low chlorophyll-a values was the smallest in the Valdivia zone (Table 3-1; Figure 3-5).

Osorno had the opposite trend and the Llanquihue zone had intermediate values.

The area influenced by plantations was concentrated between 39.3°S to 39.8°S, with the highest chlorophyll-a values located between 39.4°S to 39.6°S in the Valdivia zone. Mixed land-use influences were seen from 41.2°S until 41.7°S in the Llanquihue zone. The least influences were noted from 40.7°S to 40.9°S, which is related to the high amount of native-forest land cover in the Osorno Zone.

The ANOVAs and Tukey-Kramer's multiple comparisons confirmed that chlorophyll-a means were significantly different among zones (Figure 3-6). The Valdivian zone always had significantly higher chlorophyll-a values than Llanquihue and Osorno. The most striking difference was between the Osorno and Valdivian zones in the summer months. The Valdivian zone had about twice the amount of chlorophyll-a in the summer (5.2 compared to 2.2 mg/m³). Chlorophyll-a in Llanquihue was statistically higher than Osorno in the summer and year-round analysis, but no statistical difference was detected between these two zones in the winter months. The same pattern was found even with yearly temperature fluctuations; similar patterns were shown when using year as a block in a randomized block design; across all years, the Valdivian zone had the highest chlorophyll-a followed by Llanquihue, and then Osorno.

Watershed-Scale Findings

Chlorophyll-a values at the discharge point of the 13 watersheds were positively related to area (km²) of watershed covered in plantation in 1985 ($r=0.726$, $p=0.007$), area (km²) of watershed converted to plantation from 1985 to 2001 ($r=0.743$, $p=0.005$), percent of watershed converted to plantation from 1985 to 2001 ($r=0.744$, $p=0.006$), area

(km²) of watershed converted to native forest from 1985 to 2001 ($r=-0.841$, $p=0.001$), and percent of watershed in urban land use in 1985 ($r=0.706$, $p=0.010$).

The regression analysis showed that the area of plantation converted from 1985 to 2001 explained 55% of the variance in chlorophyll-a values at the discharge point across sites; percent of plantation converted from 1985 to 2001 explained an additional 17% of the variance, and percent urban areas explained an additional 7% (Table 3-2).

The area of the watershed converted to forest plantations from 1985 to 2001 explained the high chlorophyll-a values for Lingue (1) and Valdivia (3) watersheds (Figure 3-7). The Bonifacio (2) watershed, although classified as a mixed watershed (Chapter 2), did not have extensive plantations, but did have high chlorophyll-a values that resulted from the influence of the Valdivia watershed on the area. Interestingly, Bueno (5), which had substantial plantations, is similar to the native-forest watersheds possibly because the Bueno watershed is so large and has extensive native-forest coverage in the Andes Mountains that the influence of plantations could be mitigated. The native-forest watersheds, Quilhue (6), Hueyelhue (8), Cholguaco (9) and San Luis (10), which all have few or no plantations, all exhibited the lowest chlorophyll-a values; however, Chaihuin (4) was more similar to the mixed watersheds, perhaps because the Valdivia watershed can influence parts of the Chaihuin watershed also because Chaihuin has some plantations in the watershed. The relationship between the area (km²) of native-forest converted and chlorophyll-a show the opposite trend with more native forest cover associated with lower chlorophyll-a values (Figure 3-8).

Isotopic Signatures of *Loco* Shellfish

The raw $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values in the *loco* shellfish were enriched (+2-3‰) in plantation-influenced sites when compared with native forest and mixed landscape

influenced sites (Figure 3-9). Nitrogen likely originated from terrestrial sources; however, carbon exhibited a more characteristic marine signature. The enriched $\delta^{15}\text{N}$ values in the plantation-influenced area and depleted $\delta^{15}\text{N}$ values in areas near native forest, suggest that nutrients from forest plantations are a likely explanation for the relatively high phytoplankton biomass (as determined from chlorophyll-a) observed with the SeaWiFs satellite images.

DISCUSSION

Nutrient dynamics in watersheds with forest-plantations are driven by anthropogenic nitrogen inputs and the associated nearshore coastal waters show elevated chlorophyll-a values. The chlorophyll-a patterns are consistent with Hebbeln's (2000) findings that suggest upwelling is not the main driver of phytoplankton production in the region. The small-upwelling areas identified by Moreno et al. (1998) in the summer months could provide additional nutrients to the system, but these small upwelling events do not explain the zonal differences in chlorophyll-a patterns. Instead zonal differences are related to upland-land use. Although Hebbeln (2000) mentioned that the Antarctic Circumpolar Current could influence the system, I find more evidence that the Humboldt Current brings nutrients north from the watershed outlet of the Valdivian river to the coastal region near the Bonifacio watershed. My findings also agree with Thiel et al. (2007) whom explain that in this region the Humboldt Current influences nearshore physical dynamics yet the current is not responsible for major upwelling events.

The increase in forest plantations in the past 15 years both in area and percentage is the most important change that is influencing chlorophyll-a patterns. Urban-area increase was also influential, but explained a much smaller portion of the variance in chlorophyll-a patterns. The Valdivia and Lingue watersheds may provide some insights into the

percentage of land-area converted required to affect chlorophyll-a values. Using 2001 values, the Valdivia watershed had 1,425 km² of plantations, covering almost 14% of this large 10,263 km² watershed. Lingue had 182 km² of plantations, covering 35% of the 527 km² watershed. Both areas had elevated chlorophyll-a values.

The stable-isotope analysis and increases in the chlorophyll-a values show that nitrogen delivery in the rivers influences the nearshore environment. The stable-isotope findings confirm that nitrogen fertilizer that is used on plantations (Guerra et al. 2007) enters the rivers (Oyarzun et al. 2008; Little 2008) and enters the marine food web. Terrestrial nitrogen is an important source of nitrogen in the system since terrestrial nitrogen can be slightly enriched (McKinney et al. 2001; Freyer & Aly 1974; Kreitler et al. 1978). Marine nitrogen or atmospheric nitrogen did not explain the differences in isotopic signatures between native forest and plantation-influenced watersheds because the nitrogen values would have been depleted (Peterson & Fry 1987).

Terrestrial or marine carbon is not an influential source of carbon in the water near plantation watersheds because the ¹³C values would have been depleted (Trumbore & Druffel 1995; Coleman & Fry 1991). Instead atmospheric carbon is probably an influential component of carbon in the system since the ¹³C values were enriched (Coleman & Fry 1991) compared to native forest and mixed influenced areas.

A similar pattern of enriched ¹⁵N and ¹³C values was found in Fry's (1999) study of clams where the highest chlorophyll-a values were related to enriched carbon and nitrogen isotopic values. Bade (2006) also showed a similar pattern; an increase in nitrogen and phosphorus was accompanied by an increase in chlorophyll-a values and an elevated the uptake of CO₂ in lakes. Schindler et al (1997) also showed that an increase of

atmospheric carbon deposition was accompanied by increased primary productivity in lakes.

A shift in the food web probably has not occurred for *locos* near plantation-influenced watersheds compared to *locos* in native forest or mixed watersheds because although the nitrogen enriches according to Fry and Sherr (1984) and Miragawa and Wada (1987), the carbon does not. The *loco* food-web length may be different in plantation and native-forest influenced sites, thereby causing higher $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values. As an organism consumes another organism at a higher trophic level, $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values are generally enriched (DeNiro & Epstein 1978; Wada et al. 1987; Dauby et al. 1998). Likewise, food-web studies have also shown that top carnivores with longer food chains have enriched ^{15}N and ^{13}C values (Cabana and Rasmussen 1994; Vander Zanden et al. 1999). If *locos* had a longer food web or consumed species at a higher trophic level, the *locos* probably consume a more diverse set of organisms. However, Moreno's (2001) rapid survey of benthic organisms shows the opposite affect; a lower diversity score (-0.2) was found in the forest-plantation influenced area and a high diversity score (2) was found in the region associated with the native forest, leaving landscape change as a more likely explanation of the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values.

Conclusions and future research

Forest plantations are an important factor in driving nutrient dynamics of the nearshore environment in southern Chile. The photosynthetic biomass patterns are related to upland land use; higher chlorophyll-a concentrations are found in waters that are influenced by forest plantations. Isotopic signatures of the *loco* shellfish confirm that terrestrial nitrogen is a main source of nutrients in the marine food web in areas influenced by forest plantations. Carbon is derived from the atmosphere in areas

influenced by plantations. The increase in photosynthetic organisms fix atmospherically derived carbon, and the distinct carbon signatures are shown in the tissue of the *loco* shellfish from plantation regions.

The changes in nutrient dynamics in plantation regions are associated with other changes in the nearshore fisheries. Fishers in the Valdivian region have reported that *loco* shellfish are smaller in the region associated with landscape change and scientists (Moreno personal communication) have noted an increase in parasites on *loco* shells in the past 15 years. Indeed I found that *loco* shellfish that originated from the region with plantation development are distinct and have more epibionts and boring organisms (Van Holt in prep c) and fishers get paid lower prices for these resources (Van Holt in prep d). In particular, the Chilean TURF management strategy could be in jeopardy if management areas do not yield the same quality and quantity of products because of landscape influences. Since fishers have no legal alternative areas to harvest their *loco* resources they face losing their fishing livelihood if the quality of the resources decreases substantially.

To confirm the influence of plantation forests, a future study could analyze the isotopic signatures of carbon and nitrogen from sediment cores nearshore waters adjacent to plantation areas and compare these to sediments obtained nearshore coastal waters. This analysis would also provide a richer understanding of how nutrient dynamics may have shifted through time, something that is difficult to determine with satellite images because consistent datasets are lacking prior to 1998. Also, a more complete understanding of the isotopic changes in the food web could be undertaken by measuring additional components of the food webs in native forest and plantation-influenced region.

Forest plantations located in coastal areas could influence nutrient dynamics in other systems as well where upwelling is not the main source of marine nutrients. We need to improve our understanding of linkages in the nearshore between the terrestrial, atmosphere, and marine environments. Over half of the world's population lives in coastal systems (Cohen et al. 1997) and extensive development occurs along the coast; the livelihoods of the world's 13.1 million artisanal fishers depend on the nearshore environment (FAO 2002). Meso-scale analyses of landscape change and related changes in the primary production characteristics are an important step toward understanding the nutrient dynamics in the nearshore. With an understanding of the nutrient processes, we can begin to understand the underlying mechanisms that link landscape change to fisheries success in the nearshore.

Table 3-1. Monthly chlorophyll-a (mg/m^3) characteristics—number of months with high and low chlorophyll-a values and latitudinal and longitudinal distance covered by high and low chlorophyll-a patches-- in the Valdivia, Osorno, and Llanquihue zones from 1998 to 2005. Area, longitude, and latitude Hovmoller diagrams were used to generate values.

Measure	Valdivia	Osorno	Llanquihue	Component that was Averaged
No. of months above $5 \text{ mg}/\text{m}^3$	23	5	14	Area
No. of months above $10 \text{ mg}/\text{m}^3$	23	3	15	Longitude
Mean latitudinal distance of values above $10 \text{ mg}/\text{m}^3$	0.20°	0.08°	0.11°	Longitude
Maximum latitudinal distance of values above $10 \text{ mg}/\text{m}^3$	0.7°	0.1°	0.3°	Longitude
No. of months below $0.6 \text{ mg}/\text{m}^3$	2	24	20	Longitude
Mean latitudinal distance of values below $0.6 \text{ mg}/\text{m}^3$	0.10°	0.30°	0.28°	Longitude
Mean latitudinal distance of values below $0.6 \text{ mg}/\text{m}^3$	1°	1.0°	0.8°	Longitude
No. of months above $10 \text{ mg}/\text{m}^3$	26	10	23	Latitude
Mean longitudinal distance of values above $10 \text{ mg}/\text{m}^3$	0.25°	0.21°	0.22°	Latitude
Mean longitudinal distance of values above $10 \text{ mg}/\text{m}^3$	0.4°	0.3°	0.3°	Latitude
No. of months below $0.6 \text{ mg}/\text{m}^3$	18	38	21	Latitude
Mean longitudinal distance of values below $0.6 \text{ mg}/\text{m}^3$	0.19°	0.29°	0.24°	Latitude
Mean longitudinal distance of values below $0.6 \text{ mg}/\text{m}^3$	0.3°	0.8°	0.5°	Latitude

Table 3-2. The best regression models for 1, 2, and 3 independent variables. The best model was determined by R^2 , Adjusted R^2 , $C(p)$, AIC, and BIC values. The percent variation explained by each factor was calculated by comparing R^2 values of the best models. Where PL_CH = area (km²) of the watershed converted to forest plantations from 1985 to 2001; PPL_CH = percent of the watershed converted to forest plantations from 1985 to 2001; PURB_CH = percent of the watershed converted to an urban land use from 1985 to 2001.

Variables	R^2	Adj. R^2	$C(p)$	AIC	BIC	Variables in Model
1	0.55	0.50	9.50	-25.76	-25.21	PL_CH
2	0.73	0.66	4.78	-29.57	-26.92	PPL_CH PL_CH
3	0.80	0.72	4.00	-31.15	-25.65	PPL_CH PL_CH PURB_CH

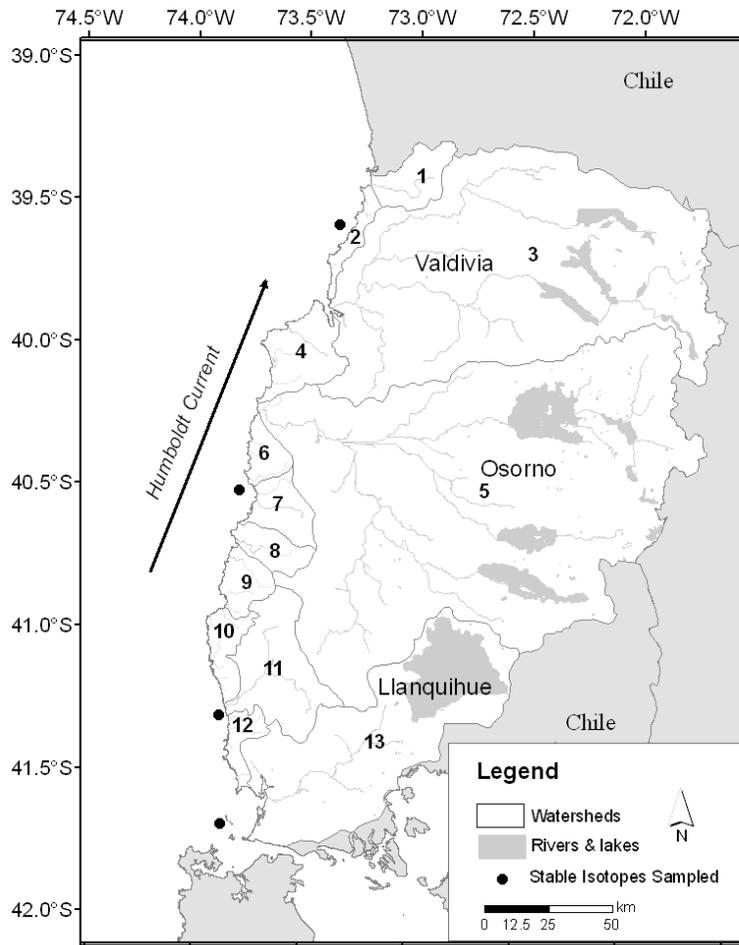


Figure 3-1. Study region in southern Chile showing zonal, watershed, and stable isotope analysis scales. In the zone-scale analysis, chlorophyll-a values were analyzed in the Valdivia (39°S to 40°S and 73°W to 74°W), Osorno, (40°S to 41°S and 73.5°W to 74.5°W), and Llanquihue (41°S to 42°S and 73.5°W to 74.5°W) areas. The names of the zones correspond to the provinces (noted on the map). In the watershed analysis, the chlorophyll-a values were obtained where the rivers in the corresponding watersheds discharge into the sea. If more than one river discharged to the sea, the main river was selected. Samples for stable isotope analysis was collected at four sites (noted by black circle). In the map the Lingue watershed is represented by (1), Bonifacio (2), Valdivia (3), Chaihuín (4), Bueno (5), Quilhue (6), Contaco (7), Hueyelhue (8), Cholguaco (9) San Luis (10), Llico (11), Putratrán (12) and Maullín (13). The names of the watersheds are derived from the main river in the area or the name of the region.

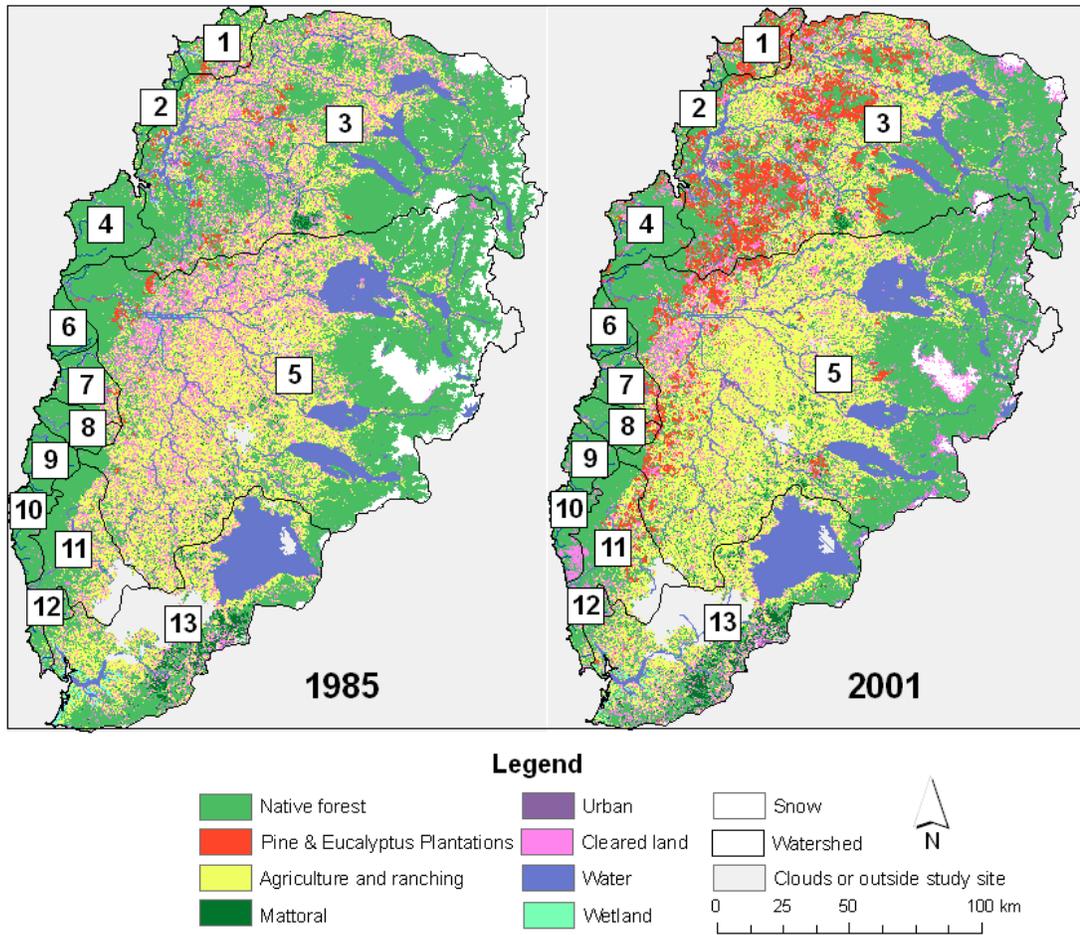


Figure 3-2. Supervised classification of October 5, 1985 (Landsat TM, path 233, rows 87-89) and November 29, 2001 (Landsat ETM, path 233, rows 87-89) images showing native forest, plantation, *matorral*, agriculture, cleared land, sand, water, urban, snow, and wetland land cover/uses. Watersheds are numbered as in Figure 3-1.

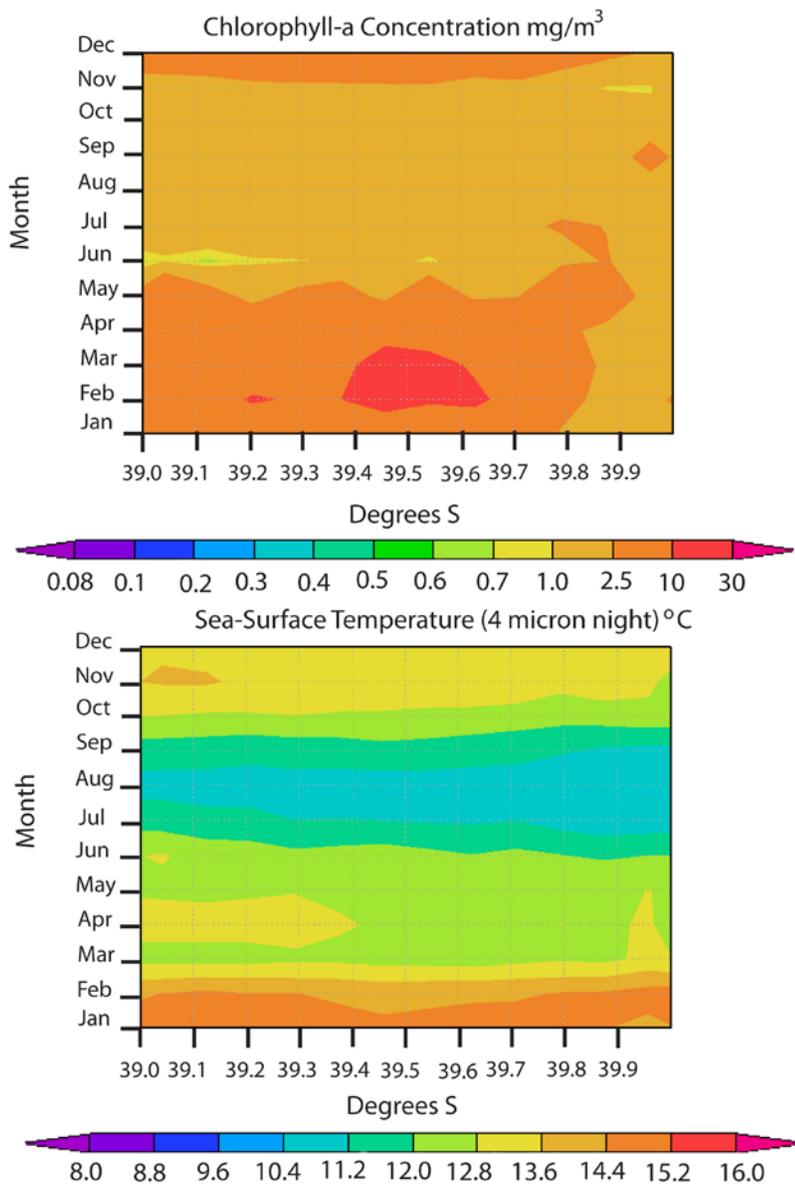


Figure 3-3. Latitudinal chlorophyll-a (mg/m^3) values (longitude averaged) derived from SeaWiFS satellite and sea-surface temperatures from MODIS in the Valdivia zone in 2003. Regions with high chlorophyll-a values are not related to low (from 9°C to 10°C) and therefore upwelling probably does not play a role in chlorophyll-a patterns in the area.

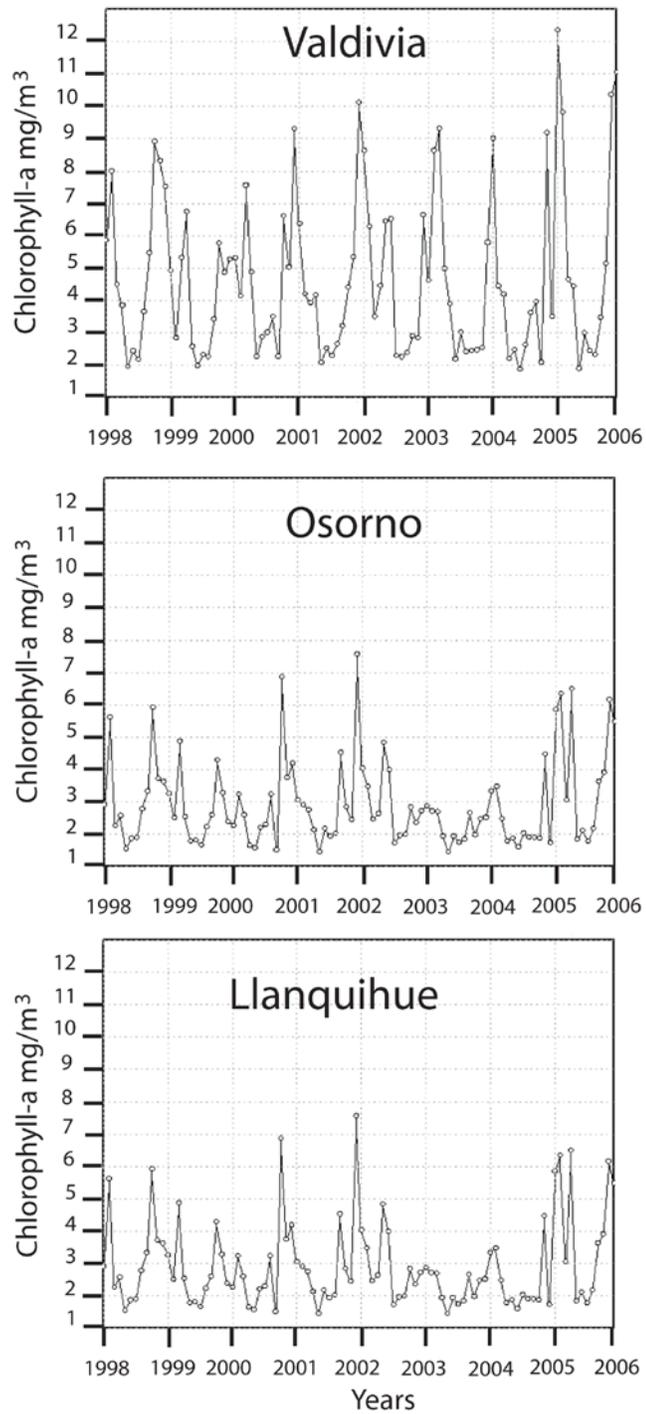


Figure 3-4. Monthly SeaWiFS chlorophyll-a averages from 1998 to 2005 for the Valdivia, Osorno, and Llanquihue zones.

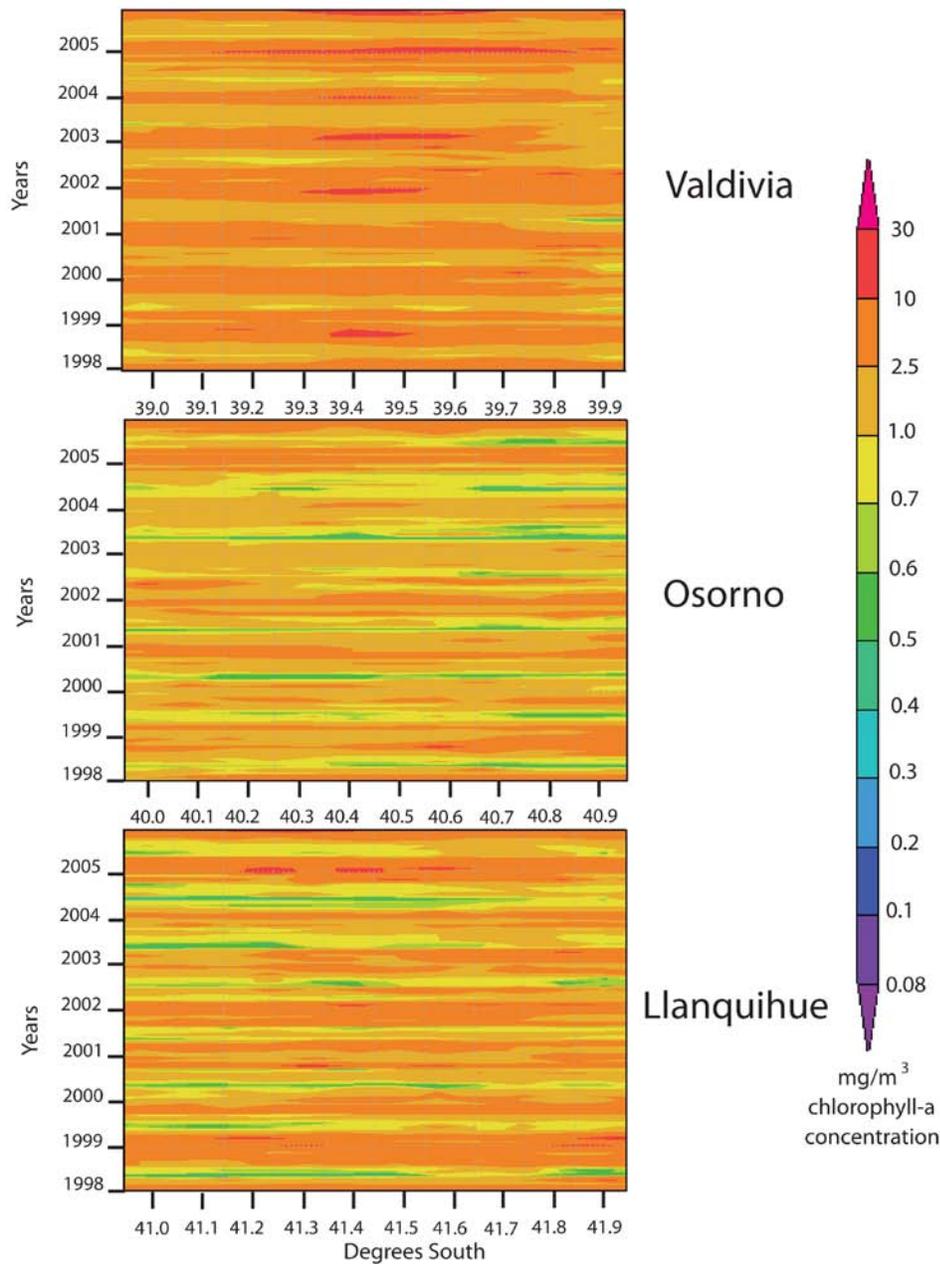


Figure 3-5. Chlorophyll a concentration (mg/m^3) Hovmoller diagrams for the Valdivia, Osorno, and Llanquihue zones. These diagrams are based on monthly SeaWiFS satellite images and describe monthly chlorophyll-a patterns from 1998 to 2005. Images were generated using NASA’s Giovanni online software. The Valdivia zone has more frequent, high chlorophyll-a patterns that extend across more degrees latitude, the Osorno zone has more frequent, low chlorophyll-a patterns and no high chlorophyll-a patterns. The Llanquihue zone has a mixture of high and low chlorophyll-a patterns.

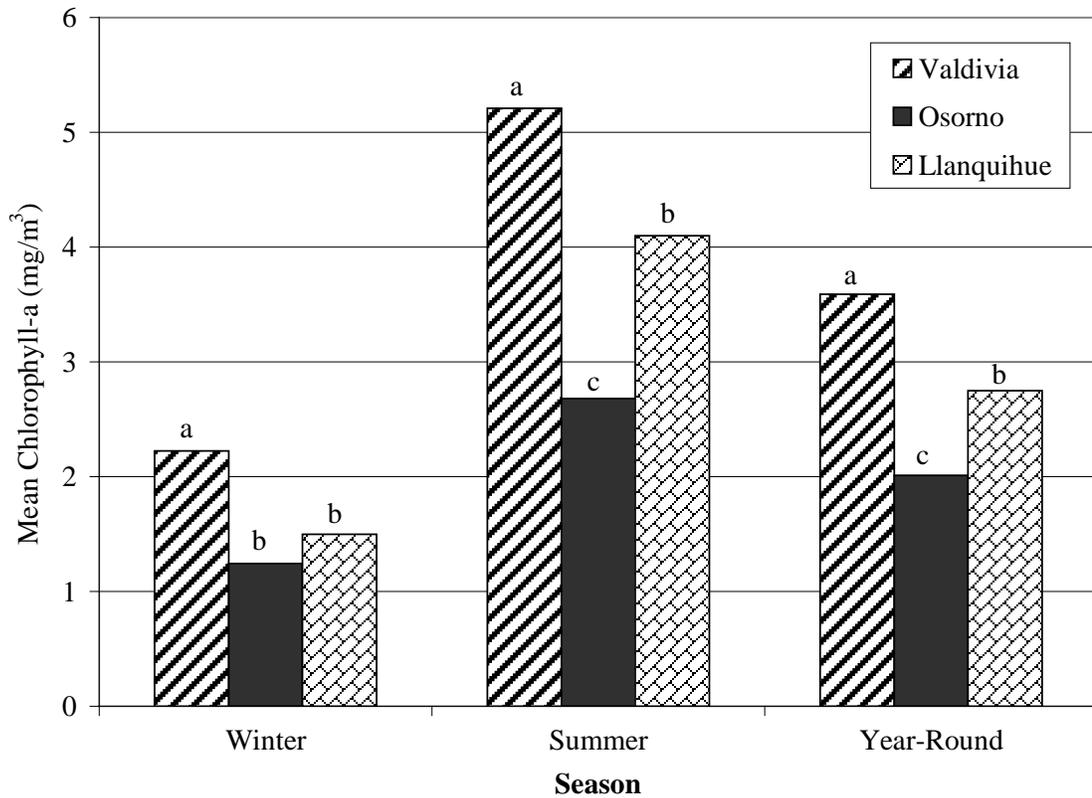


Figure 3-6. Mean chlorophyll-a values (mg/m^3) as determined by the SeaWiFS satellite images from 1998-2005 in the winter (April to July), summer (November to February), and year-round, in the Valdivia (39° to 40°), Osorno (40° to 41°), and Llanquihue (41° to 42°) zones. ANOVAs were highly significant for all analyses ($p\text{-value} < 0.01$). Lower case letters over the bars signify significant differences of mean chlorophyll-a values as indicated by Tukey-Kramer's multiple comparison tests ($\alpha = 0.05$). All significant comparisons were highly significant ($p\text{-value} < 0.005$) except for the Valdivia-Llanquihue in the winter ($p\text{-value} = 0.024$).

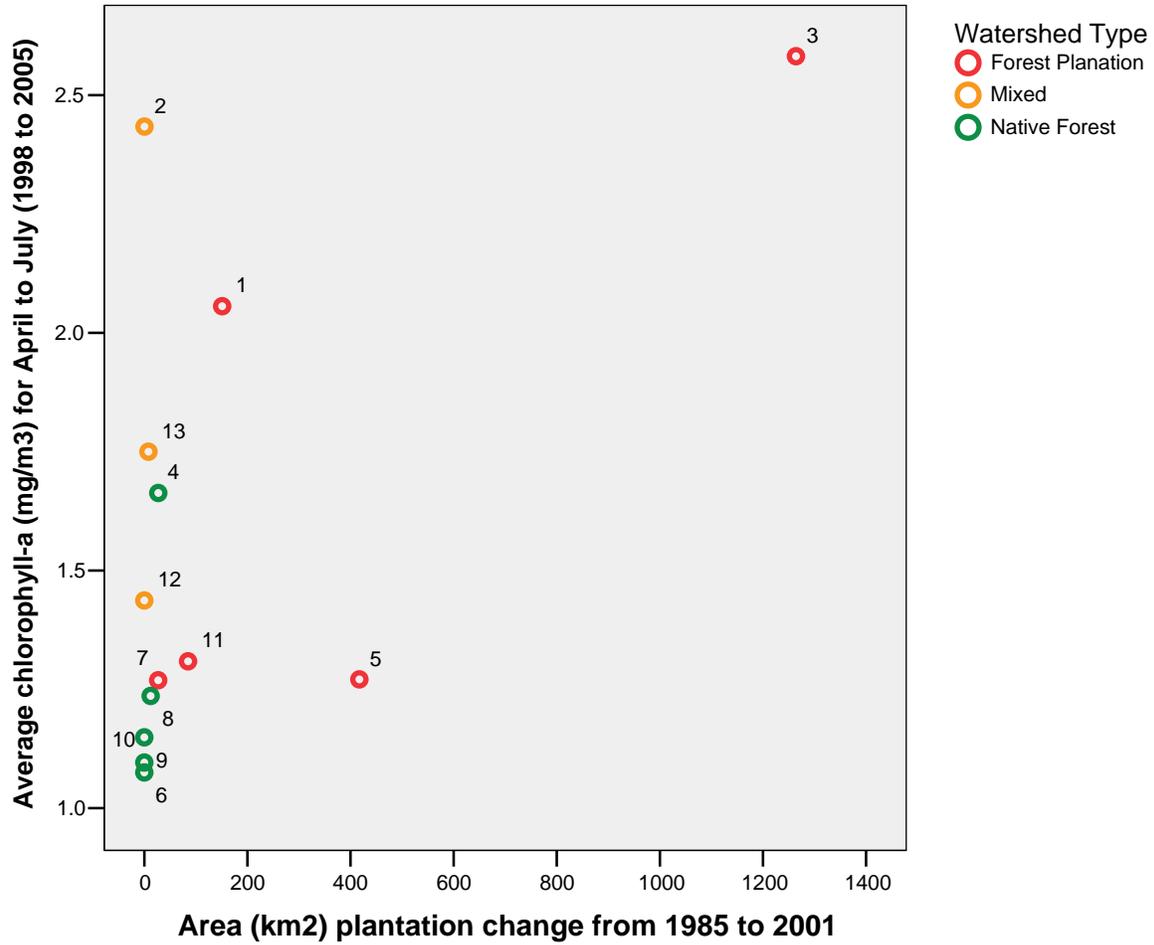


Figure 3-7. Scatter plot of mean chlorophyll-a values at the watershed outlet (an average of one pixel for 8 years) from April to July (1998-2005) based on the SeaWiFS satellite images and area (km²) converted to plantation in each watershed (identified by numbers 1-13; see figure 3-1) from 1985 and 2001.

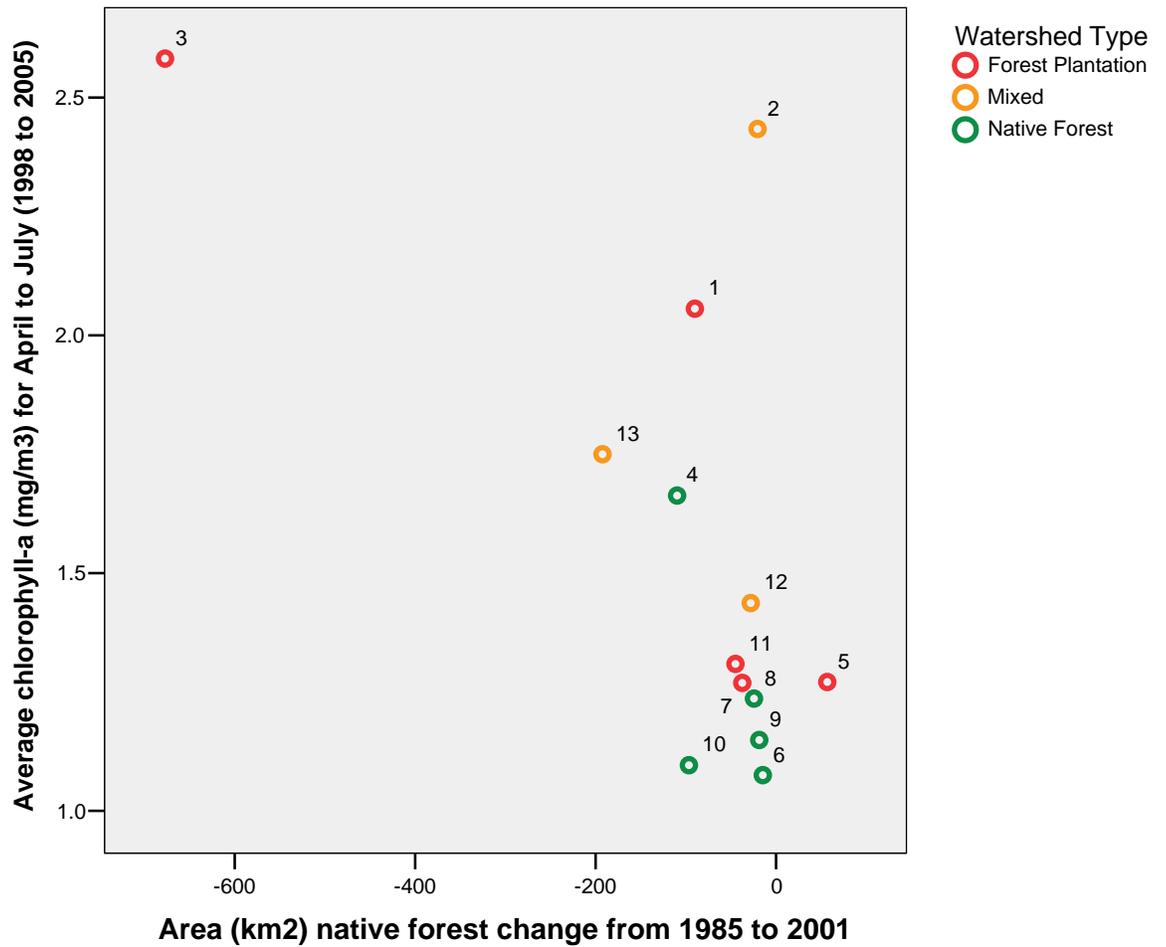


Figure 3-8. Scatter plot of mean SeaWiFS chlorophyll-a values at the watershed outlet from April to July (1998-2005) based on SeaWiFS satellite images and area (km²) change native-forest land cover in each watershed (identified by numbers 1-13) from 1985-2001.

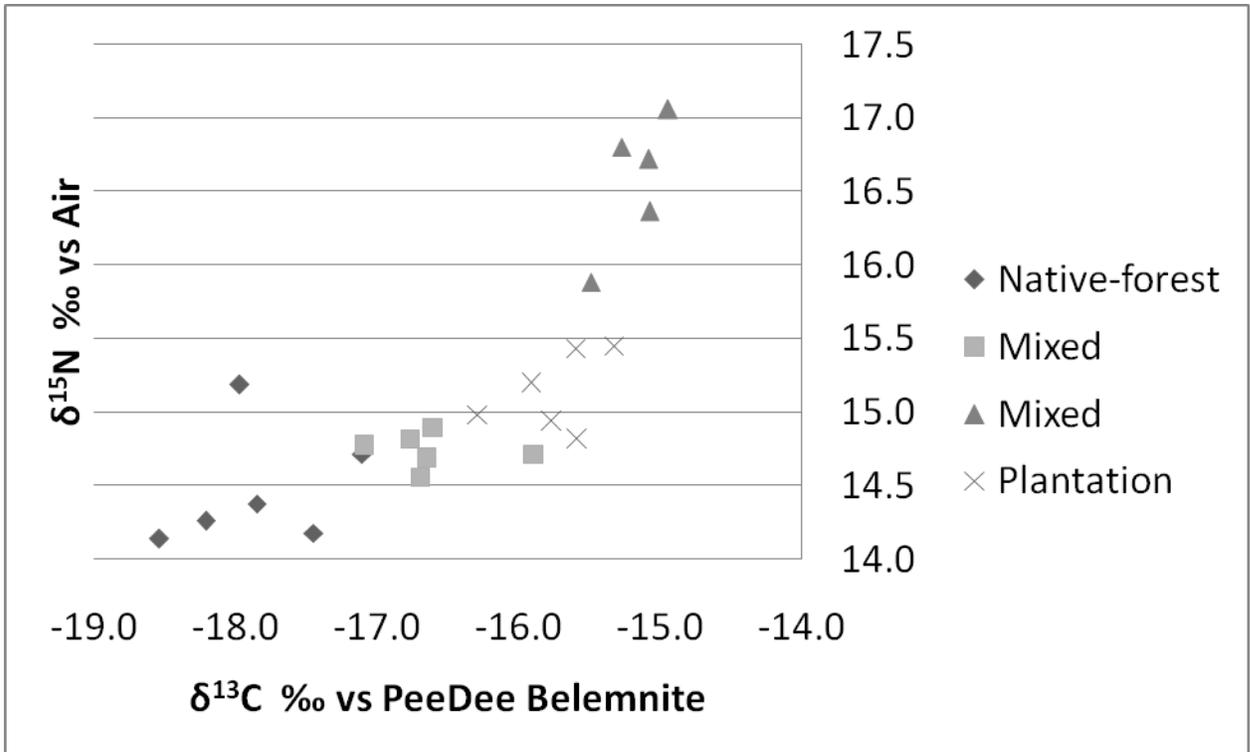


Figure 3-9. $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values for *loco* meat for native forest, mixed, and plantation-influenced regions. See Figure 3-1 for location of sites.

CHAPTER 4
MESO-SCALE ANALYSIS OF THE INFLUENCES OF LANDSCAPE CHANGE ON *LOCO*
(*CONCHOLEPAS CONCHOLEPAS*) HEALTH CONDITION CHARACTERISTICS

Introduction

Fishery managers are concerned about shellfish-health condition. Of particular concern is the influence of epibionts and shell-boring parasites on shellfish health because these organisms can cause extensive financial losses in aquaculture (Grabowski et al. 2007). Less information is known about the distribution and causes of epibiont and shell-boring parasites and their influence on other health-related characteristics in nature. Epibiont and shell-boring parasites abundance has been attributed to eutrophication of the nearshore environment (Gabaev et al 2005; Belan 2003; Chang et al. 1992; Beukema 1991; Llanos 1992; Crema et al. 1991; Losovskaya 1988; Risk et al. 1995; and Perus and Bonsdorff 2004), which is related to human activities on the landscape, as well host species characteristics (Wahl 1989). Over half of the world's population lives in coastal systems (Cohen et al. 1997) and extensive development occurs along the coast; the livelihoods of the world's 13.1 million artisanal fishers depend on the nearshore environment (FAO 2002). Modeling the relationship between shellfish-health condition, landscape change, and related changes in the nearshore nutrient dynamics at the meso-scale provides a new perspective on the distribution, causes, and management of epibionts and shell-boring organisms. In addition, today many fisheries are becoming closed-access to help reduce overharvest of marine resources (Defeo & Castilla 2005). If epibionts, shell-boring parasites, and associated health problems are related to landscape change, fishers working in management areas that are close to landscape change are at a disadvantage. The management systems that have been established to help fishers sustainably harvest resources may be in jeopardy if resource quality declines and fishers lose money.

This study examines if the health condition of *locos* (*Concholepas concholepas*) in southern Chile is affected by upland land-cover change, specifically forest-plantation development, and the associated changes in phytoplankton biomass in the nearshore. Landscape change can alter nearshore systems (Foley et al. 2005). When people fertilize the soil, clear the land, or change the species that dominate the ecosystem, nutrient and sediment loading increases in the watersheds and rivers and hydrology patterns of the rivers change (Nixon 1995; Farley et al. 2005; Iroume et al. 2006; Binkley & Resh 1999; Stevens et al. 1994; Farelly & Kelly 2005; Oyarzun et al. 2007). The nearshore system usually responds to the changing nutrient dynamics, sediments, and hydrological patterns by becoming more eutrophic. Eutrophic systems are enriched with nutrients and may also have more turbidity and decreased oxygen levels (Smith et al. 1999; Kemp et al. 2005). Scientists have documented changes in the community structure and food webs of organisms in eutrophic systems (Dougherty & Morgan 1991; Bini et al. 1999; Eyre 2000; Grigalunas et al. 2001; Kiirikki et al. 2001; Ludsin et al. 2001; Anderson et al. 2002; Diaz and Rosenberg 1995; Kemp et al. 2005). Eutrophication also compromises health of organisms in these environments (Johnson et al. 2007) and an abundance of generalist parasites can be found in eutrophied systems (Zander & Reimer 2002). The compromised health of organisms can lead to decreased growth (McDiarmid et al. 2004), which influences the food web structure and function (Marcogliese 2005).

Locos are economically the most important shellfish for artisanal fishers in Chile. The environmental changes in the region are especially relevant to the 23,000 artisanal fishers (over a third of Chile's artisanal fishers) in the northern portion of region X (Figure 4-1) who fish predominantly in designated management areas along the coast (SERNAP 2003). *Locos* are the top-carnivores in the benthic food web and consume tunicates, barnacles, and mussels as their

main prey source (Stotz et al. 2003). To determine if *loco* health condition is affected by landscape change and associated changes in the nearshore system, I measured *loco* health condition—the percentage of epibiont and shell-boring organisms on *loco* shells, lipid content in the *loco* muscle tissue, and weight of the *loco* muscle tissue-- and related these characteristics to landscape change patterns and addressed the following questions:

- Do *locos* located in management areas influenced by forest plantations have more epibionts and shell-boring organisms on their shells?
- Do *locos* located in management areas influenced by forest plantations have lower lipid content in their muscle tissue?
- Do *locos* located in management areas influenced by forest plantations weigh less than *locos* from other regions?

The landscape is rapidly changing in Chile, an important international trade partner on the global pulp market. In 2005, 8.8% of all national-export income came from forest plantations, which covered 2.1 million hectares or 13.4% of the total forest area (INFOR 2006). From 1985 to 2001 in southern Chile (administrative region X), forest plantations increased by 1,992 km² (Van Holt a in prep.). Signs of eutrophication are present in the nearshore environment (Van Holt b in prep.). The majority of plantations are north of the Rio Valdivia (Figure 4-1). Forest plantations are fertilized with nitrogen, phosphorus, potassium, and boron (Geldres & Schlatter 2004; Schlatter 1977; Guerra et al. 2007) to increase productivity and subsequently, increased nitrogen levels have been measured in Chilean the rivers of watersheds with forest plantations (Little et al. 2008; Oyarzun et al. 2007). Also, increases in forest plantations have lead to lower water levels in rivers because of increased evapotranspiration (Iroume et al. 2006).

Nutrients that enter the water cause an increase in nitrogen-limited primary producers in the nearshore system which, in turn, increases photosynthetic biomass. Chl-a values from 1998 to 2005 Sea-viewing Wide Field-of-view Sensor (SeaWiFS) measurements (an average of a one-degree by one degree summary) show that chlorophyll-a values are higher (2.06 mg/m^3) in the nearshore region near Valdivia, which has extensive forest plantations and lower (1.2 mg/m^3) in the Osorno region that has extensive native forest (Van Holt b in prep; Figure 4-1). Chlorophyll-a (CHLA) concentration values that are derived from the SeaWiFS satellite image are derived from an empirically based bio-optical algorithm (O'Reilly et al., 2000) that is performed on reflectance values, which are derived from calibrated digital counts that have been atmospherically corrected (Hu et al. 2009). Chlorophyll-a concentration is one of the best predictors of photosynthetic biomass available today (Huot et al. 2007), although there are other photosynthetic pigments and biomass that supports photosynthesis that are not related to chlorophyll-a. Samples of loco-shellfish muscle tissue from management areas near forest plantations have enriched $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (Van Holt b in prep). The enriched $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values indicate that terrestrial nitrogen is main source of nitrogen for the filter-feeding organisms that *locos* consume. The increase in nitrogen-limited phytoplankton is also related to an increase in atmospherically-derived carbon in the plantation region. The variation in the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values indicates that the nearshore waters of the Valdivian region are more eutrophic.

In 2003, 1,572 tons of *locos*, almost 20% of the country's entire catch, came from the Xth region; in 2003, fishers received up to US\$ 1 for each loco. The Territorial User Rights Fisheries (TURF) (Bernal 1999) management program was established after the 1990 *loco* fishery collapse. Fishers gained fishing rights to parcels of the ocean, called managed exploitation areas for benthic resources (MEABR), and the *loco* fisheries recovered. Consequently, fishers cannot

move to another management area if the environmental conditions degrade in their assigned region; therefore upland activities and the consequences to fisheries are of concern to the fishers.

In a pilot study, fishers reported and I noticed distinct differences between *locos* at various sites. *Locos* from the south are considered “good,” mainly because they are big and fishers are paid a premium price. Northern *locos* were considered “bad” and “skinny.” Indeed shells from the north had many epibionts and shell-boring organisms—some fishers reported that when they harvest a highly infected *loco* the shell cracks when they pull the *loco* from a rock rendering the meat useless for the market. In contrast, many shells in the south were clean with no shell-boring organisms or epibionts. Because there was a notable difference in *loco* quality, I analyzed the percent cover of epibionts and shell-boring organisms, which may represent a parasitic or commensal relationship, as a component of *loco* health condition. The shell-boring organisms include phoronids (*Phoronis* spp.), polychaetes (Class Polychaetea), most likely the native *Dodecaceria* cf. *opulens* (Moreno et al. 2006) and shell-boring bivalves (*Hiatella solida*). Barnacles (*Verruca laevigata* and *Jehlius cirratus*) were the main epibiont.

I expected that shells with many epibionts and shell-boring organisms were from coastal regions that were located near forest plantations and where the ocean is more eutrophic. Other studies have linked increased abundance of phoronids (Belan 2003; Chang et al. 1992), barnacles (Gabaev et al 2005) and bivalves (Risk et al. 1995) in compromised, eutrophic ecosystems that have high levels of chemicals, nutrients, and dissolved organic matter that originated from human disturbance of the landscape. Polychaetes are also abundant in eutrophic areas (Beukema 1991; Llanso 1992; Crema et al. 1991; Losovskaya 1988; and Perus and Bonsdorff 2004).

Methods

Study Site

The northern half of region X, an administrative region of Chile, contains three large watersheds with roughly one large watershed in each province. The watershed names are derived from the main river in the watershed: Valdivia (watershed # 3), Bueno (5), and Maullín (13), and ten small watersheds-- Lingue (1), Bonifacio (2), Chaihuín (4), Quilhue (6), Contaco (7), Hueyelhue (8), Cholguaco (9) San Luis (10), Llico (11) and Putratrán (12) (Figure 4-1).

High annual precipitation (2,000-4,000 mm) and a mean annual temperature of 12.5°C (Eldridge & Pacheco 1987) gave rise to the temperate rainforest ecosystem. There are three provinces in the region. The Valdivian province (Figure 4-1) has extensive forest plantations and agriculture. The Osorno province has extensive native forest cover, agriculture activities, and a less extensive, but increasing, number of plantations. The Llanquihue province has extensive agriculture and ranching, as well as *matorral* (new growth or shrubby forest) land cover and few plantations. Urban and commercial activities are not common in the area, with the exception of the Celulosa Arauco (CELCO) pulp mill, located in the northern part of the study site that began operating in late 2003.

In the nearshore rocky-intertidal ecosystem of Chile's central-coast region, uniform wind patterns, topography, and temperature give rise to similar invertebrate and fish communities (Moreno et al. 1979; Fernandez et al. 2000; Lancellotti & Vasquez 2000; Camus 2001). Terrestrial inputs are the main source of nutrients in the ecosystem (Hebbeln 2000; Van Holt b in prep). Small, coastal-upwelling events reportedly occur in the summer months (January to March) in the northern-Valdivia region (Moreno et al. 1998) but these events don't contribute to regional differences in photosynthetic biomass. The photosynthetic biomass characteristics follow three zones, which are related to upland-land use (Van Holt in prep b). The Valdivia zone

(39°S to 40°S and 73°W to 74°W), had relatively high chlorophyll-a values that ranged from 1 to 11.5 mg/m³, the Osorno zone (40°S to 41°S and 73.5°W to 74.5°W), had values ranging from 0.7 to 6.6 mg/m³, and the Llanquihue zone (41°S to 42°S and 73.5°W to 74.5°W) had values ranging from 0.7 to 9.2 mg/m³ (the ranges of the one-degree by one-degree blocks were created by averaging longitudinal data values from 1998 to 2005) (see Van Holt b for details). Also, chlorophyll-a values at the discharge point of the watershed were positively related to percent and area (km²) of the watershed converted to plantation from 1985 to 2001 (Van Holt b in prep). The geomorphology is also similar throughout the region--the continental shelf extends to approximately 6.54 km and to 200 m depth (Gallardo 1984). Fjords, which have complex geomorphology and therefore have distinct ecological processes, are located further south of the study site (Fernandez et al. 2000). The Humboldt Current is the main oceanographic system that influences the region (Lancelloti & Vasquez 2000; Fernandez et al. 2000) and typically flows north.

Sampling and Data Processing

Between June and August of 2003 (the *loco* harvest season) I sampled 30 *locos* from each of the 41 management area for a total of 1260 *locos* (Figure 4-1). To characterize the health of each shell, I counted the presence of epibionts and shell-boring bivalves. I generated a random sample of 25 points on the inner and outer shell surfaces. I identified and quantified phoronids (PPHOR), polychaetes (PPOLYC), shell-boring bivalves (PBIVAV), and barnacles (PBARN) on each shell. Next I measured the weight of the muscle (WGHMT) and the viscera (WGHV) with an Ohaus HH320 scale with a precision of 0.1g. The length (SHELGT), weight (WGHS), height (SHELHGT), of each shell was also measured. I also calculated the ratio of WGHV to SHELGT to create a fat index (FATIND); the purpose of this ratio was to characterize *locos* that were skinny (had a low weight) given their shell size, which was a concern for some fishers.

Finally, on a sub-sample of six *locos* from each site, I analyzed the lipid content (PLIP) of the muscle tissue using a modified Folch et al. (1957) method for the isolation and purification of total lipids from animal tissues. I then created distribution maps for the following variables: PPOLYC, PBIVAV, PPHOR, PBARN, PLIP, and WGHMT and used them in combination with the statistical analysis to describe regional *loco* health condition patterns.

Statistical Analysis

I ran a cluster analysis on *loco*-health and land-cover change characteristics. The cluster analyses used polythetic, non-overlapping, sequential agglomerative techniques. I first ran a hierarchical cluster analysis on the independent variables based on a correlation matrix to eliminate highly multicollinear variables (SAS 2001 v8.2). Then a non-hierarchical cluster analysis was used to generate the most stable, robust, cluster analysis, which was followed by a hierarchical cluster analysis that generated relationship trees (McGarigal et al. 2000). I tested four different fusion strategies (average linkage, single linkage, complete linkage and Ward's minimum variance linkage) and Ward's best matched the groupings of the non-hierarchical analysis. I used the average value for each of the 41 management areas for the following variables: WGHMT, SHELGT, SHELHGT, PLIP, PPHOR, PPOLYC, PBIVAV, and PBARN. For the LCLUC cluster analysis, 38 LCLUC variables that included 1985 and 2001 total area and percent area of each land cover as well as the area and percent change from 1985 to 2001 was used. I also included the chlorophyll-a values for each management area. I then ran a stepwise discriminant analysis on the groupings of management areas obtained from the cluster analysis of the health-related characteristics to understand which health-related variables helped to form the clusters (SAS 2001).

I ran a canonical correlation to see if *loco* health condition characteristics were highly correlated to a combination of LCLUC characteristics (SAS 2001). The squared canonical

correlation identified how well canonical variables correlated; the standardized canonical coefficients identified which *loco* and LCLUC variables contributed the most to each canonical dimension.

Results

Landscape-Level Patterns of Loco-Health Distribution

There is a clear relationship between a high percentage of phoronids on *loco* shells and forest-plantation cover (Figure 4-2; Figure 4-3). The *loco* shells that contained the greatest percentage cover of phoronids (35.1-45%) were located north of Rio Valdivia (Watershed 3). Just south of Rio Valdivia, *loco* shells also contained some phoronids, up to 5% of the shell was covered. *Locos* had little to no phoronids south of the Valdivian region. *Locos* in the Valdivian region (both north and south of Rio Valdivia) had a high percentages of polychaetes (7-14%); however, a high polychaete percentage was also measured near the outlet of Rio Maullin (watershed 13), as well as near Bahia Mansa (Watershed 7), and Bahia San Pedro (Watershed 10); so other factors influence polychaete distribution as well (Figure 4-2). The *locos* from the Valdivian region (both north and south of Rio Valdivia) have a higher percentage of barnacle epibionts compared to areas south (Figure 4-2). The percent bivalve cover is higher along the coast of more remote watersheds with high percentage of native forest such as Bahia San Pedro (Watershed 10) and Bahia Mansa (Watershed 7), and just south of the Valdivian river (Watershed 4).

Loco meat in the northern-Valdivia region weighed less than *locos* from most other management areas; interestingly *locos* from some other remote regions also had low weight (Figure 4-2). *Locos* from the Llanquihue region had the highest weight, which follows reports from fishers that *locos* in the south are fatter; fishers hypothesize that *locos* in the south have more food resources and indeed the south is famous for the *Austromegabalanus psittacus*

barnacles that are a favored food choice for *locos* (Stotz et al. 2003). These barnacles appear to be abundant as I observed fishers harvesting these barnacles and also the barnacles were sold in local restaurants; normally fishers don't harvest resources that *locos* consume at large-scales because the fishers want the *loco* food source to remain abundant. *Loco* meat further south of the northern Valdivia region had mid-range weights. Lipid content in *loco* meat did not follow any specific patterns; although *locos* in the south and in remote places such as Manquemapu and El Manzano had high lipid content in the *loco* meat, some management areas (Bonifacio A and Mississippi) in the northern Valdivia region also had *locos* with high lipid content (Figure 4-2).

***Loco* Health Condition Groups**

I identified four distinct groups of *locos* (Figure 4-4). As expected, management areas that were geographically close together were in the same groups. The *Northern Valdivia* group contained *locos* from management areas from north of Rio Valdivia. The *Valdivia* group includes *locos* from management areas in the Valdivia province (below and a few above Rio Valdivia), but also includes *locos* from a few management areas (Estaquilla B, Amortajado, and Cullinco) from the Osorno and Llanquihue regions. The *Osorno* group contains *locos* from the Osorno province, with the exception of Estaquilla and Guar Guar, which are from Llanquihue. Within the *Llanquihue* group three subgroups exist—two of which are the true Llanquihue group that has *locos* solely from Llanquihue and the first group in Figure 4-4 that has *locos* from all regions.

Percent phoronid infestation was the most influential variable that discriminated *loco* groups. Percent shell-boring bivalve cover was the next most important variable in discriminating groups followed by the height of the shell, weight of the *loco* meat, percent total barnacle cover, and percent polychaete cover (Tables 4-1 & 4-2). Shell length and percent-lipid content of the *loco* meat were not significant discriminators. *Northern Valdivia* has at least five times more phoronids than any other group. *Osorno* has the most shell-boring bivalves (3% total

cover). *Northern Valdivia* and *Valdivia*, have at least 1.5 times more barnacles than *Llanquihue* and *Osorno*. *Loco* meat from *Llanquihue* weighs the most, on average at least 23 grams heavier.

I excluded viscera weight, shell width, and fat index from the final cluster analysis model of *loco*-health characteristics because the variables were multicollinear with other variables. In the LCLUC cluster analysis, I included only percent agricultural change, percent cleared land change, percent urban change, percent change in matorral, area (km²) plantation change, percent plantation change, and chlorophyll-a in the management area because the other variables were multicollinear.

Relationships between *Loco* Health-Related Characteristics and LCLUC Variables.

The discriminant analysis of *loco* groups showed that percent change in plantations from 1985 to 2001 (PLCH) best explained the variation among groups, followed by the chlorophyll-a characteristics (CHLA) (Table 4-3). The plantation and chlorophyll-a patterns matched regional patterns—the Valdivia province had the highest nearshore chlorophyll-a and upland forest plantations and the Osorno province has the lowest amounts (Table 4-4).

The overall misclassification rate from the discriminant analysis is 37%, but misclassifications are unevenly distributed among groups (Table 4-5 and 4-6). *Osorno* and *Northern Valdivia*, which represent *loco* health condition and LCLUC extremes, have the lowest misclassification rate (12%). In contrast, *Valdivia* has 89% of the management areas misclassified and *Llanquihue* has a 35% misclassification rate. Cross-validation estimates of misclassification increased the estimate of the overall misclassification rate to 43% (Table 4-7).

The LOCO1 canonical correlation coefficient measures parasite presence because percent cover of phoronids and total barnacles have high weighting (Table 4-8). The LCLUC1 canonical coefficient represents eutrophication because the percentage of plantation change and chlorophyll-a levels are positive have a high weight on LCLUC1 (Table 4-9). A high canonical

correlation between LOCO1 (the parasite measure) and LCLUC1 (the eutrophication measure) shows that *locos* with more phoronids and barnacles are associated with management areas that have high chlorophyll-a values in the ocean, which stems from the nutrients input that flow from forest plantations to the nearshore environment. The squared canonical correlation for LOCO1 and LCLUC1 is 0.881 and a scatter plot of these factors demonstrates a linear and highly significant ($p < 0.0001$) relationship (Figure 4-5). All other canonical measures are more difficult to interpret because the correlations don't follow consistent patterns. *Loco* lipid content and *loco* weight were not important components of canonical correlates and therefore were not the driving factors that distinguished *loco* groups.

Discussion

The cluster analysis, discriminant analysis, and distribution maps show that *locos* in management areas north of Valdivia are distinctly less healthy than *locos* in other parts of the region. Northern-Valdivia shells contain a high percent cover of barnacle epibionts, shell-boring phoronids, and polychaetes, and they weigh less. The discriminant analysis demonstrates the link between high percent cover of phoronids and barnacles, upland plantations, and high chlorophyll-a concentrations in the nearshore. Previous research (Van Holt b in prep) indicates that the distinct nutrient dynamics in the Northern Valdivia region are related to upland land use. The positive relationship I found between eutrophic environments (high chlorophyll-a concentration) and presence of polychaetes, barnacles, and phoronids is demonstrated in many other studies worldwide (Belan 2003; Chang et al. 1992; Korpinen et al. 2007; Beukema 1991; Llanso 1992; Crema et al. 1991; Losovskaya 1988; and Perus and Bonsdorff 2004; Zander & Reimer 2002).

Percent cover of bivalves on *loco* shells does not relate directly to forest-plantations. Instead, *locos* that are larger in size and possibly older are infected with shell-boring bivalves.

Locos that have bivalves also have a lower fat index or are “*locos flacos*”—these *locos* have large shells but the meat weight is lower than expected given the shell length. *Locos flacos* occurred in some of the most remote sites.

The misclassified observations in the discriminant analysis help to identify management areas that were not typical given the land cover/use and chlorophyll-a characteristics. For example, Bonifacio A, was classified in the *Valdivia* group in the hierarchical cluster analysis using *loco* characteristics; however, if the *locos* were classified according to LCLUC characteristics, these *loco* would be classified with *Northern Valdivia*. Bonifacio A has better *locos* than one would expect for the LCLUC and is considered by local fishers to be one of the best sites in *northern Valdivia*, always producing abundant, good quality *locos*. Bonifacio A *locos* were probably classified in *Valdivia* because they have fewer phoronids than *locos* in Bonifacio B. The Bonifacio B site, which is managed by the same group of fishers, was not as productive. Perhaps small-scale upwelling as suggested by Moreno et al (1998) and Zamorano (pers. comm.) occurs in the Bonifacio A site and the upwelling diminishes the *locos* susceptibility to phoronids. Also local fishers and the scientist hired by the fishers (Zamorano pers. comm.) have reported that tunicates are abundant in Bonifacio A. Indeed *locos* from Bonifacio A have an unexpectedly high lipid content, which could be a result of more tunicates for the *locos* to consume. The abundant food source could help keep *locos* less susceptible to phoronids.

I hypothesize two possible mechanisms to explain the expansion of epibionts and shell-boring organisms on *locos* near plantation watersheds. Either the food web of the *locos* changed and *locos* became weaker and susceptible to infestation, or the epibionts and shell-boring organisms become more abundant because they have increased food resources or a hybrid of

both mechanisms are possible. Gabaev et al. (2005) link increases of diatoms to an increase in barnacles. Enriched $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values of the *loco* shellfish meat suggest that high chlorophyll-a values result from diatom blooms (Van Holt b). I hypothesize that an increase in diatoms could also foster epibiont barnacle growth. Also it is possible that there are fewer food resources in Northern Valdivia. Moreno (2001) identified a lower diversity of organisms in Northern Valdivia. Fewer food resources could influence the *loco*'s ability to combat epibionts by not allowing *loco* to produce antifouling agents. Although the ability for *locos* to produce antifouling agents is purely hypothetical, antifouling agents are produced by other species and it is energetically costly to do so (Wahl 1989). So hypothetically *locos* with less food produce less antifouling agents and this causes increased infestation of epibionts.

Percent phoronid cover is also correlated with percent polychaete cover, percent barnacle cover, and shell weight. Gallardo and Osorio (1978) hypothesized that shell-boring bivalves originally penetrate *loco* shells after barnacles are present and, although I found no evidence of this phenomenon with shell-boring bivalves (no significant correlation exists between bivalve presence and barnacle presence), a significant positive correlation does exist between barnacle cover and phoronid and polychaete cover (Table 4-10). Gallardo and Osorio (1978) do have a promising hypothesis, however, that the presence of some epibionts fosters growth of other epibionts and boring organisms. I hypothesize that barnacle presence could leave *locos* susceptible to shell-boring phoronids and polychaetes. Indeed Bers & Wahl (2004) show that substrate microtopography influences epibiont presence and Wahl (1989) explains that the presence of some epibionts is dependent on another epibiont.

Interestingly the length of *locos* does not correlate with presence of phoronids or polychaetes, but the width is related to phoronid presence (Table 4-10). *Locos* infested with

phoronids are narrower. *Loco* weight is negatively related to bivalves and not significantly related to phoronids or polychaetes.

Since the management system restricts fisher movement, fishers are limited in how they can adapt to the changes in shellfish quality. Fishers harvest in unsolicited areas outside of their management area, go further out to sea and harvest distinct species, or leave the fishery altogether. In the Mehuin region of Chile, an area that has poor quality *locos*, fishers are leaving the fishery because of the low-quality resources and a conflict with the Celco Arauco pulp mill. Fishers lose \$1 per kg for each 10% increase in parasites (phoronids and polychaetes) (Van Holt in prep d). Plantations will likely increase in southern Chile and it is possible that *locos* in other regions will also experience changes in the shellfish quality as a consequence of this landscape change. An integrated coastal management approach is necessary to mitigate the influence of epibionts and shell-boring organisms, particularly phoronids, barnacles, and polychaetes on the *loco* shellfish.

Conclusions

In conclusion, landscape change and the associated changes in chlorophyll-a values in the nearshore are the main factors that describe the distribution of phoronid borers and barnacle epibionts. Bivalve borers and lipid content are not linked to landscape change and chlorophyll-a values. Boring polychaetes are slightly linked to the abovementioned environmental changes, but other factors also contribute to polychaete distribution. This meso-scale study shows that epibionts and boring organisms are abundant in areas where the nitrogen dynamics in the nearshore shift because of plantations or other land-use activities. If climate change influences the nearshore nutrient dynamics we can expect that similar changes in shellfish parasites can occur. Other regions of Chile with extensive land use change likely also have high levels of phoronids and barnacles, and possibly polychaetes on *loco* shells. Additionally the presence of

one species barnacle, phoronid, or polychaete, may help another species colonize. In Chile and beyond, managers can monitor shellfish and use the epibiont and boring organism presence as indicators of environmental change over time. In Chile, the government could consider reducing the proposed cost associated with maintaining management areas that have high levels of parasites that affect a fisher's income. Fishers lose \$1 per kilo for each 10% increase of parasites on *loco* shellfish (Van Holt in prep d). We need to better understand how parasites influence resource quality. It is also important to better understand the relationship between harvest pressure and parasite abundance; it is difficult from the available data to tell whether harvest pressure or parasites or both factors reduce *loco* size. I hypothesize that harvest pressure accounts for only a small fraction of difference but an experimental study is needed to test this hypothesis. In Chile, the government may consider allowing fishers who have compromised management areas to solicit new management areas. Finally, this study demonstrates one reason why integrated coastal management is a necessary. Management systems in place have helped *loco* and other species recover but without addressing the relationship between landscape change, shifting nutrient dynamics in the nearshore, management areas, and shellfish parasites, the management system could be in jeopardy in Chile and in other managed fisheries in the nearshore.

Table 4-1. Mean and standard deviation (in parenthesis) values of *loco* characteristics of each group in the hierarchical cluster analysis for phoronids (PPHOR), shell boring bivalves (PBIVAV), polychaetes (PPOLYC), barnacles (PBARN), shell height (SHELLHT), *loco* meat weight (WGHMT), shell length (SHELLGT) and percent lipid in *loco* meat (PLIP).

GROUP	PPHOR (%)	PBIVAV (%)	PPOLYC (%)	PBARN (%)	SHELLHT (mm)	WGHMT (g)	SHELLGT (mm)	PLIP (%)
Llanquihue	0.25 (0.68)	0.64 (0.62)	4.42 (2.15)	27.34 (15.92)	53.18 (1.82)	121.4 (17.22)	112.21 (3.55)	7.11 (2.16)
Osorno	0.00 (0.00)	3.03 (0.90)	5.23 (2.13)	12.71 (5.98)	55.63 (2.17)	91.4 (10.97)	115.23 (3.75)	7.95 (2.70)
Valdivia	5.84 (9.61)	1.26 (0.49)	8.73 (3.47)	43.16 (16.74)	58.11 (2.38)	128.2 (14.70)	116.14 (1.60)	6.99 (2.18)
Northern Valdivia	29.36 (7.49)	0.60 (0.57)	7.55 (1.78)	43.75 (11.71)	56.66 (1.35)	104.6 (14.76)	110.83 (3.10)	6.00 (1.59)

Table 4-2. Partial r-square, significance levels, and average squared canonical correlations from the stepwise discriminant analysis of *loco* grouping using the *loco* characteristics, mean values for phoronids (PPHOR), shell boring bivalves (PBIVAV), polychaetes (PPOLYC), barnacles (PBARN), shell height (SHELLHT), *loco* meat weight (WGHMT), shell length (SHELLGT) and percent lipid in *loco* meat (PLIP). SHELLGT and PLIP were not statistically significant at $p < 0.05$.

Step	Variable	Partial R-Square	Pr>F	Average squared canonical correlation
1	PPHOR	0.8199	<0.0001	0.273
2	PBIVAV	0.6728	<0.0001	0.488
3	SHELLHT	0.5033	<0.0001	0.620
4	WGHMT	0.3200	0.0034	0.672
5	PBARN	0.2225	0.0339	0.703
6	PPOLYC	0.2085	0.0497	0.737

Table 4-3. Partial r-square, significance levels, and average squared canonical correlation of stepwise discriminant analysis of LCLUC characteristics using percent change in plantations from 1985 to 2001 (PPL_CH) and ocean color characteristics (CHLA) in a canonical discriminant analysis of the hierarchical cluster analysis.

Step	Variable	Partial R-Square	Pr>F	Average squared canonical correlation
1	PLCH	0.5917	<0.0001	0.197
2	CHLA	0.3370	0.0015	0.293

Table 4-4. Mean and standard deviation (in parenthesis) values of LCLUC characteristics, percent change in plantations from 1985 to 2001 (PPLCH) and ocean color characteristics (CHLA), for the corresponding upland watershed for each group in the hierarchical cluster analysis of *loco* characteristics.

Group	PPLCH (%)	CHLA (mg/m ³)
Llanquihue	2 (3)	1.73 (0.47)
Osorno	3 (3)	1.22 (0.12)
Valdivia	6 (5)	2.06 (0.53)
Northern Valdivia	16 (8)	2.45 (0.18)

Table 4-5. Number of observations, percent correctly classified (diagonal) and misclassified (off diagonal) estimates of hierarchical cluster analysis groups Llanquihue, Osorno, Valdivia, and Northern Valdivia using percent change in plantations from 1985 to 2001 (PLCH), percent native forest in 2001 (PFNF), and ocean color characteristics (CHLA) from canonical discriminant analysis.

Actual Group	Predicted Group				Total
	Llanquihue	Osorno	Valdivia	Northern Valdivia	
Llanquihue	11 65%	5 29%	0 0%	1 6%	17 100%
Osorno	1 13%	7 88%	0 0%	0 0%	8 100%
Valdivia	4 44%	2 22%	1 11%	2 22%	9 100%
Northern Valdivia	0 0%	0 0%	1 13%	7 88%	8 100%
Total	16 38%	14 33%	2 5%	10 24%	42 100%
Rate	0.35	0.13	0.89	0.13	0.37
Priors	0.25	0.25	0.25	0.25	

Table 4-6. Probability of group membership of mis-classified observations of the canonical discriminant analysis of hierarchical cluster analysis groups Llanquihue, Osorno, Valdivia, and Northern Valdivia using percent change in plantations from 1985 to 2001 (PLCH), percent native forest in 2001 (PFNF), and ocean color characteristics (CHLA).

Site	From group	To group	Llanquihue	Osorno	Valdivia	Northern Valdivia
Amargos	Llanquihue	Northern Valdivia	0.00	0.00	0.19	0.81
Cholhuaco	Llanquihue	Osorno	0.06	0.87	0.07	0.00
Chaihuaco	Llanquihue	Osorno	0.34	0.53	0.13	0.00
Capitanes	Llanquihue	Osorno	0.24	0.69	0.08	0.00
Punta Colun	Llanquihue	Osorno	0.08	0.89	0.03	0.00
Roco Covodonga B	Llanquihue	Osorno	0.37	0.52	0.11	0.00
Estaquilla	Osorno	Llanquihue	0.57	0.21	0.22	0.00
Amortajado A	Valdivia	Llanquihue	0.70	0.00	0.30	0.00
Niebla	Valdivia	Llanquihue	0.61	0.00	0.39	0.00
Huape A	Valdivia	Llanquihue	0.48	0.00	0.34	0.18
Huiro	Valdivia	Llanquihue	0.59	0.00	0.41	0.00
Cullinco	Valdivia	Osorno	0.34	0.53	0.13	0.00
Estaquilla B	Valdivia	Osorno	0.06	0.87	0.07	0.00
Bonifacio A	Valdivia	Northern Valdivia	0.00	0.00	0.19	0.80
Los Molinos A	Northern Valdivia	Valdivia	0.01	0.00	0.55	0.44
Isla Mancera	Valdivia	Northern Valdivia	0.00	0.00	0.19	0.81

Table 4-7. Cross-validation summary and error count estimates of the canonical discriminant function of hierarchical cluster analysis groups Llanquihue, Osorno, Valdivia, and Northern Valdivia using percent change in plantations from 1985 to 2001 (PCPL) and ocean color characteristics (CHLA).

From Group	Llanquihue	Osorno	Valdivia	Northern Valdivia	Total
Llanquihue	9 55%	5 29%	2 12%	1 6%	17 100%
Osorno	1 13%	7 88%	0 0%	0 0%	8 100%
Valdivia	4 44%	2 22%	0 0%	3 33%	9 100%
Northern Valdivia	0 0%	0 0%	1 13%	7 88%	8 100%
Total	14 33%	14 33%	3 7%	11 26%	42 100%
Rate	0.47	0.13	1.00	.13	0.43
Priors	0.25	0.25	0.25	0.25	

Table 4-8. Standardized canonical coefficients for the three canonical variables, LOCO1, LOCO2 and LOCO3 that describe the association between *Loco* Health Variables and *loco* groupings. , Note: phoronids = PPHOR, shell boring bivalves = PBIVAV, polychaetes = PPOLYC, barnacles = PBARN, shell height = SHELLHT, *loco* meat weight = WGHMT, shell length = SHELLGT and percent lipid in *loco* meat = PLIP.

<i>Loco</i> Variables	Loco1	Loco2	Loco3
Eutrophication			
WGHMT	0.253	0.452	-0.173
SHELLGT	-0.188	0.424	0.212
SHELLHT	-0.069	-0.478	0.066
PBARN	0.438	-0.130	0.950
PPOLYC	0.193	0.234	0.073
PPHOR	0.675	-0.030	-0.770
PBIVAV	0.240	-0.680	0.236
PLIP	-0.032	0.041	0.076

Table 4-9. Standardized canonical coefficients for the three canonical variables, LCLUC1, LCLUC2, and LCLUC3 that describe the importance of each landscape change variable on the canonical variable. Note land cover change is from 1985 to 2001 and PAG_CH = percent change in agriculture, PCL_CH = percent cleared land change, PURB_CH = percent urban land class change, PMAT_CH = percent matorral change, PL_CH = area (km²) plantation change, and PPL_CH = percent plantation change

LCLUC Variables	LCLUC1	LCLUC2	LCLUC3
Plantation			
PAG_CH	0.187	-0.218	0.832
PCL_CH	0.245	0.401	-0.624
PURB_CH	0.028	0.303	-0.474
PMAT_CH	0.036	0.582	-0.627
PL_CH	0.294	0.565	-1.264
PPL_CH	0.702	-0.595	-0.437
CHLA	0.399	0.393	1.316

Table 4-10. Pearson's Correlation among *loco* health condition variables where WGHMT = weight of *loco* meat (g), WGHV = weight of *loco* viscera (g), WGSB = shell weight (g), SHELGT = shell length (cm), SHELHGT = shell height (cm), SHELWDT = shell width (cm), FATIND = fat index (WGHMT/SHELGT), PLIP = percent lipid (per xx g) in *loco* meat, PPOLYC = percent polychaete cover on shell, PPHOR = percent phoronid cover on shell, PBIVAV = percent bivalve cover on shell; PBARN = percent barnacle cover on shell; MALE = sex, male coded as 1. Note: ** is highly significant where p<0.01 and * is significant where p<0.05.

	WGHMT	WGHV	WGSB	SHELGT	SHELHGT	SHELWDT	FATIND	PLIP	PPOLYC	PPHOR	PBIVAV	PBARN	MALE
WGHMT	1.00	0.78**	0.31*	0.35*	0.13	0.37*	0.98**	-0.15	0.10	-0.23	-0.39*	0.22	0.34*
WGHV	0.78**	1.00	0.09	0.08	-0.10	-0.01	0.80**	-0.16	0.05	-0.03	-0.44**	0.11	0.26
WGSB	0.31*	0.09	1.00	0.51**	0.50**	0.49**	0.23	-0.17	0.54**	0.42**	0.13	0.71**	-0.05
SHELGT	0.35*	0.08	0.51**	1.00	0.36*	0.80**	0.17	0.03	0.14	-0.31	0.43**	0.06	-0.08
SHELHGT	0.13	-0.10	0.50	0.36	1.00	0.16	0.07	-0.03	0.35	0.26	0.12	0.18	-0.01
SHELWDT	0.37*	-0.01	0.49**	0.80**	0.16	1.00	0.22	-0.03	-0.16	-0.44**	0.28	0.27	-0.17
FATIND	0.98**	0.80**	0.23	0.17	0.07	0.22	1.00	-0.18	0.08	-0.18	-0.49**	0.22	0.37*
PLIP	-0.15	-0.16	-0.17	0.03	-0.03	-0.03	-0.18	1.00	-0.04	-0.13	0.27	-0.44**	-0.07
PPOLYC	0.10	0.05	0.54**	0.14	0.35*	-0.16	0.08	-0.04	1.00	0.46**	0.07	0.30	0.24
PPHOR	-0.23	-0.03	0.42**	-0.31	0.26	-0.44**	-0.18	-0.13	0.46**	1.00	-0.19	0.40**	-0.13
PBIVAV	-0.39*	-0.44**	0.13	0.43**	0.12	0.28	-0.49**	0.27	0.07	-0.19	1.00	-0.28	-0.18
PBARN	0.22	0.11	0.71**	0.06	0.18	0.27	0.22	-0.44**	0.30	0.40**	-0.28	1.00	-0.11
MALE	0.34	0.26	-0.05	-0.08	-0.01	-0.17	0.37	-0.07	0.24	-0.13	-0.18	-0.11	1.00
N	41	41	41	41	41	41	41	41	41	41	41	41	41

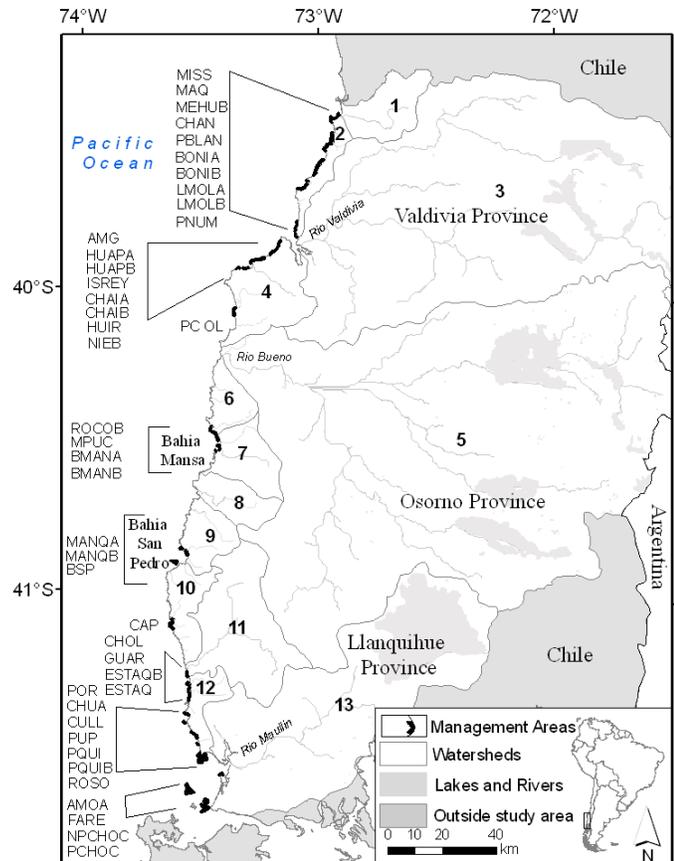
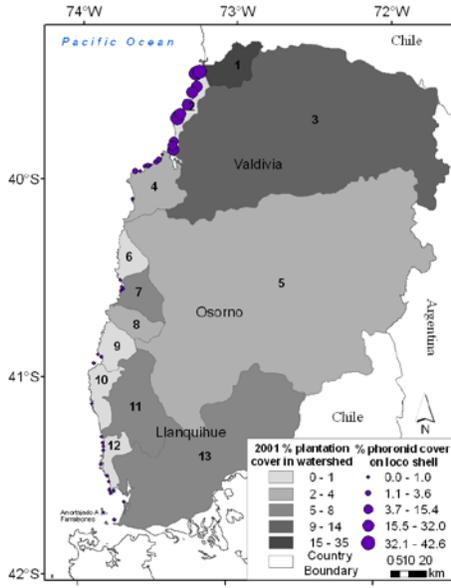
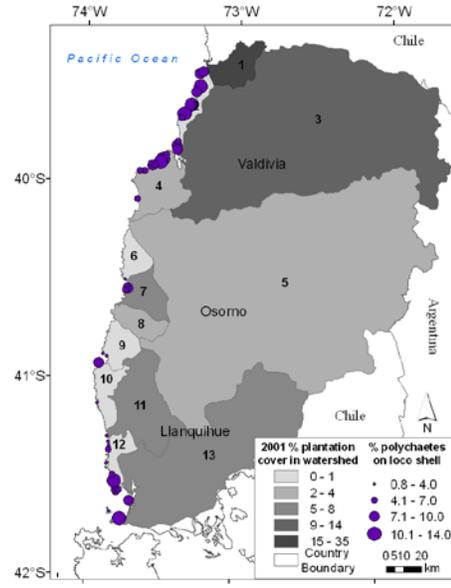


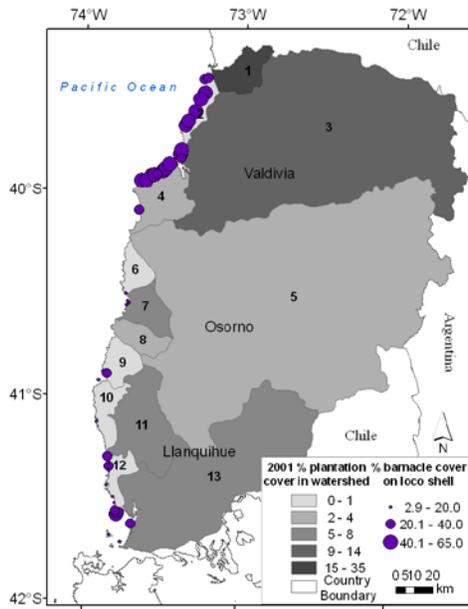
Figure 4-1. Management sites where *loco* shellfish were sampled. Where AMG = Amargos, AMOA = Amortajado A, BMANA= Bahia Mansa A, BMANB = Bahia Mansa B, BONIA = Bonifacio A, BONIB = Bonifacio B, NPCHOC = Norte Punta Chochoi, BSP = Bahia San Pedro, CHAIA = Chaihuin A, CHAN = Chan Chan, CHOL = Cholhuaco, CHUA = Chaihuaco, CULL = Cullinco, ESTAQ = Estaquilla, ESTAQB = Estaquilla B, FARE = Farellones, GUAR = Guar Guar, NIEB = Niebla, HUAPA = Huape A, HUAPB = Huape B, HUIR = Huiro, ISMAN = Isla Mancera, ISRE = Isla del Rey, CAP = Capitanes, LMOLA = Los Molinos A, LMOLB = Los Molinos B, MANQA = Manquemapu A, MANQB = Manquemapu B, MAQ = Maquillahue, MEHUB = Mehuin B, MISSI = Mississippi, MPUC = Manzana Pucatriuhue, PLBAN = Piedra Blanca, PCHOC = Punta Chocoi, PCOL = Punta Colun, PNUM = Punta Numpulli, POR = Punta Ortiga/Puga, PQUI = Punta Quillahue, PQUIB = Punta Quillahue B, PUP = Pupelde, ROCOB = Roco Solataria B, ROSO = Roco Solataria



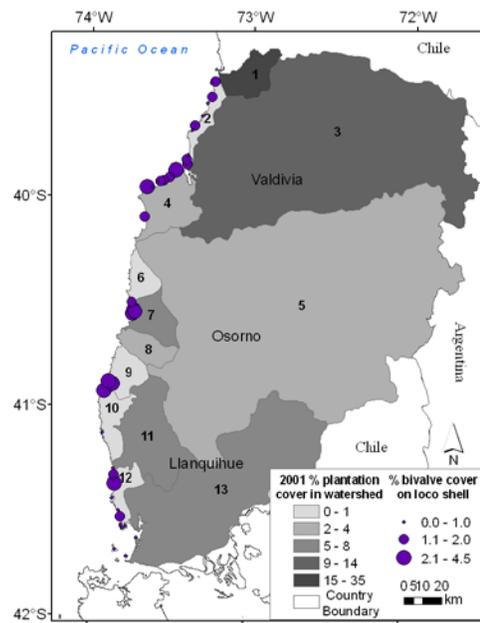
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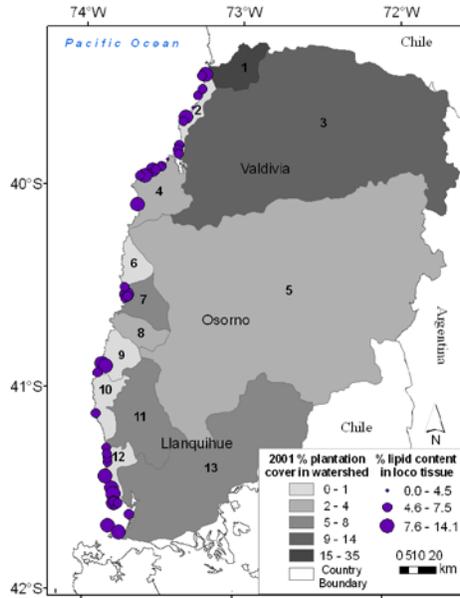
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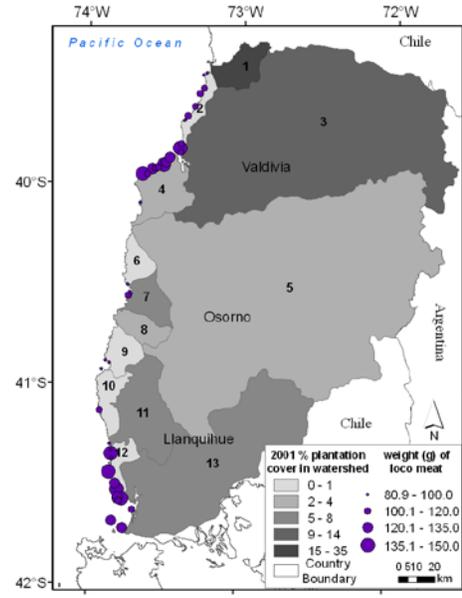
C



D



E



F

Figure 4-2. Average percent A) phoronid, B) polychaete, C) barnacle, and D) bivalve cover of on *loco* shells as well as E) lipid content and F) weight of *loco* meat in each management area and the percent forest plantation cover in 2001. (Averages obtained from a sample of 30 *locos* per management area).

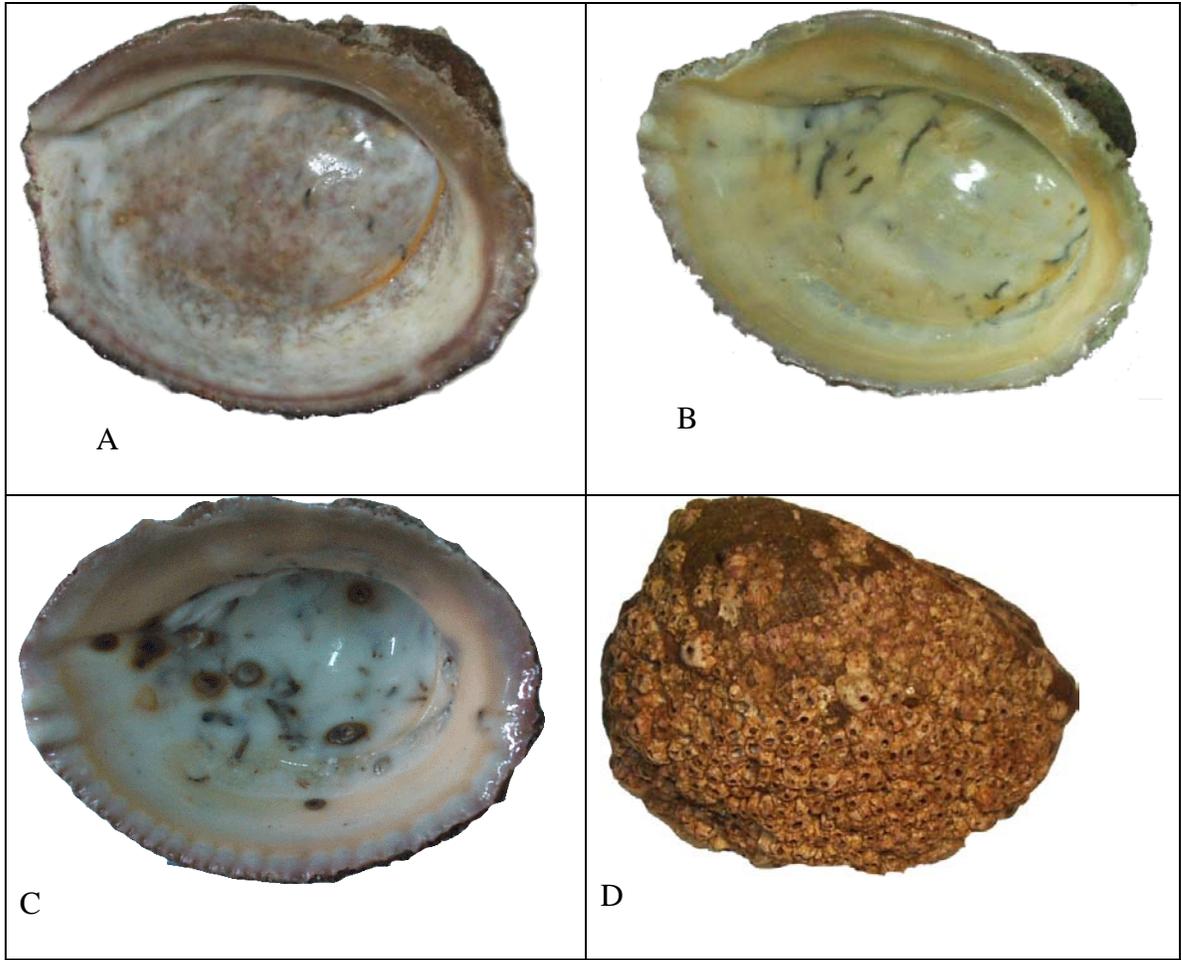


Figure 4-3. Loco shells showing A) phoronid, B) polychaete, C) bivalve and D) barnacles. A,B, and C are the ventral side of the loco shell. D is the dorsal side. Phoronids leave light brown marks on shell A. The dark black lines in B are polychaetes. The circular marks on shell C reflect the damage from the bivalves..

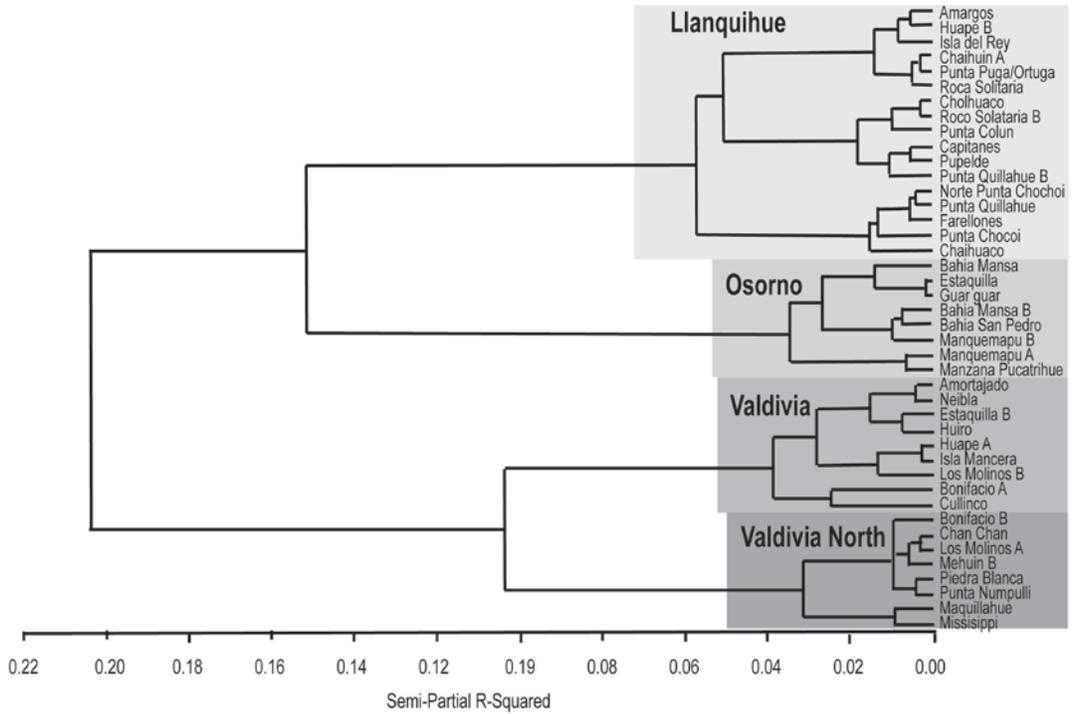


Figure 4-4. Cluster analysis of *loco* shellfish in each management area based on health characteristics (percent phoronid, polychaete, and bivalve cover on *loco* shells, as well as weight and lipid content of meat, and shell length). Distinct levels of gray signify distinct clusters.

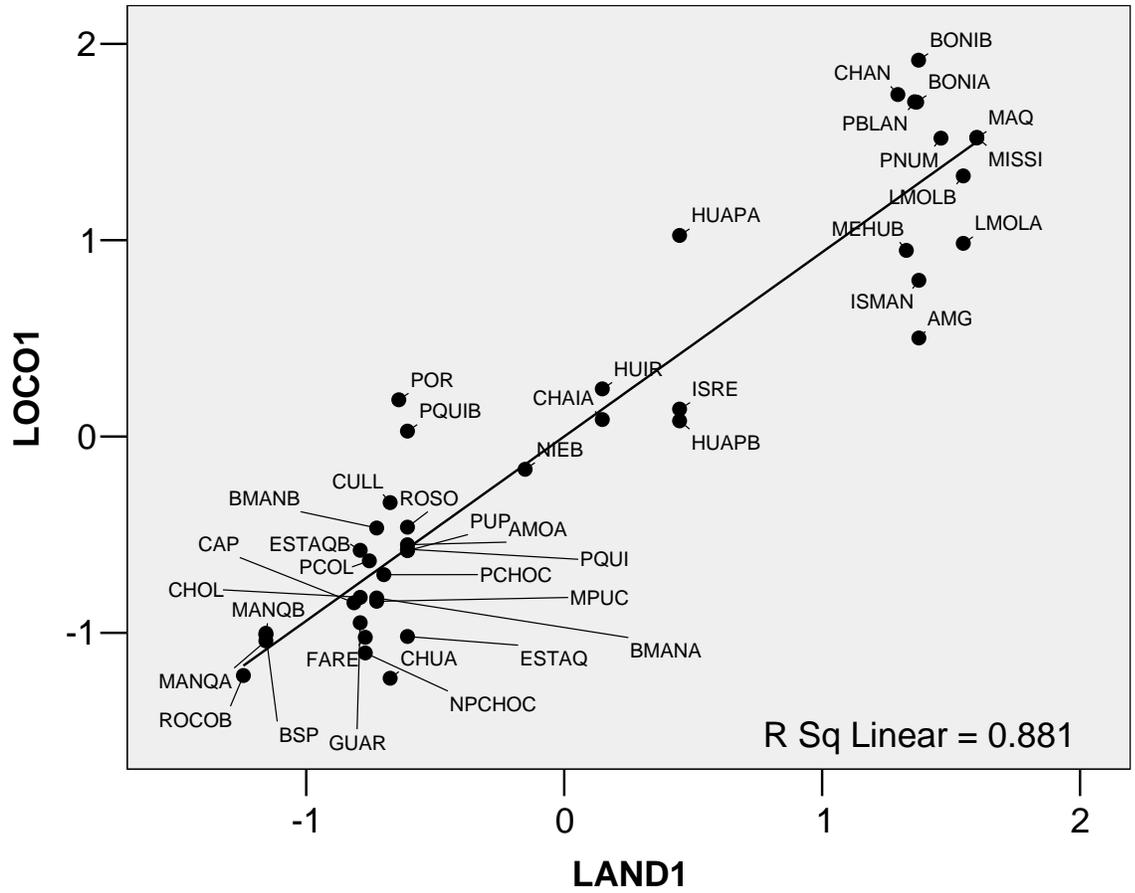


Figure 4-5. Scatterplot of LOCO1 and LAND1 from the canonical correlation analysis ($R^2=0.881$; $p=0.000$). Abbreviations as in Fig. 4-1)

CHAPTER 5 ADAPTIVE CAPACITY FOR FISHER SUCCESS

Introduction

Nearshore Systems and Landscape Change

This study examines how nearshore fishers on the coast of Chile adapt to environmental change. Human activities that include agriculture, deforestation, plantation development, animal production, and urbanization can alter nearshore systems, which receive outflows from the upland ecosystem (Nixon 1995). To develop the landscape, people clear the land and fertilize the soils and these activities increase nutrient loading and sediment delivery to the rivers (Nixon 1995). Land-use/land-cover change (LULCC) has a major influence on the hydrologic regimes of the rivers since evapotranspiration rates and the amount of water that flows from the watershed to the rivers depends on the dominant species in the landscape (Farley et al. 2005; Iroume et al. 2006). Nearshore systems respond to nutrient increases by becoming more eutrophic. Eutrophic systems are enriched with nutrients and may also be more turbid and have decreased oxygen levels (Smith et al. 1999; Kemp et al. 2005). Consequently phytoplankton blooms in eutrophic areas and extreme changes in the phytoplankton dynamics can alter the benthic community structure (Diaz and Rosenberg 1995) and food-web structure and function (Kemp et al. 2005). Organisms living in eutrophic environments are also more susceptible to parasites (Zander & Reimer 2002; Johnson et al. 2007; Van Holt in prep c). This cascade of effects may cause problems for nearshore fishers in Chile because they are restricted by recent management laws to specific areas, and cannot move to new areas if upland LULCC alters the nearshore environment in ways that degrade the

fisheries. To understand how nearshore fishers adapt to environmental change, I answered the following questions:

- What factors (knowledge, technology, and environment) contribute to fisher success?
- Do fishers use the same strategies to adapt for success in the *loco* (closed-access) and *congrío* (open-access) fishery?

In southern Chile, the nearshore environment is influenced by forest-plantation development, which is the most significant landscape change that occurred from 1985 to 2001. Forest plantations are fertilized (Schlatter 1977; Guerra et al. 2007) to increase productivity and subsequently, increased nitrogen levels have been measured in watersheds with forest plantations (Little et al. 2008; Oyarzun et al. 2007). Increases in forest plantations have also lead to increased evapotranspiration and consequently a reduction in the amount of water that flows to the rivers (Iroume et al. 2006). The nearshore environment that receives outflows of nutrients from plantation areas has higher photosynthetic activity, which has been measured by high chlorophyll-a concentrations in data derived from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite images (Van Holt b in prep). The *loco* (*Concholepas concholepas*) shellfish from the regions influenced by plantations have a higher parasite load (Van Holt c in prep) and weigh less.

Fisheries Management in Chile

Recently Chile implemented a Territorial User Rights Fisheries (TURF) management system to protect benthic species from overharvesting by providing fishers

quasi-property rights to parcels of the ocean called “managed exploitation areas for benthic resources” (MEABR) and exclusive rights to the benthic resources in those areas (Bernal et al. 1999). Fishers usually only harvest *loco* and refrain from harvesting other benthic species in management areas to avoid disrupting the valuable *locos* and also because fishers must hire a scientific expert to create quotas for all species harvested in the MEABRs—an expense that few fishers want to incur. If fishers harvest another species, they usually harvest *lapa* (*Fisserella* sp) at a very small scale. The MEABRs were implemented to control harvest of the *loco* fishery, a benthic fishery that collapsed in the mid 1980’s from overfishing. In addition to successfully bringing back the *loco* fishery, the new management system changed how fishers can respond to environmental change because the fishers can no longer move to another region if the resource quality is poor in their management area. Fishers can legally harvest *locos* only from their management area. Today most of the coast in the study site (Figure 5-1) is registered to fishing syndicates that consist of local village-level groups. Fishers can’t shift to harvest in regions other than their management area to escape the consequence of environmental changes in their management area and in the coastal system.

Fisher knowledge varies greatly because of how the MEABRs were established. Essentially anyone that is a certified diver, fisher, or coastal-resource gatherer can join a fisher syndicate and solicit a management area from Servicio Nacional de Pesca (SERNAPESCA). People were attracted to government assistance and the potential to earn money from the coast and as a result, many new people entered the fishery. Many of these new fishers are part-timers, have less experience than traditional fishers, and have

other sources of income. When prices are low, these part-timers stay on shore and await better prices. In contrast, those who depend entirely on fishing, and have traditionally fished marine resources with boats, have better boats, fishing knowledge, and organizational skills, yet they cannot always wait for a better price. These fishing skills, technology, and greater marketing experience, allow the full-time fishers to capture species that are beyond the reach of the part-timers. More experienced divers often work in the rivers as well as the management areas and harvest multiple species of benthic shellfish—not only *locos*. More experienced fishers also spend more time offshore and harvest multiple species of fin fish. In contrast, the newer fishers and those with other livelihoods tend to harvest resources only in the management areas.

To understand how fishers adapt to environmental change, I used a space-for-time substitution (Fukami 2005) and measured the success of fishers who worked in environments that had varying levels of eutrophication and associated natural-resource degradation (Figure 5-1). Adaptation takes time, so instead of following a group of fishers over time, I examined cases that stand in for different times along the adaptation process. I also compared the factors that predicted success across a closed-access (*loco* shellfish) and open-access [*congrío* (*Genypterus* sp.)] fishery to determine if fishery type and management regimes (closed or open access) affected success. Success was my proxy for adaptation—I defined successful fishers as those who caught more fish, made more money, or gained a higher price per kg of fish than unsuccessful fishers.

Studies that measure fisher success (usually measured as catch-per-unit effort), find that successful fishers have more knowledge and technology compared to

unsuccessful fishers (Acheson 1977; Palsson 1994; Palsson & Durrenberger 1982).

Because new fishers were introduced to the system when the management areas became established, the amount of time that fishers spend in the open ocean, rivers, and management areas are important indicators of knowledge because they help separate new and experienced fishers; fish species harvested and other livelihood activities also help isolate new and experienced fishers. Presence of boats was the most relevant indicator of technology since established fishers usually had more boats and novices had fewer boats. Knowledge, however, is dependent on the environment and therefore the environment is a relevant factor in success; Harris (1979) demonstrates that the derivatives of culture or knowledge stem from the environment, production, and infrastructure. Including the environment was particularly important in this study because the environmental conditions varied throughout—some fisheries management areas were influenced by landscape change. These management areas had higher chlorophyll-*a* concentrations in the water and the *locos* harvested from those management areas had higher parasites on their shells. I included environmental variables that measured the level of eutrophication in the system (chlorophyll-*a* concentration in the ocean and the percentage of parasites on the *loco* shellfish) because these factors likely affect fisher success and can isolate how fishers adapted to environmental change. Spatial measures that address infrastructural features of the landscape such as management-area size, distance from the management area to the fishing headquarters, and distance to Valdivia, the central market, were also included because these factors can influence success because they are derivatives of

knowledge and fisher movement is restricted under the new management system and those fishers who have less time to travel may gain an advantage.

To measure success, I included catch per unit effort (CPUE) measures, when available, because CPUE has traditionally been used to measure success in the literature. Monthly income, the total profit that each fisher gained, also measured success; this income measure took into account the costs associated with fishing such as fuel costs, payment for management- area scientists, and equipment costs. Finally, to compare success in *loco* and *congrío* fisheries, I used price per kg, which measures broad-scale regional differences in success. Since the interviews with fishers were conducted over two months when no major fishing events happened, the prices reported were not subject to seasonal influences.

Study Site

The Valdivian province of Chile contains four large watersheds (Figure 5-1). The names of watersheds on Figure 5-1 are derived from the main river in the watershed: Lingue (1), Bonifacio (2), Valdivia (watershed 3), and Chaihuín (4). High annual precipitation (2,000-4,000 mm) and a mean annual temperature of 12.5°C (Eldridge & Pacheco 1987) give rise to a temperate rainforest ecosystem, today the remaining forest is located along the coastal and Andes mountains (Figure 5-1). Principal economic activities include forestry, fisheries, agriculture, and cattle ranching. Forest plantations represent the most significant land cover change in the past 15 years (Van Holt a in prep). Forest plantations are extensive in the Lingue and Valdivia watershed. Chaihuin is covered by mainly native forest, but also has some forest plantations. Some agriculture occurs in the

Lingue, Bonifacio, and Valdivia watershed. The nearshore environment from the outlet of the Valdivia river to the outlet of the Lingue river has high chlorophyll-a levels that indicate that nitrogen from the forest plantations are leaching into the rivers and eventually affecting the chlorophyll-a concentration in the nearshore environment.

Across the Valdivian province, located in the northern part of administrative Region X (Figure 5-1), artisanal fishers dive for benthic *locos* in the management areas yet fishers are not restricted to harvest *congrío* only in the management areas. Harvesting *locos* in the management areas is a group effort—a president of each syndicate helps process the legal paper work and organizes the group; however, the money that individual fishers receive are not always divided equally and the way that money is divided varies from syndicate to syndicate. The fishers tend to work in smaller groups for other fisheries, such as *congrío*. Although prices may differ slightly within a fishing syndicate because fishers have distinct rules on how to divide the money; the “going price” for a resource is relatively similar in the same region. On average, in management areas across Region X, artisanal fishers harvested 1,979 tons of *locos* each year between 2003 and 2005. The finfish catches are very small; from 2003–2005 the entire purse-seine and artisanal fishers together, across region X, reported selling, on average, 116 tons of *congrío* annually (SERNAP 2003, 2004, 2005).

Forest plantations have increased differentially across the study site and environmental change in the nearshore environment follows forest-plantation development patterns (Van Holt d in prep.). From 1985 to 2001, in the northern portion of the study site (across watersheds 1-3), 1,415 km² of plantations have become

established. In comparison, across in the southern portion of the study site (watershed 4), only 27 km² of land has converted to plantations. Chlorophyll-a concentration values are also higher (3.7 mg/m³) in the nearshore region with plantations as opposed to 2.0 mg/m³ across all months between 1998 2005 (Van Holt c in prep). Finally, *loco* shellfish parasites are also higher in plantation-influenced areas with an average of 30% of the shell covered with phoronid (*Phoronis* spp.) and polychaete (Class Polychaetea) parasites in the plantation areas and about 5% cover in non-plantation areas (Van Holt d in prep).

Methods

Independent Variables

Knowledge

A team that included employees of Proyecto de Fomento (PROFO) Cerqueros, students from Universidad Austral, and myself interviewed 279 fishers from 11 fishing syndicates for the first Fisher Census of fishers from the Federación Provincial de Pescadores Artesanales del Sur (FIPASUR). I identified 21 variables to test whether they explained success (Table 5-1). To measure local knowledge fishers were asked to select the benthic invertebrates (BENT) and fish (FISH) they harvested from a picture-list of 43 resources. Fishers then reported how the proportion of their time fishing distributed across working in the management area (MAT), open ocean (OCT), and rivers (RIVT). Fishers reported on the number of other fisheries (purse seine, diving, and fishing) they pursued (FAC) and the number other livelihood activities that they pursued (OAC) that included: tourism, raising domestic animals, agriculture, forestry, and commercialization

of products. Fishers also reported how many years they had fished (YEAR), and how long they studied in school (EDU).

Environment

Thirty *locos* were collected by fishers in each of the 11 management areas; *locos* were sampled from the north, south and mid sections of each management area from July to August during the 2004 harvesting season. The percentage of parasites (PARA) -- phoronids and polychaetes-- were recorded with assistance of marine biology students from Universidad Austral. To measure parasites, first I generated thirty randomly selected points on the shell, then each point was assessed for presence or absence of a parasite (a polychaete, for example), finally, I created a proportional relationship. If three out of 30 points were covered with polychaetes, then 10% of the shell was covered. The percent-cover analysis was repeated for phoronids. Then both percentages were summed to create PARA; a simple summation was possible because the sampling point cannot have both a polychaete and phoronid. *Loco*-shell length and meat weight (WEIGH) was also recorded.

SeaWiFS satellite images from April 9, 2003 and May 1999 were used to calculate change (1999 to 2003) in chlorophyll-a in the water. These dates were selected because the images were cloud-free, upwelling does not usually occur during this time period, and chlorophyll-a values are likely related to landscape change rather than upwelling (Moreno et al. 1998). Chlorophyll-a concentration values were extracted from SeaWiFS satellite images using SeaDAS 5.3 (Baith et al. 2002). The NASA-generated chlorophyll-a concentration values are derived from an empirically based bio-optical algorithm

(O'Reilly et al., 2000) that is performed on reflectance values, which are derived from calibrated digital counts that have been atmospherically corrected (Hu et al. 2009). Chlorophyll-a concentration is one of the best predictors of photosynthetic biomass available today (Huot et al. 2007), although there are other photosynthetic pigments and biomass that supports photosynthesis that are not related to chlorophyll-a. One pixel was selected to represent chlorophyll-a concentration in each management area (PHOT); if fishers harvested in more than one management area, the values from the management areas were averaged.

Informants reported how far they traveled from home to the fishing headquarters (DISHQ), which is the area where they keep their boats. I calculated area of the management area (AREMA) by digitizing management areas using published coordinates from the Diario Oficial of Chile and calculating the distance from the fishing headquarters to the center of the management area (DISMA) (ArcGIS 9.0™). Distances were averaged if two or more management areas were present. Two or more management areas were usually located next to each other making this calculation simple. I also measured the distance (km) from the fishing headquarters to Valdivia, the nearest city (ROADV).

Landscape change, and specifically plantation land cover, was measured from 1985 to 2001 in four watersheds near the management areas (PLANT) (Van Holt a in prep). The influence of plantations in the nearshore environment was not related to the four separate watersheds, but rather across two distinct zones; the coastal region near watershed 4 was the first zone where few plantations were established, and the second

zone was the coastal area near watersheds 1-3, where extensive landscape change occurred. Other variables—chlorophyll-a, *loco* parasites, and the distance from the fishing headquarters to the Valdivian marketplace were correlated to landscape change and had more refined measurements (not only two zones) and therefore those variables were used in the final analysis.

To measure available technology (BOAT) I totaled the number of boats that registered with Servicio Nacional de Pesca for each syndicate and verified the registration records with fishers. Each fisher in the same fishing group, therefore, had the same value for boat availability. This syndicate-level variable BOAT best represented how many boats were available to harvest resources because fishers share boats and not owning a boat doesn't necessarily signify that you don't actively dive or fish.

Personal variables

Age (AGE) was measured by direct interviews.

Dependent Variables

I tested, five separate dependent variables (1) the total catch of *locos* by the syndicate in the 2004 harvest season (TOTAL), (2) the number of *locos* harvested per day by the syndicate for the 2004 *loco* harvest (Catch per Unit Effort, or CPUE), (3) the price each fisher reported receiving for one kilogram of *loco*, (4) the price each fisher reported receiving for one kg of *congrío*, and (5) the total monthly income each fisher reported from the management area (MAI). Since fishers provided the price for their top five resources harvested, not all informants were included in the individual-scale analysis [*loco* (N=108) and *congrío* (N=74)]. The individual-level data were obtained through

personal interviews and the syndicate-level data were obtained from the Chilean fisheries agency, the SERNAPESCA. The management-area income was a rank-order estimate of income generated from the *loco* fishery but in a few cases includes a small fraction of the income from the *lapa* fishery as well.

Analysis

For the syndicate-level analysis (catch-per-unit effort and total catch), I ran a stepwise regression. Since the degrees of freedom were low, I selected specific variables to use and had to create separate environmental and knowledge-technology models. The environmental model included *loco* parasites, chlorophyll-a concentration in the management area, and *loco* weight. The knowledge-technology model included time spent in the ocean, in the management areas, and the river, as well as total number of boats.

For the individual-fisher analysis, (*loco*, *congrío*, and management-area income), I first tested for and removed the following multicollinear independent variables: PLANT, WEIGH, YEAR, and DISTMA because they were not found to be important by preliminary analysis. I then ran a stepwise multiple regression for all remaining independent variables with the dependent variable for each analysis. I compared all models using, in this order, Mallows' C_p statistic, the Bayesian information criterion (BIC), a scree plot of mean square error (MSE) vs. model size, and R^2 (Mallows 1973; Spiegelhalter et al. 2002). In the final model, the condition index, tolerance values, and variation-inflation index were used to check if any multicollinearity issues remained. I plotted the residuals from the regression and the dependent variables to check for

normality of the error term. I also tested for interactions between EDU, YEAR and AGE, and between DISTMA and PHOT. Including interactions did not improve the models.

To understand general trends for the fisheries, I then plugged in average independent variable numbers in the regression-model equations to solve for the dependent variable. I used the averages for all fishers for the following variables: FISH, MAT, RIVT, YEARS, and EDU (Table 5-2). Fisher-syndicate averages were used for PARA, PLANT, PHOT, DISTMA, and ROADV variables since the syndicate-level average was used in the individual analysis for these variables (Table 5-3). An exchange rate of \$1USD = 600 pesos was used.

To confirm the findings with an alternative analysis, I ran a stepwise discriminant analysis (PROC STEPDISC in SAS 2001) on groups of successful and unsuccessful individuals. I divided informants into two groups: those with median prices and above for their catches were the successful group and those with prices below the median were the not-successful group. I split the data using mode, median, and 50 percentile; median best split the data and was used to generate the two groups. In the discriminant analysis, independent variables entered and remained in the model if p-value ≤ 0.15 .

Results

Closed Fisheries

A larger fraction of time spent working in the rivers, management areas, or the ocean increased total catch of *locos* for the syndicate (Table 5-4). Environmental variables, however, were not statistically significant in explaining total catch. The number of *locos* harvested per day was positively influenced by the proportion of time

spent fishing in the river, negatively influenced by the amount of time working in the open ocean; and positively influenced if fishers had more boats. The only environmental factor that influenced the number of *locos* harvested per day was increased chlorophyll-a concentration in the management area (Table 5-5). The importance of knowledge in total catch and catch per unit effort agrees with other studies (Acheson 1977; Palsson 1994; Palsson & Durrenberger 1982). Chlorophyll-a concentration also explains a large fraction of the variation in catch-per-unit effort, but knowledge explain a much larger fraction of catch-per-unit effort. Time spent working in the river accurately reflects diving experience since it was so influential in determining catch-per-unit effort.

For *locos*, parasites alone explained 43% of the variance in price and chlorophyll-a concentration explained another 21% (Tables 5-6 and 5-7; Figure 5-2). Lack of boats explained an additional 5% in the model. Knowledge explained only 6% of the price variance--if fishers were experienced, harvested multiple fishes; however they did not spend a lot of time in the open ocean, and had specific experience in rivers, they reported higher prices for *locos*. The resource quality as measured by parasites, which is influenced by environmental change associated with eutrophication, overwhelmingly predicted price.

I used the *loco* regression model to predict price changes using \$7.20 as the average price for a kilo of *loco* (Table 5-6). A ten percent increase in parasites had a dramatic affect and decreased *loco* price per kilo by \$0.99 or 17%. A 0.2 mg/m³ increase in chlorophyll-a concentration in the management area increased price per kilo by \$0.28. Chlorophyll-a concentration and parasites are related. If the chlorophyll-a concentration

is higher than 2.4 mg m^{-3} , the benefits of the chlorophyll-a may diminish and the parasite's influence dominates (Figure 5-3).

To adapt to environmental changes, either environmental problems are mitigated or fishers use their knowledge or technology to adapt. If the fisher group had one boat *less*, the price of *loco* would increase \$0.08. To completely compensate for a 10% increase in parasites, fishers would need to have fewer than four boats, which is an unrealistic scenario. A fisher's knowledge is the most likely the way that fishers can adapt to environmental change since boats negatively influence the price of *locos* however, price gains from knowledge were not as substantial as the environmental effects of increased parasites. The *loco* price increases \$0.05 for each additional fish-species harvested by an individual; spending 10% more time working in river-based fisheries adds \$0.09; and spending 10% less time working in the open ocean fisheries adds \$0.11 per kg. Fishers who work in rivers gain an advantage (and those that spend more time in the open ocean do not) with the *loco* harvest because fishers who work in the rivers have more diving experience. Working in additional offshore fisheries also adds to the price individuals are paid for *locos*.

The discriminant analysis of successful (> median price) vs. non-successful (< median price) *loco* fishers confirmed that fishers with few parasites on their *locos* were more successful (Table 5-8). Weight of the *loco* meat best explained the successful groups of fishers in the discriminant analysis since fishers are paid higher prices/kg for heavier *locos*. Parasites were the most important success factor in both the regression and discriminant analyses. Chlorophyll-a concentration continued to be important—

successful fishers had management areas with high chlorophyll-a concentration and low parasite loads, which confirms the regression analysis and illustrates the complex relationship between parasites and chlorophyll-a. Also fishers had an advantage if they lived further away from the Valdivian market—probably because of the associated environmental changes close to Valdivia. Fishers with more years experience had a slight advantage. The discriminant analysis model was highly accurate for successful (94.34%) and unsuccessful fishers (83.05%) (Table 5-9).

The monthly income that fishers receive from the management areas (consisting of mainly *loco* resources) shared similar findings with the *loco*-price data (Table 5-6; Table 5-7). Management area income was dependent on the number of benthic fisheries harvested (working in multiple benthic fisheries was better); weight of the *loco* resources (the heavier the *loco*, the better); the size of the management area (larger areas were better); and how close a fisher lived to the fishing headquarters (closer was better); chlorophyll-a concentration negatively influenced income. The discriminant analysis has similar results; successful fishers had *locos* with a low number of parasites (associated with higher weight), larger management areas, more benthic species and fewer boats. Fishers who worked in multiple fishing activities (diver, purse seine fishery, and the small-scale open fishery) had an advantage, but the mean difference in successful and unsuccessful fishers was very small. Also distance to the headquarters had the opposite relationship when compared with the multiple regression analysis (being located further away from the headquarters was better in the discriminant analysis), but only a small fraction of success was explained by distance to headquarters.

Open-Access *Congrio*

The multiple regressions show that chlorophyll-a concentration explained 13% of the price variation in *congrío*. Fisher knowledge and experience explained 16% of the variance and formal education explained 11% of the variance (Tables 5-6 and 5-7; Figure 5-2). Fishers who worked in multiple fin fisheries, had spent many years fishing, and those who did not spend time working in the rivers were most successful. More formal schooling also benefited price.

The *congrío* model (Table 5-6) (using a base price of \$1.45) shows that knowledge was most influential in price, adding \$0.02 per kg for each additional species fished; \$0.05 per kg for each additional year spent in school, \$0.01 for each additional year fishing, and a loss of \$0.05 per kg for each additional 10% of a fishers' time that is dedicated to fishing in the river. An additional 0.2 mg/m³ increase in chlorophyll-a concentration in the management area added \$0.03 per kg. Knowledge and experience explain a larger fraction of success when compared with the environment.

The discriminant analysis (Table 5-8) confirmed that successful fishers dedicated themselves to artisanal fishing and included fewer activities outside of the fisheries and worked in fewer different types of fisheries i.e. they did not work in purse seine, benthic fisheries, and offshore small scale fisheries. These fishers also had more boat power. The most influential factor, however, was how close the fishers were to the market. Interestingly fishers located near the market were probably located in plantation watersheds, had a degraded management area, and found a new niche by using their knowledge and technology to work in fisheries that were more resilient to environmental

change. Successful fishers had a slightly higher formal education that probably helped them negotiate higher prices for their resources. Smaller management areas benefitted the fishers, perhaps because they require less work to monitor and care for year-round. The model predicted successful fishers with 81.25% and unsuccessful fishers with 88.57% accuracy (Table 5-9).

Adapting to Change

Fishers cannot easily adapt to be successful if their management areas contain *locos* with high parasite loads. While fishers can reduce fleet size and increase knowledge, these factors do not mitigate the overwhelming influence of parasites. While boats are important in explaining the catch-per-unit effort, having more boats does not translate to higher prices. For success in these nearshore fisheries where changes in chlorophyll-a concentration and parasites affect the *locos*, conservation efforts must address the influences of eutrophication in the system. Fishers, especially those who are new to the management system, could be vulnerable if their resources become affected by eutrophication. New fishers are not rewarded for having more boats and they are only slightly rewarded for focused diving skills so these new fishers are not developing the skills that will help them adapt to environmental change. The *congrio* fishery demonstrates how fishers may adapt to environmental change. The fishers who were successful in the *congrio* fishery had extensive fishing knowledge, technology, and they were more connected to the market. The offshore fisheries may be a means that fishers can adapt to the environmental change in the management areas. To help fishers be less

vulnerable to environmental changes associated with eutrophication, fishers should continue to develop their offshore fishing skills and improve technology.

In the management areas with higher concentration of chlorophyll-a, fishers spent more time working offshore; they harvested more fishes ($r=0.12$, $p=0.05$), and fewer benthic resources ($r=-0.38$, $p=0.00$). These fishers also spent a lower proportion of their time diving in the rivers ($r=-0.42$, $p=0.00$) and a higher proportion of time in the open ocean ($r=0.15$, $p=0.02$). The fishers still spend a large fraction of their time working in the management areas ($r=0.16$, $p=0.01$), possibly because the economic benefits are highest in the management areas.

In the open-access *congrío* fishery, knowledge and technology was more influential and could help fishers adapt to environmental change. Knowledge alone can help fishers adapt to change in nearshore environmental conditions, specifically, changes in chlorophyll-a concentration and parasite loads in the benthic fisheries. Boats also helped fishers adapt to environmental change (discriminant analysis). These findings agree with other studies on fisher success that explain that knowledge and technology help fishers succeed.

To foster success in nearshore fisheries, environmental condition must be improved. Fishers mitigate poor environmental conditions in closed-access areas nearshore by harvesting offshore. Ecological knowledge and boats help make offshore fishers successful. A recent fishing-net diversification program supported by the Chilean Government in the Valdivia Province is an example of a program that could foster adaptability to environmental change. Fishers were given different sized fishing nets to

diversify catches. Based on our analysis, fishers working in the offshore fisheries would benefit and those working in nearshore fisheries gain a smaller benefit from such a program. Becoming skilled in diverse fishing strategies, however, could prove very useful if the environmental condition in the healthy management areas degrades, because the fishers trained in using other gear types will be able to harvest other open access resources that are not as influenced by the immediate, nearshore environmental effects.

Conclusions

Environmental features best explained price differences for the benthic, closed access, *loco* fisheries because these organisms are relatively stationary compared to finfish and are directly influenced by local environmental conditions. Knowledge and technology, which help fishers catch more fish and perhaps find the better resources, don't compensate for environmental change in these fisheries. Those fishers in management areas with poor quality resources are vulnerable to changes in the environment because the traditional means by how fishers adapt to change (knowledge and technology) does not foster success.

Local knowledge explained a smaller fraction of success for the *loco* fishery and a larger fraction of success for the *congrio* fishery. Diving experience helped *loco* fishers succeed and offshore-fishery experience helped the *congrio* fishers succeed. Only in the open-access fisheries were fisher knowledge powerful enough and the influence of the environment low enough that fishers could adapt to changes in the environment.

Table 5-1. Dependent and independent variables tested in this study.

Type	Variable	Measure	Method	Code
Independent variables				
Knowledge	Benthic species harvested	# of benthic species harvested	interview	BEN
	Fish harvested	# of species of fish harvested	interview	FISH
	Management area time	Proportion of time spent in MA	interview	MAT
	Open ocean time	Proportion of time spent in ocean	interview	OCT
	River time	Proportion of time spent in river	interview	RIVT
	Livelihood	# of activities outside the fishery	interview	OAC
	Livelihood	# of fishing activities (purse seine, diving, fishing)	interview	FAC
Environment	Fisher experience	# of years fishing	interview	YEAR
	Years of education	Years of education	Interview	EDU
	Carnivore Health	% <i>Loco</i> shell w/ parasites*	ecological survey	PARA
	Carnivore Health	Weight <i>loco</i> meat (g)	ecological survey	WEIGH
	Carnivore Health	Length <i>loco</i> meat (cm)	ecological survey	LENGTH
	Chlorophyll-a	Change in chlorophyll-a (mg/m ³) in management area (1999- 2003)	satellite image	PHOT
	Distance to market	Distance (km) from fishing headquarters to Valdivia city	GIS	ROADV
	Conversion to plantations	% new plantation in watershed	satellite image	PLANT
	Distance to headquarters	Distance to fisher headquarters	interview	DISTHQ
	Land owned	Area of land owned (m ²)	interview	LAND
	Distance to MA	Distance to management area (m)	GIS	DISTMA
Size MA	Size (ha) of management area	GIS	AREAMA	
Personal	Boats availability	Boats (#)	interview	BOAT
	Fisher age	Age	Interview	AGE
Dependent Variables				
Economy	Price of <i>loco</i>	Price per kilo (pesos/kg)	Interview	<i>loco</i>
	Price of <i>congrío</i>	Price per kilo (pesos/kg)	Interview	<i>congrío</i>
	Management area income	Rank order of income per month in management area	Interview	MAI
	Catch-per-unit effort <i>locos</i>	# <i>locos</i> /day per syndicate in 2004	SERNAPESCA	CPUE
	Total catch	# <i>locos</i> caught in the 2004 season per syndicate	SERNAPESCA	TOTAL

Table 5-2. Descriptive statistics for variables used for the *loco*, *congrío*, and management area income analysis where fisher is the unit of analysis.

Variable	N	Mean	Std Dev	Minimum	Maximum
PLANT (km ²)	279	896.0	566.5	27.1	1264.0
ROADV (km)	279	68.4	45.9	17.9	152.9
PHOT (mg/m ³)	279	2.1	0.5	1.2	2.7
PARA (%)	255	19.2	15.5	3.7	42.6
WEIGHT (g)	255	112.1	16.2	88.4	134.8
BOAT (#)	279	17.8	6.8	7.0	28.0
EDU (y)	277	9.0	3.1	0.1	17.0
YEAR (y)	244	24.7	12.1	1.0	63.0
DISTHQ (m)	278	1622.1	3057.9	0.0	25000.0
AREAAM (ha)	279	126.1	65.4	49.0	352.0
MAT (%)	279	35.7	25.7	0.0	100.0
OCT (%)	279	49.7	31.4	0.0	100.0
RIVT (%)	279	18.0	27.8	0.0	100.0
FISH (#)	279	7.8	5.9	0.0	23.0
BEN (#)	279	5.8	3.6	0.0	14.0
<i>Loco</i> (\$/kg)	142	4787.0	863.8	3000.0	6000.0
<i>Congrio</i> (\$/kg)	92	947.3	172.0	400.0	1300.0
MAI (rank order)	279	1.4	0.9	0.0	4.0
TOTAL (#)	279	64659.3	60331.2	3723.0	262703.0
CPUE (catch/day)	279	16395.5	11206.7	3016.0	39633.0

Note for MAI, monthly management area income (UD\$/month):

1: <\$50

2: \$50 - \$99

3: \$100 - \$149

4: \$150 - \$200

Table 5-3. Descriptive statistics for variables used for the *loco*, *congrio*, and management area income analysis where fishing syndicate is the unit of analysis.

Variable	N	Mean	Std Dev	Minimum	Maximum
PLANT (km ²)	11	926.7	577.8	27.1	1264.0
ROADV (km)	11	70.6	48.2	17.9	152.9
PHOT (mg/m ³)	11	2.3	0.5	1.2	2.7
PARA (%)	11	21.5	16.4	3.7	42.6
WEIGHT (g)	11	114.1	16.2	88.4	134.8
BOAT (#)	11	16.2	6.6	7.0	26.0
EDU (y)	11	8.9	0.9	7.2	10.2
YEAR (y)	11	24.6	3.7	18.5	31.1
DISTHQ (m)	11	1806.8	1388.4	353.1	4200.0
AREAAM (ha)	11	134.9	78.6	70.0	352.0
MAT (%)	11	36.3	14.2	17.8	62.0
OCT (%)	11	51.2	17.2	27.3	79.9
RIVT (%)	11	15.9	18.0	0.0	52.8
FISH (#)	11	8.4	3.2	4.9	16.4
BEN (#)	11	5.5	1.8	2.7	9.1
<i>Loco</i> (\$/kg)	11	4362.9	953.5	3000.0	5800.0
<i>Congrio</i> (\$/kg)	11	922.7	133.3	700.0	1133.3
MAI (rank order)	11	1.4	0.5	0.4	2.1
TOTAL (#)	11	71261.6	73860.1	3723.0	262703.0
CPUE (#/day)	11	13774.4	10480.1	3016.0	39633.0

Table 5-4. Regression models of total *locos* caught in the 2003 season (TOTAL) and catch-per-unit effort (CPUE) for knowledge models. Independent variables used in the analysis shown in column 1. Note: ** is highly significant where $p < 0.01$, * is significant where $p < 0.05$, and + is slightly significant where $p < 0.1$.

Dependent Variables	Total Catch Knowledge (B) # of <i>locos</i>	Total Catch Knowledge (F)	CPUE Knowledge (B) <i>Locos/day</i>	CPUE Knowledge (F)
R ²	0.82		0.88	
Intercept	-507267**	16.05	19250*	11.63
MAT	6660**	2209		
OCT	4963**	14.55	-335*	10.07
RIVT	5354**	27.22	211+	4.55
BOAT			612*	7.51
N	11		11	
Unit of analysis	Syndicate		Syndicate	

Table 5-5. Regression models of catch-per-unit effort (CPUE) for environmental models. Independent variables used in the analysis shown in column 1. Note: ** is highly significant where $p < 0.01$, * is significant where $p < 0.05$, and + is slightly significant where $p < 0.1$.

Dependent Variables	CPUE Environment (B) <i>Locos/day</i>	CPUE Environment (F)
R ²	0.50	
Intercept	50339**	16.68
PARA		
PHOT	-16212*	9.13
WEIGH		
N	11	
unit of analysis	Syndicate	

Table 5-6. Regression models of total *locos* caught in the 2003 season (total catch) and catch per unit effort (CPU). Independent variables used in the analysis shown in column 1.

	Dependent Variables	<i>Loco</i> (B) pesos/kg	<i>Loco</i> (F)	<i>Congrio</i> (B) pesos/kg	<i>Congrio</i> (F)	Management Area Income (B) Units	Management Area Income (F) Units
	R ²	0.75		0.45		0.35	
	Intercept	4518.44**	273.73	0.00	0.08	-1.63	11.39
Knowledge	BEN					0.05	8.12
	FISH	32.41**	12.34	11.39**	14.3		
	MAT						
	OCT	-6.51**	12.17				
	RIVT	5.17*	6.25	-3.10**	7.37		
	YEARS			3.7*	5.29		
	EDU			30.60**	20.54		
Environment	PARA	-59.32**	251.78				
	PHOT	801.30**	51.65	220.16**	19.18	-0.62	28.41
	WEIGHT					0.03	55.90
	DISTHQ					0.00	20.97
	AREAMA					0.00	14.46
	BOAT	-46.55**	36.91				
	N	109		75		218	
	Unit of analysis	Fisher		Fisher		Fisher	

Table 5-7. The best models for each number of variables with R^2 , Adjusted R^2 , C(p), AIC, BIC, and the explanatory variables. Percent variation explained by each factor was calculated by comparing R^2 values.

	Variabl es	R^2	Adj. R^2	C(p)	AIC	BIC	Variables in Model
<i>Loco</i> Price	1	0.43	0.43	149.72	1413.80	1412.85	PARA
	2	0.64	0.64	58.24	1365.95	1365.80	PHOT PARA
	3	0.70	0.69	35.27	1349.61	1349.93	PHOT PARA BOAT
	4	0.71	0.70	30.65	1346.18	1346.54	PHOT PARA BOAT RIVT
	5	0.74	0.72	21.57	1338.44	1339.46	PHOT PARA BOAT OCT FISH
	6	0.75	0.74	16.72	1333.96	1335.62	PHOT PARA BOAT OCT RIVT FISH
	7	0.76	0.75	14.27	1331.53	1333.79	PHOT PARA BOAT YEARS OCT RIVT FISH
	8	0.77	0.75	13.19	1330.36	1333.18	PHOT PARA BOAT AGE YEARS OCT RIVT FISH
<i>Congrio</i> Price	1	0.14	0.13	35.35	777.55	778.22	PHOT
	2	0.23	0.20	26.38	771.50	772.14	PHOT FISH
	3	0.34	0.31	14.12	761.72	762.72	PHOT EDU FISH
	4	0.40	0.36	9.10	756.54	758.66	PHOT EDU RIVT FISH
	5	0.45	0.40	6.00	753.20	756.21	PHOT EDU YEARS RIVT FISH
Monthly Management Area Income	1	0.08	0.07	87.0	-69.50	-68.75	DISTHQ
	2	0.16	0.15	61.74	-88.23	-87.53	PHOT WEIGH
	3	0.23	0.22	40.78	-105.33	-104.41	PHOT WEIGH DISTHQ
	4	0.29	0.27	24.81	-119.53	-118.18	PHOT WEIGH DISTHQ AREAMA
	5	0.33	0.31	12.13	-131.74	-129.74	PHOT WEIGH DISTHQ AREAMA BEN
Total Catch (know)	1	0.27	0.19	22.10	246.15	244.89	RIVT
	2	0.42	0.32	16.55	244.85	243.43	MAT RIVT
	3	0.82	0.75	4.00	234.48	240.40	OCT MAT RIVT
CPU Know	1	0.70	0.67	11.20	192.14	192.24	RIVT
	2	0.81	0.76	6.55	189.14	190.85	BOAT OCT
	3	0.88	0.83	4.00	185.63	191.54	BOAT OCT RIVT
CPU Env	1	0.50	0.45	0.98	198.91	202.13	PHOT

Table 5-8. Partial r-square, significance levels, and average squared canonical correlation of stepwise discriminant analysis of *loco* characteristics.

Step	Variable	Partial R-Square	Pr>F	Average squared canonical correlation	Mean Values Successful	Mean Values Unsuccessful
<i>Loco</i>						
1	WEIGH (g)	0.43	<0.001	0.44	126	104
2	PARA (%)	0.17	<0.001	0.53	10	19
3	PHOT (mg/m ³)	0.15	<0.001	0.65	2	2
4	ROADV (km ²)	0.10	<0.001	0.68	96	49
5	BEN (#)	0.04	0.03	0.69	4	6
6	YEAR (y)	0.03	0.07	0.70	23	23
<i>Congrio</i>						
1	ROADV (km ²)	0.23	<0.001	0.24	47	92
2	FAC (#)	0.05	0.05	0.28	1	2
3	AREAMA (ha)	0.04	0.10	0.30	95	115
4	BOAT (#)	0.06	0.04	0.34	20	16
5	OAC (#)	0.07	0.02	0.39	1	2
6	PARA (%)	0.08	0.02	0.43	22	23
7	EDU (y)	0.05	0.06	0.47	9	8
Management area						
1	PARA (%)	0.16	<0.001	0.16	13	25
2	AREAMA (ha)	0.07	<0.001	0.21	144	112
3	DISTHQ (km ²)	0.05	<0.001	0.25	1887	1418
4	FAC (#)	0.04	<0.001	0.28	2	1
5	BOAT (#)	0.02	0.03	0.29	16	19
6	BEN (#)	0.04	0.01	0.32	6	6

Table 5-9. Number of observations and percent classified and error count estimates of successful and unsuccessful groups using stepwise discriminant analysis.

	Successful	Unsuccessful	Total
<i>Loco</i>			
Successful	50	3	53
	94	66	100
Unsuccessful	10	49	59
	17	83.05	100
Total	60	52	112
	54	46.43	100
Rate	0.06	0.17	0.11
Priors	0.50	0.50	
<i>Congrio</i>			
Successful	39	9	48
	81	19	100
Unsuccessful	4	31	35
	11	89	100
Total	43	40	83
	52	48	100
Rate	0.19	0.11	0.15
Priors	0.50	0.50	
<i>Management Area</i>			
Successful	93	27	120
	77.5	23	100.
Unsuccessful	55	79	134
	41.04	59	100
Total	148	106	254
	58.27	42	100
Rate	0.23	0.41	0.32
Priors	0.50	0.50	

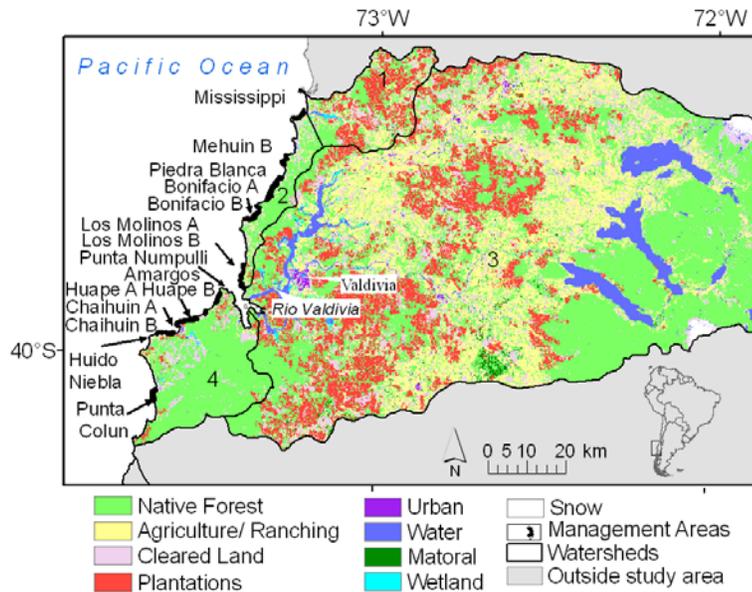


Figure 5-1. Study Site in the Valdivia-Province Coastal System, Chile. The management areas are located in black along the coast. In some cases two management areas are listed due to space constraints (i.e. Huape A and Huape B). Watersheds are numbered from 1 to 4. Some fisher syndicates have more than one management area. The influence of forest-plantations (high chlorophyll-*a* concentration values in the nearshore and *loco* shellfish with high levels of parasites) extends from the outlet of Rio Valdivia (the river from the Valdivian watershed, #3) northward (management areas Punta Numpulli northward).

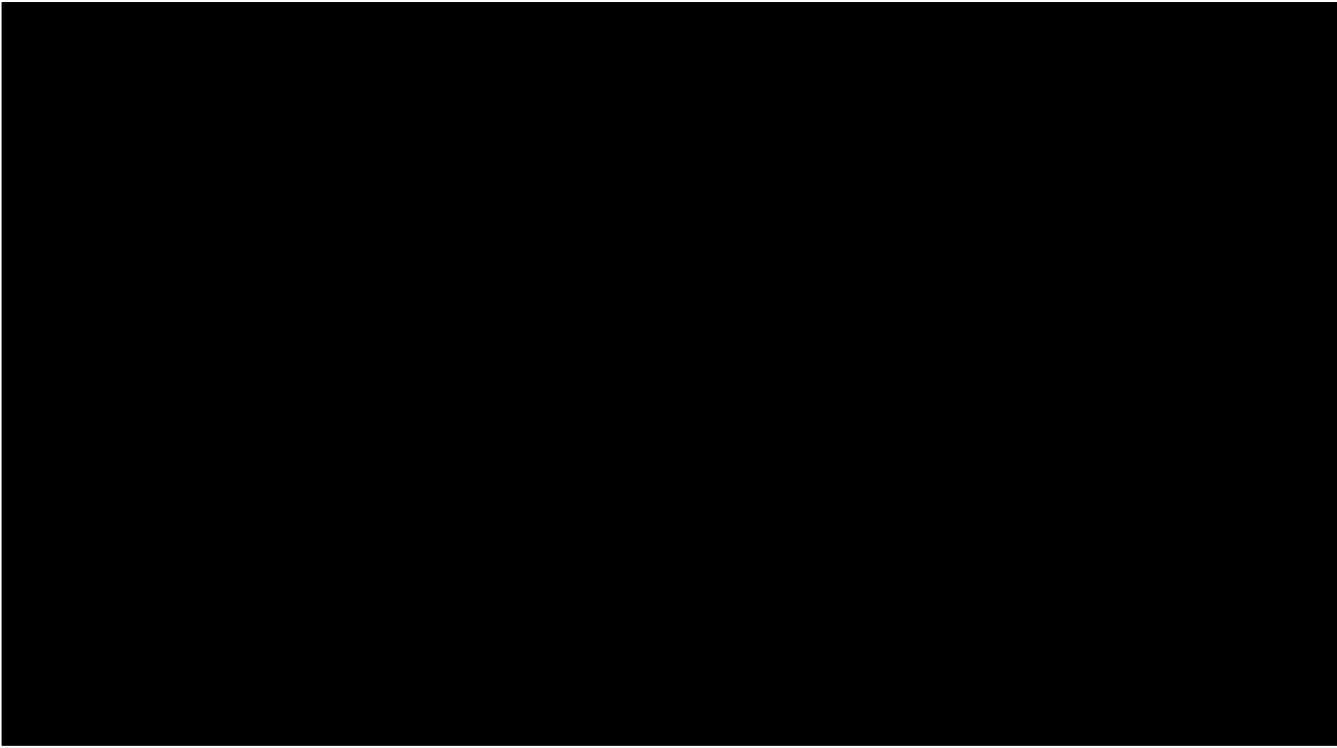


Figure 5-2. Percent variance in price explained by environmental and knowledge factors for the *loco* and *congrío* fisheries.

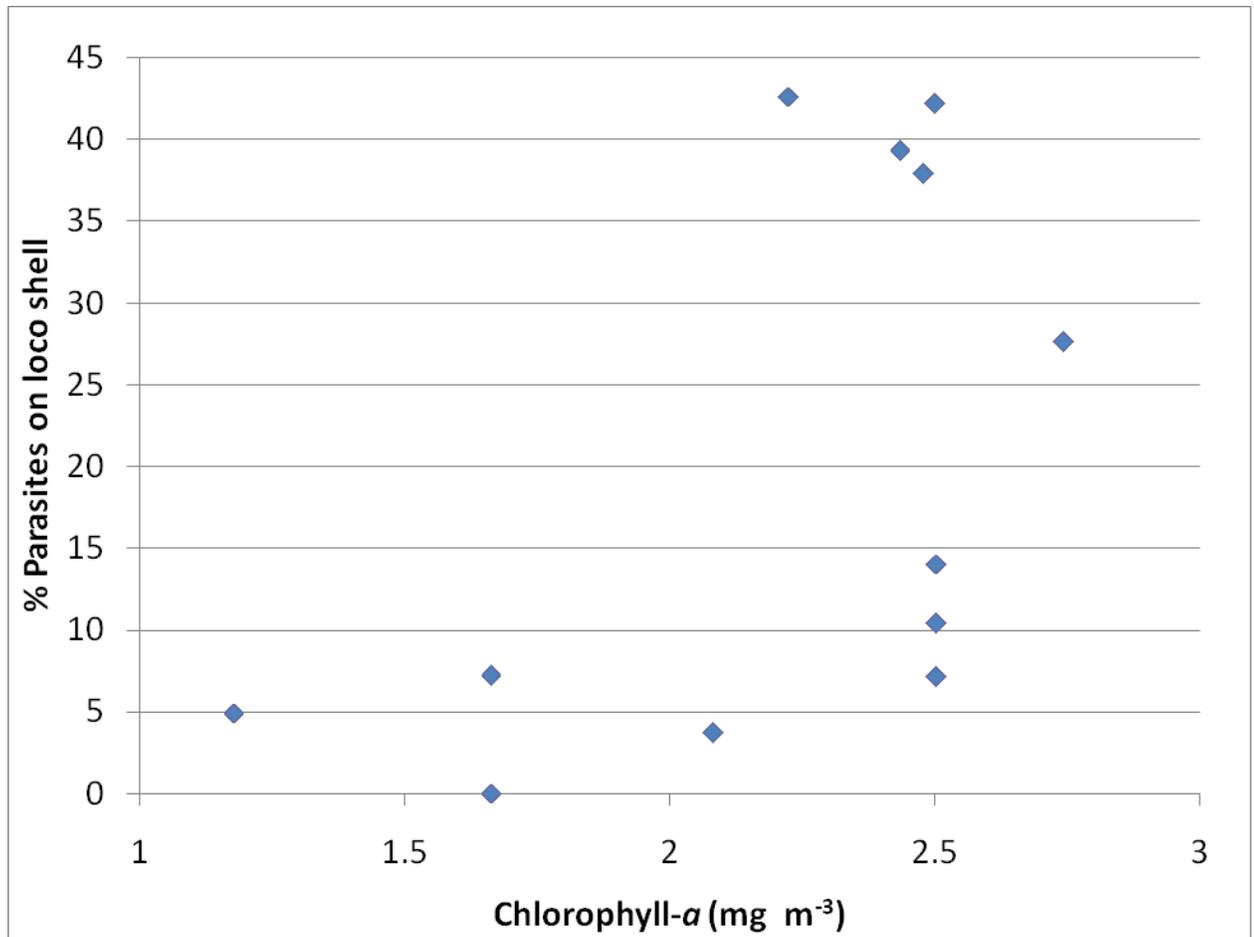


Figure 5-3. The relationship between chlorophyll-a and parasites on *loco* (*Concholepas concholepas*) shells in the management areas. If chlorophyll-a increases above 2.4 mg/m³ then the % of parasites on the *loco* shells increases.

CHAPTER 6 CONCLUSIONS

In region X of Chile, forest plantations represent the most recent development threat to the coastal system. Native forest is substituted and marginal agricultural areas are being converted to forest plantations; fishers and farmers livelihoods are therefore changing. The Valdivia zone has changed from a system dominated by agriculture and to a lesser extent native forest to a region where plantations dominate. People living in counties with forest plantations are migrating. The small-scale farmers on the sloped mountains have likely migrated to urban areas since forestry companies buy out small-scale farmers and replace their land with forest plantations. Fishers living in regions that are influenced by forest plantations are vulnerable to the associated changes in the nutrient dynamics in the nearshore.

The chlorophyll-a patterns in the nearshore show that chlorophyll-a concentration is influenced by landscape change. The Valdivia region has the highest chlorophyll-a concentration in the nearshore. The high chlorophyll-a values are the result of nutrients that enter the water and increase the presence of nitrogen limited primary producers in the system. The enriched $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values of the *loco*-shellfish tissue confirm that terrestrial nitrogen is entering the nearshore that is influenced by forest plantations. The nitrogen is increasing the photosynthetic biomass in the region and these new photosynthetic organisms are fixing atmospheric carbon. In contrast, the native forest influenced watersheds have low chlorophyll-a values and depleted isotopic signatures.

Landscape change and the associated changes in chlorophyll-a values in the nearshore are the main factors that describe the distribution of phoronid shell-borers and barnacle epibionts across *loco* shellfish in region X. Epibionts and boring organisms are

abundant in areas where the nitrogen dynamics in the nearshore have shifted because of plantation development.

Fishers have been adapting to the environmental changes in the region. Environmental features best explained price differences for the benthic, closed access, *loco* fisheries. Knowledge and technology, which help fishers catch more fish and perhaps find the better resources, don't compensate for environmental change in these fisheries. Those fishers in management areas with poor quality resources are vulnerable to changes in the environment because the traditional means by how fishers adapt to change (knowledge and technology) does not foster success.

Local knowledge explained a smaller fraction of success for the *loco* fishery and a larger fraction of success for the *congrío* fishery. Diving experience helped *loco* fishers succeed and offshore-fishery experience helped the *congrío* fishers succeed. Only in the open-access fisheries were fisher knowledge powerful enough and the influence of the environment low enough that fishers could adapt to changes in the environment

We need to continue to understand the terrestrial influences on the nearshore ecosystem beyond the traditional scope. Companies and governments need to proactively understand the potential impacts of plantations at landscape and seascape levels.

Economic models that incorporate environmental variables need to characterize other environmental costs not previously considered or seen. For example, if landscape change and the associated changes in the chlorophyll-a influence the growth of the *loco* shellfish in Valdivia by 20 grams, these 20 grams translate into 2,000 kg for fishers given an average harvest of 100,000 *locos* during the year. If of six *locos* sell per kilo, and *locos* cost \$1 per loco, a fisher group may lose \$12,000 per year, and each fisher could lose

\$400, the equivalent of about two months salary. Over half of the world's population lives in coastal systems (Cohen et al. 1997) and extensive development occurs along the coast; the livelihoods of the world's 13.1 million artisanal fishers (FAO 2002) depend on our continued understanding of the nearshore environment.

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BIOGRAPHICAL SKETCH

Tracy Van Holt is a Landscape Socio-Ecologist finishing her Ph.D. at the University of Florida. Her research focuses on the ecological and social factors that influence natural resource harvest and marketing of these products with a focus on Latin American Conservation and Development. For her dissertation, Tracy has studied the effects of land use/land cover change on the nearshore fisheries in southern Chile. She has identified how forest plantations influenced the nearshore environment and the impacts on the loco shellfishery. Her work also addressed fisher success and the social and ecological (at the small scale and landscape level) factors that influence price for various artisanal fisheries in Chile.

Her past work with hunters in Bolivia has addressed how researchers can gain a consensus about a community's opinion on natural resources. For her MS at the University of Florida, Tracy worked in the Brazilian Pantanal and examined how wildlife movements were influenced by palm fruits and spatial arrangement of forest islands. Prior to grad school, Tracy ran the Research Fellowship Program at the Wildlife Conservation Society for three years. Her B.S. degree is in Biochemistry from SUNY at Stony Brook. Her research has been supported by NASA, Fulbright, NSEP, Rotary, and the TCD program at the University of Florida.