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## The consequences of landscape change on fishing strategies



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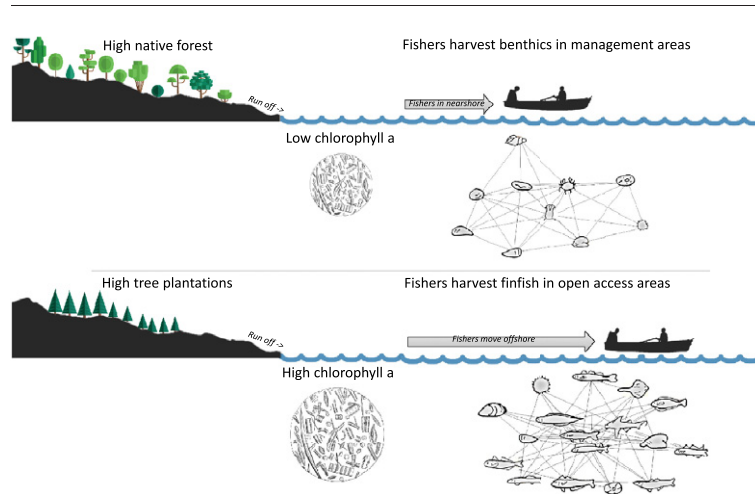
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### HIGHLIGHTS

- Spatially restricting fishing to areas makes fishers vulnerable to changes.
- Design addressed: anthroposphere (land-use), biosphere (fisher strategies), and hydrosphere (eutrophication).
- Incorporated remote sensing (Landsat/SeaWiifs), biological data, and behavioral networks.
- Fisher harvesting patterns differ according to upland land use.
- Fisher harvesting strategies are vulnerable to land use change, such as plantations.

### GRAPHICAL ABSTRACT



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### ABSTRACT

We show how land-use change can affect fisher-harvesting behavior. We test whether fisher harvesting behavior can be predicted by landscape change patterns at local (~200 km) and regional (~1200 km) levels. Our data suggest that fishers harvesting in areas near tree plantations reduced benthic-invertebrate harvests in favor of demersal and pelagic finfish that are usually located further offshore. Fishers' management areas, which were near tree plantations, had higher chlorophyll-*a* values, and contained shellfish with more endobionts. Technology (owning a boat) and experience (age, years fishing, and alternative livelihoods) explained little in fisher-harvesting behavior. The flagship Chilean fisheries management program and seafood companies sourcing from these areas will need to respond to these new challenges. Despite complexities in designing cross-scale, social-ecological studies, we can no longer ignore the interconnectedness of commodities in the biosphere.

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## 1. Introduction

Evidence suggests that anthropogenic pressures on Earth have disrupted the nitrogen cycle to such an extent that the boundary where humans can safely operate has been passed (Rockstrom, 2009). The altered nitrogen flow is driven by land use changes that is tied to the increasing speed and scale at which commodities are traded and transported (Lambin and Meyfroidt, 2011; Geist and Lambin, 2002). These land-use changes include deforestation, agricultural expansion and intensification, urbanization and tree plantation establishment (Nixon, 1995; Lambin and Meyfroidt, 2011; Van Holt et al., 2016a). Such land-use changes, including tree plantations (Oyarzun and Pena, 1995; Oyarzun et al., 2007), have been shown to be associated with higher nutrient flows to coastal waters that affect marine ecosystems (Diaz and Rosenberg, 1995; Smith et al., 1999; Anderson et al., 2002; Kemp et al., 2005; Van Holt et al., 2012).

Industrial tree plantations are becoming an extensive land-use globally (Rudel, 2009; Lambin and Meyfroidt, 2010; Van Holt et al., 2016a) that is fuelled by the shift from primarily supplying domestic energy and wood-product needs (e.g. China; Berndes et al., 2003; Popp et al., 2011) to supplying global pulp and carbon markets (Sedjo, 1999; Berndes et al., 2003). The FAO forecasts that by 2030 tree plantations<sup>1</sup> will account for 7% of the global tree cover (Penna, 2010). Plantations are projected to increase from 260,538 million/ha to 344,702 million/ha from 2005 to 2030 (a 32.3% increase globally) (Penna, 2010).

The influence of terrestrial commodities, such as plantations, on marine environments has been given little attention despite calls from the scientific community for more efforts linking land and sea in research and management (Sloan et al., 2007; Tallis et al., 2008; Halpern et al., 2009). We build on research that has shown that Chilean fishers working in management areas influenced by tree plantations are losing income because of the declining value of their main commercial catch, the Chilean loco (*Concholepas concholepas*) (Van Holt, 2012). One reason is that nutrients entering the coast have led to an increase in phytoplankton biomass, which increased the abundance of epibionts and endobionts on the loco shells (Van Holt et al., 2012) and reduced the loco size and price (Van Holt, 2012). In some areas of the Chilean coast, the economic effect for fishers was so dramatic that in the loco fishery even skill and long-term experience could not compensate for the economic loss (Van Holt, 2012). Only fishers with the ability to move into fisheries entering the management areas [also known as Territorial User Rights Fisheries (TURF)] have reported economic success in areas with heavy influence of plantations (Van Holt, 2012).

This study moves beyond the water and considers the interaction between two elements of the biosphere, the land and the sea, and how this ultimately affects fisher behavior, and the TURF fisheries management model. First, at a local level, data is drawn from interviews in 11 fishing communities in a region of southern Chile across ~200 km that encompasses 17 fisheries management areas. Here we test whether shared harvesting behaviors at the local level can be explained by the environmental characteristics by comparing harvest strategies of fishers working in management areas near and far from tree plantations. We control for other potential explanations for harvesting behavior including technology (owning a boat) and experience, that is, alternative livelihoods, years fishing, and age, as well as new fishers entering the areas. Then, to test whether we find evidence of our findings at regional scales, we analyzed whether harvesting patterns across four administrative regions that spanned ~1200 km were related to tree-plantation coverage in these regions. Finally, we discussed how linkages across commodity sectors such as forestry and fisheries could affect management and seafood sourcing.

## 2. Methods

### 2.1. Study site

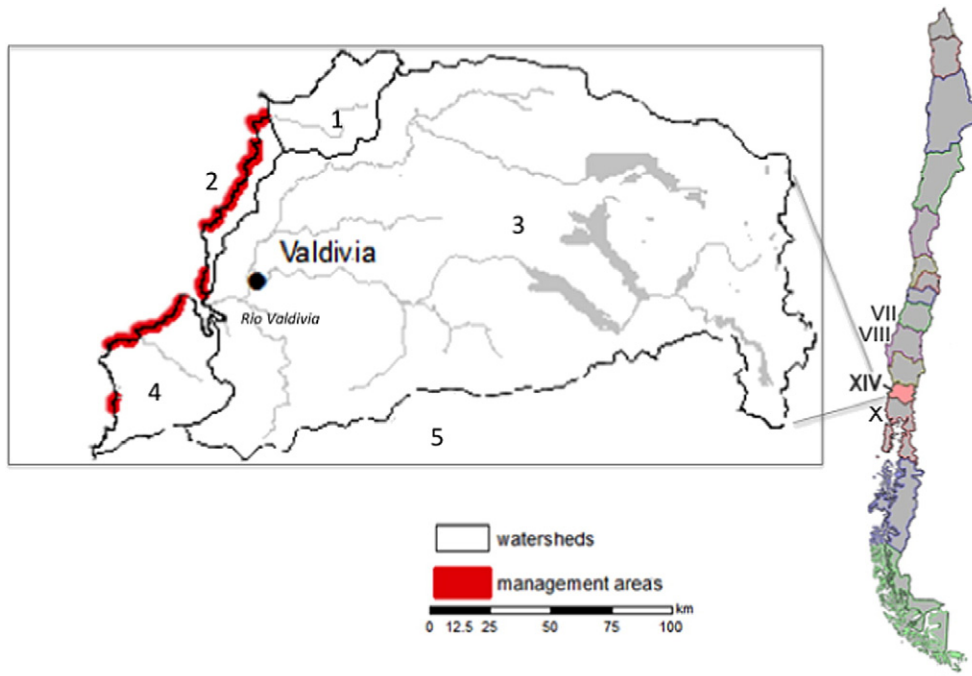
Chilean small-scale fisheries management is known across the globe as a relatively successful model, in part, because at its very core, it is guided by ecosystem-based principles (Moreno et al., 1984, 1986; Castilla, 1994). The rights and responsibility for fishery management are devolved to the fishers, who are responsible for benthic species in their assigned management areas. Both forestry and fishing sectors are essential to Chile's national economy and it makes sense to consider how these sectors may influence each other. Chile has strong agriculture, forestry, and fisheries commodity sectors, which have been developed, in part, as a means to strengthen the national economy from fluctuations in the mining sector and to develop the country (Auty, 1993; Gwynne, 1996). On the land, there have been dramatic changes since the 1980's when subsidies were given to establish tree plantations. Plantations have become an increasingly dominant part of the landscape. As of 2013, tree plantations covered ~20% of the total tree cover. In the sea, over 90,000 fishers relied on small-scale fisheries, which are central to the economy of many coastal communities. The TURF management system for benthic resources was implemented in the region in the 2000s in response to the decline of the prized loco, *Concholepas concholepas*, shellfish (Gelcich et al., 2010).

The loco fishery is key for many coastal communities because the price it commands on the global market makes fishing a viable livelihood; if the quality is good, fishers can gain the bulk of their yearly income from this fishery, though all fishers supplement with other fisheries or other activities. Since locos are carnivores, their successful production indicates that their prey—i.e., mussels and tunicates—are also well off; in areas with high overharvest, the ecosystem dynamics shift (Moreno et al., 1984, 1986; Castilla, 1999). The TURFs focus on benthic resources and commercialized finfish species are formally managed through seasonal closures and quotas; though, of course, if a non-member is catching finfish in someone else's benthic management area, they are essentially thrown out regardless of whether technically this type of fishing is open access. Fishers located near rivers may also harvest riverine species such as mussels or *navajuela* clams. The fisheries management system is considered an ecological success story within Chile because species within management areas are available for harvest and species diversity is higher within surveyed management areas (Gelcich et al., 2012). In a global comparison of 18 fisheries traded globally, the strong institutions in place with the TURF system in Chile was found to be the main condition that explained the successful outcome of maintained or increased stocks of locos (Crona et al., 2015). The Chilean model assumes that controlling overharvest results in well functioning management areas, and now that overharvest is under control, attention can be turned to factors outside of fisher's control, such as environmental conditions. One potential challenge in the set-up of the TURFs is that fishers were restricted to harvesting benthic resources in certain management areas; they cannot easily switch to another location to harvest benthic species as a way to adapt to local environmental changes.

### 2.2. Research design and sampling

The highest concentrations of plantations are found between regions VII and X (Chile numbers their administrative regions) (Heilmayr et al. 2016). Van Holt et al. (2016a) showed that at the plantation frontier between 1985 and 2001, about half of plantations were established as a result of deforestation of native forest and half were a result of planting trees on agricultural areas or bare soil. Plantations were established predominantly at the foothills and rarely established on flat land, which were reserved for commercial agricultural production. Tree plantations were established on higher sloped lands ( $8^\circ \pm 5^\circ$  average slope and 228 m  $\pm$  114 m average elevation) (Van Holt et al., 2016a) and these agricultural crops require fertilizers, which run off down the watershed. Van Holt et al. (2012) showed that phytoplankton blooms (high

<sup>1</sup> This FAO definition does not include palm trees (Penna, 2010).



**Fig. 1.** The local analysis of fisher behavioral networks were characterized for 279 fishers across 11 syndicates harvesting in benthic fisheries management areas across ~200 km of coastline (Region XIV and a portion of X). Management areas in watersheds 4 and 5 (watersheds labelled 1–5 on the figure inset) had little influence from tree plantations, whereas management areas near watersheds 1–3 had higher influence from tree plantations based on chlorophyll-*a* patterns and characteristics of loco (*Concholepas concholepas*) shellfish. The regional analysis of fishing behavioral networks was conducted across four regions covering ~1200 km with varying influence from tree plantations (Regions VII, VII, XIV, and X).

chlorophyll-*a* levels) coincided with tree-plantation cover in the nearby watersheds (using SeaWiFS satellite images combined with Landsat data); the blooms were highly correlated with more epibionts and endobionts on loco shells. Epibionts or endobionts were essentially absent on loco shells historically; similar types of shells were found recently in more pristine areas far from plantations and phytoplankton blooms (Van Holt et al., 2012). This variation is well known to fishers and buyers alike that know where the “good” locos are located; these locos have fewer epibionts or endobionts, they are heavier, and command a higher price on the market. This variation in tree-plantation coverage and in loco quality also serves as our justification for space-for-time substitution, where we compared different sites across space, rather than through time.

#### 2.2.1. Local

We studied the harvesting behavior of fishers working near the plantation frontier, which spanned across five watersheds and 200 km of coastline (see Fig. 1). The Rio Valdivia divides the surveyed area in two with approximately half of the syndicates and management areas located below the river, and the other half above the river. The plantation influence is mainly from Rio Valdivia northward (Van Holt et al., 2012). We analyzed the behavior of individual fishers ( $N = 279$ ) rather than syndicate communities ( $N = 11$ ) because individuals and smaller groups often specialize and syndicate-level co-harvest is typically reserved for annual events like the loco harvest. In August and September 2004 we conducted the first census of fishers in the Valdivian region in conjunction with syndicate leaders (Fig. 1A); posters were set up, letting fishers know of the census, and syndicate leaders helped to gather fishers for the census.

#### 2.2.2. Regional

Here we focus on four regions that had varying levels of tree-plantation coverage (Fig. 1). Regions VII and VIII had higher percentages of tree plantation coverage (15% and 24%, respectively) and represent the origin of tree-plantation establishment in Chile. Region XIV represents medium plantation cover (11%) and region X, lower plantation cover with the percentage of tree plantation coverage as low as 1%

(INFOR, 2004). All regions are influenced by the Humboldt Current and contain similar species and therefore are biogeographically similar (Lancellotti and Vasquez, 2000; Fernandez et al., 2000; Thiel et al., 2007).<sup>2</sup>

### 2.3. Data

#### 2.3.1. Local

We test whether plantation cover can predict fisher behavior. For our dependent variable, we asked fishers to report the top five species that they harvested. The top five species was the best way for us to focus on the key species in the absence of catch data as other survey questions showed us that most fishers dabble in many species. Independent variables included the environment, technology, and experience. Environmental variables were assessed for each fisheries management area; if the fisher was associated with two management areas via their syndicate, then the environmental information was averaged and then we assigned a syndicate-level value for each variable for each fisher. First, we assessed the percentage increase in tree plantations by classifying tree-plantation land use in October 5, 1985 Landsat 5 TM and November 29, 2001 Landsat 7 ETM+ satellite images and calculating the percentage change in tree plantations in the watershed nearest and most influential to the TURF for each fisher (PPL\_CH). Next, the average chlorophyll-*a* value ( $\text{mg}/\text{m}^3$ ) (CFAM) was calculated for the pixels on the satellite image that were located near the TURFs for each fisher using the SeaWiFS satellite images (9 km resolution) and NASA's Giovanni tool (Acker and Leptoukh, 2007). We considered April, May, June, and July from 1998 to 2005. Finally, loco-shellfish quality (POLFOR) was measured by assessing the percentage of phoronids

<sup>2</sup> Regions VII and VII have the least rocky shoreline (<5%, and <15%, respectively) whereas regions X and XIV are mainly rocky shoreline (>80%). Region XIV is the site of the local analysis and in the regional analysis this area is included in region X because Chile divided region X into two and we had to aggregate these sites.

**Table 1**

MRQAP model of fisher-harvesting behavior with 11,130 dyadic observations. \*Note the absolute difference was taken between values, except for BOAT, since those values were dichotomous (present or absent). For terrestrially-based livelihoods, a one mode affiliation matrix was generated.

	Stdized coef	Std err	p-Value	Adj. R <sup>2</sup>
Environmental				.315
CFAM*	-.537	.130	.000	
PPL_CH*	-.062	.007	.078	
POLFOR	-.035	.002	.038	
Intercept	.000	.000	.000	
Environmental + Technology				.315
CFAM*	-.537	.127	.000	
PPL_CH*	-.062	.007	.073	
POLFOR	-.035	.002	.041	
BOAT	.000	.030	.438	
Intercept	.000	.000	.000	
Environmental + Technology + Experience				.323
CFAM*	-.530	.128	.001	
PPL_CH*	-.063	.007	.083	
POLFOR	-.035	.002	.041	
BOAT	.000	.030	.543	
YEARS *	-.036	.006	.209	
AGE*	.022	.005	.330	
ALTLIV	.084	.069	.012	
Intercept	.000	.000	.000	

(*Phoronis ovalis*) and polychaetes (*Dodecaceria cf. opulens*) in a sample of thirty locos in fishers' management areas in 2004, since the quality of shellfish has been tied to tree-plantation establishment. To control for the influence of technology on fisher behavior, we included whether the informant reported owning a boat (BOAT). To account for experience, we asked fishers to report on the years that they had been fishing (YEARS), their age (AGE), and the land-based activities they participated in (from a choice of business, forestry, non-timber forest products, agriculture, or ranching) (ALTLIV), because these factors might also explain harvesting patterns. For example, if a fisher had many land-based activities, they may only harvest locos during the season, and forgo harvesting other species of lesser value.

We also identified the percentage of fishers that had left or transferred to different syndicates from 2004 to 2012 to test if fisher mobility could be explaining fisher behavior. Our preliminary analyses showed that official fisher classifications of whether they specialized in diving and fishing had little to do with what fishers actually catch so these classifications were excluded in our final analysis. This finding matched our participant observations.

### 2.3.2. Regional

To compare the harvesting profiles at regional scales, we used the total harvest data reported for artisanal fisheries across four adjacent Chilean administrative regions that had varying influence of tree plantations. We aggregated annual landings statistics in the artisanal sector between 2007 and 2012 (SERNAPECA 2006-12).<sup>3</sup> We calculated the percentage of tree-plantation coverage in these regions using a publically available government dataset (INFOR, 2004). Also we evaluated how benthic and pelagic catches varied over these six years.

## 2.4. Analysis

### 2.4.1. Local

The local analysis was done in three steps. First, we identified communities of fishers that had similar harvesting behavior. We restricted

the rest of the analyses to the harvesting behavioral communities (explained below) with more than ten fishers. Second, we tested to see what independent variables – environmental, technology, or experience – affected fisher behavior in a network-level regression called a multiple regression quadratic assignment procedure or MRQAP. The MRQAP dyadically compared fisher-harvesting behavior (dependent variable) to the independent variables—environment, technology, and experience. For the MRQAP, all variables were transformed into a fisher-by-fisher matrix. Third, we went back to the communities from Step 1 and characterized the species harvested, environmental, technology, and experience variables to see what where the characteristics associated with each harvesting behavioral community. Each step is explained in detail below.

First, harvesting behavioral communities were identified using a network. To do this, a fisher-by-species matrix, a fisher harvesting profile, was created where  $x_{ij} = 1$  if the  $i$ th fisher reported harvesting species  $j$  and  $x_{ij} = 0$  otherwise. This yielded a two-mode matrix  $X$ . We can look at the similarities in species harvested across fishers by producing a product matrix of  $X$  and the transpose  $XX'$ , where the  $ij$ th cell reflects the number of fish harvested that both fishers  $i$  and  $j$  have in common. This can be viewed as an indicator of similarities in harvesting behavior between each  $i$  and  $j$ . This yields an  $n \times n$  one-mode fisher-by-fisher matrix (or network). To find cohesive subsets of fishers vis-a-vis their harvesting behaviors, we subjected the behavioral network to the Girvan-Newman community detection algorithm (Girvan and Newman, 2002). The algorithm finds cohesive subcommunities using an edge betweenness removal approach. Because we were interested in explaining larger patterns, we only included communities with more than ten fishers for further analyses; these four unique fisher behavioral communities contained 106 fishers in total. This yielded a  $106 \times 106$  network of fisher-harvesting behavior that bounded the behavioral network for further analysis.

Second, a multiple regression quadratic assignment procedure (MRQAP) was used to see if at a dyadic level, environmental conditions, technology, or experience explained fisher-harvesting behavior. In other words, are dyadic similarities in the fishing-harvesting behavioral network accounted for by environmental and other variables? We used the semi-partialling MRQAP test proposed by Dekker et al. (2007), since this test is robust to issues of multicollinearity. In the MRQAP, the rows of the independent variable matrix are randomly permuted and compared with the observed matrix or matrices to see how likely the relationships could have occurred by chance. As noted, the dependent variable or matrix was created using harvest profiles for just the fishers that remained after the Girvan Newman groupings of harvesting behavioral communities. For the independent variables or matrices, a matrix of the absolute difference between each pair of fishers was calculated creating a fisher-by-fisher matrix for each of the environmental variables—CFAM, PPL\_CH, POLFOR—and for YEARS and AGE. For ALTLIV, we created, a fisher-by-livelihoods matrix where  $x_{ij} = 1$  if the  $i$ th fisher reported participation in alternative livelihoods (ALTLIV)  $j$  and  $x_{ij} = 0$  otherwise, yielding a two-mode matrix  $X$  (ALTLIV was generated from choices of business, forestry, non-timber forest products, agriculture, or ranching). We then produced a product matrix of  $X$  and the transpose  $XX'$ , where the  $ij$ th cell reflects the number of alternative livelihood activities that both fishers  $i$  and  $j$  have in common. This can be viewed as an indicator of similarities in alternative livelihoods between each  $i$  and  $j$ . This yields an  $n \times n$  one-mode fisher-by-fisher matrix or network, focused on livelihoods. For BOAT, we created a matrix that reflected a match, that is, both fishers had a boat. We ran three separate MRQAPS, first only involving the environmental variables, then we added technology and, finally, experience.

Third, after testing which factors best explained fisher behavior at the dyadic level, we went back to the harvesting behavioral communities from the first step to see what characteristics these behavioral communities had for each of our variables. To see what species were harvested, we created four individual species-by-species matrices, one

<sup>3</sup> Analysis began after 2007 when the administrative region X had been divided into X and XIV.



**Table 2**  
Mean and standard deviation of independent variables for four harvesting behavioral communities. Note for ALTLIV we show the percentage of fishers that reported participating in that livelihood activity.

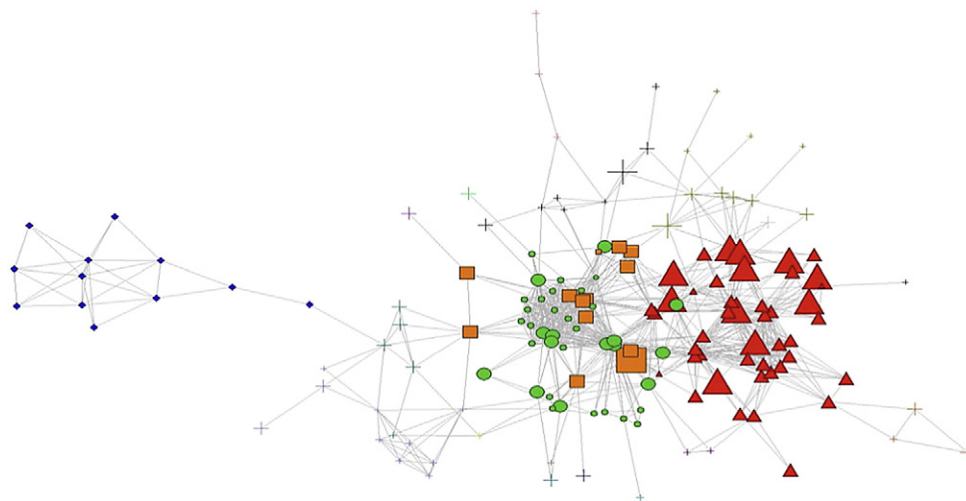
Community	N	PPL_CH	POLFOR	CFAM	BOAT	AGE	YEARS	ALTLIV				
								Business	NTPF	Forestry	Ranching	Agriculture
1	44	15.8 ± 7.9	25.3 ± 14.3	2.4 ± 0.3	28	44.9 ± 12.1	28.3 ± 12.4	0.18	0.14	0.16	0.20	0.14
2	13	12.8 ± 5.4	32.8 ± 8.8	2.3 ± 0.4	8	38.8 ± 10.3	21.8 ± 11.1	0.08	0.00	0.15	0.00	0.08
3	37	6.9 ± 4.3	15.4 ± 14.1	2.4 ± 0.3	17	41.5 ± 13.0	24.1 ± 13.0	0.19	0.41	0.22	0.65	0.41
4	12	2.7 ± 0.0	4.1 ± 0.0	1.2 ± 0.0	6	37.6 ± 5.5	21.4 ± 4.0	0.08	0.17	0.08	0.08	0.00

**Table 3**  
Harvest profiles for four harvesting behavioral communities. Communities 1 & 2 have the highest influence from tree plantations, community 3, a medium influence, and community 4, low influence. The number of species harvested in common with each species (degree centrality) is indicated in parentheses. Notes: \* indicates finfish \*\* are benthic species that are harvested in rivers, \*\*\* are benthic species that are harvested in the management areas.

High influence plantations		Medium	Low influence plantations
Community 1	Community 2	Community 3	Community 4
* <i>Cilus gilberti</i> (16)	*** <i>Concholepas concholepas</i> (10)	*** <i>Fissurella</i> sp. (11)	*** <i>Cancriidae</i> (9)
** <i>Thyrsites atun</i> (16)	* <i>Thyrsites atun</i> (10)	* <i>Cilus gilberti</i> (11)	*** <i>Pyura chilensis</i> (9)
* <i>Genypterus</i> sp. (14)	*** <i>Loxechinus albus</i> (9)	*** <i>Concholepas concholepas</i> (10)	** <i>Tagelus dombeii</i> (8)
* <i>Callorhynchus callorhynchus</i> (13)	* <i>Cilus gilberti</i> (8)	* <i>Thyrsites atun</i> (10)	*** <i>Venus</i> sp. (7)
** <i>Mytilus chilensis</i> (9)	** <i>Mytilus chilensis</i> (7)	*** <i>Loxechinus albus</i> (7)	*** <i>Concholepas concholepas</i> (7)
*** <i>Concholepas concholepas</i> (8)	* <i>Genypterus</i> sp. (4)	* <i>Genypterus</i> sp. (7)	** <i>Mytilus chilensis</i> (6)
* <i>Eleginops maclovinus</i> (8)	** <i>Choromytilus chorus</i> (4)	*** <i>Canceridae</i> (6)	*** <i>Aulacomya ater</i> (5)
* <i>Dipturus chilensis</i> (6)	* <i>Trachurus murphyi</i> (4)	** <i>Choromytilus chorus</i> (5)	*** <i>Fissurella</i> sp.(5)
*** <i>Loxechinus albus</i> (5)	*** <i>Fissurella</i> sp. (4)	* <i>Eleginops maclovinus</i> (5)	*** <i>Loxechinus albus</i> (4)
*** <i>Fissurella</i> sp. (5)	* <i>Callorhynchus callorhynchus</i> (4)	** <i>Tagelus dombeii</i> (4)	*** <i>Chorus giganteus</i> (4)
* <i>Micropogonias manni</i> (5)	* <i>Sardina</i> (4)	* <i>Callorhynchus callorhynchus</i> (4)	
* <i>Merluccius gayi gayi</i> (5)		* <i>Basilichthys australis</i> (4)	
** <i>Choromytilus chorus</i> (4)			
* <i>Trachurus murphyi</i> (4)			
* <i>Basilichthys australis</i> (4)			
* <i>Pinguipes chilensis</i> (4)			
* <i>Sardina</i> (4)			

for each harvesting behavioral community, where two species i and j were tied together if three or more fishers harvested a pair of species in common. For each species, we then calculated the number of other species that were harvested in common with it (adjacent in the network), which is known as degree centrality in network terms. A species with high degree centrality therefore was harvested most often alongside other species and a species with low degree centrality was not

often harvested in combination with other species. These networks helped to see which species were behind cohesive harvesting behavioral communities and to interpret the independent variables associated with different behavioral patterns. We also calculated the mean and standard deviation value for the independent variables relating to environment, technology, and experience for each harvest behavioral community.



**Fig. 2.** Fishers' behavioral network, based on similarity in harvesting pattern. Each node represents a fisher. A tie represents three or more species harvested in common. Larger-sized nodes indicate a higher percentage increase in tree plantations in watersheds (1985–2001) near the benthic management area through which each fisher must operate. Red triangles and orange squares = high plantation influence (behavioral communities 1 and 2 respectively), green circles = medium plantation influence (community 3), and blue diamonds = low plantation influence (community 4).

Finally, we also examined the degree of mobility, or fidelity among fishers to syndicates, by identifying the percentage of fishers that have left or transferred to different syndicates from 2004 to 2012.

2.4.2. Regional

Using UCINET version 6.510, a region-by-species matrix was created where the top ten species harvested in a region based on volume reported in landings statistics were  $x_{ij} = 1$  if the *i*th region reported harvesting species *j* and  $x_{ij} = 0$  otherwise. This yields a two-mode matrix *X*. We can look at the similarities in species harvested across regions by producing a product matrix of *X* and the transpose *XX'*, where the *ij*th cell reflects the number of species harvested that both regions *i* and *j* have in common. This can be viewed as an indicator of similarities in species

harvested between regions *i* and *j*. This yields an *n* × *n* one-mode regions-by-regions matrix or network that represents regional harvesting behavior.

2.4.3. Management

To understand the implication of landscape change for fisheries sustainability and management, we examined whether the species included in this study were managed. A fishery was considered managed if documentation existed from the fisheries department indicating opening and closing dates and/or quotas for a specific species ([www.sernapesca.cl](http://www.sernapesca.cl)) or if the fishery was part of the TURF management system as of 2012.

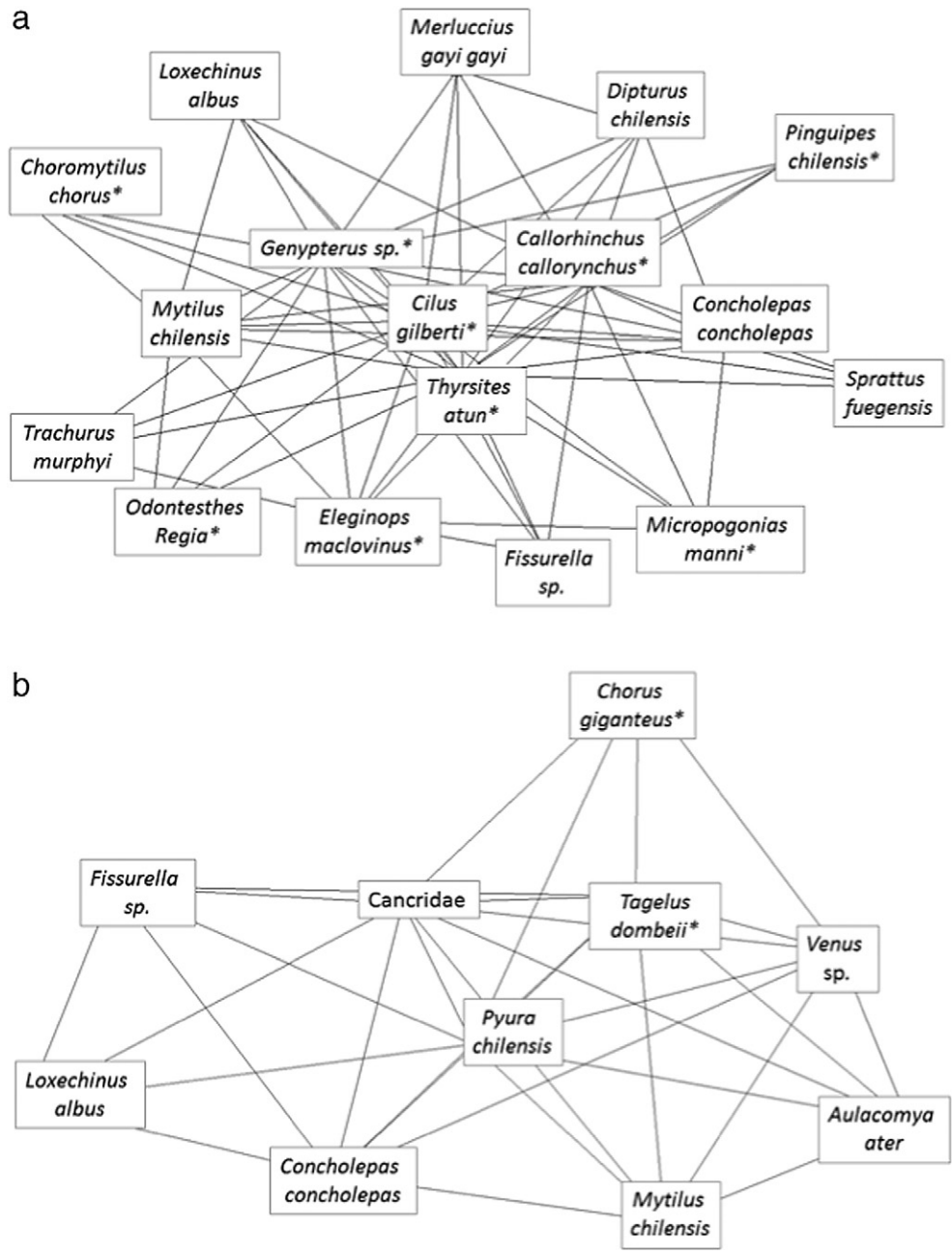


Fig. 3. Harvesting profiles of fishers from community 1 that worked mainly in management areas that had high influence from tree plantations harvest contained mainly finfish (a.) whereas fishers from community 4 that worked mainly in management areas with low influence harvest mainly benthic species (b). Species that were not currently managed by government regulations are indicated \*.

### 3. Results

#### 3.1. Local analysis ~200 km

##### 3.1.1. Landscape change characteristics were related to fisher-harvesting behavior

For the 106 fishers analyzed in the MRQAP, the environmental analysis contributed the most toward explaining the variation in fisher-harvesting behavior ( $R^2 = 0.315$ ;  $p \geq 0.0001$ ) (Table 1). CFAM, the average chlorophyll-*a* value ( $\text{mg}/\text{m}^3$ ) in the management area for each fisher, was the most influential, followed by POLFOR, the percentage of polychaetes and phoronids on the loco shells in each fisher's management area, and PPL\_CH, the percentage increase in tree plantations from 1985 to 2001 in the watershed nearest to the management area for each fisher. The model was essentially unchanged when technology, that is, BOAT—having a boat—was added ( $R^2 = 0.315$ ;  $p \geq 0.0001$ ) as having a boat was not a statistically significant explanatory variable. In the third model, where experience—YEARS (years fishing), AGE (age), and ALTLIV (alternative livelihoods)—was also added, the model improvement was almost negligible ( $R^2 = 0.323$ ;  $p \geq 0.0001$ ). What is clear is that 32% of the variation in the fisher harvesting behavior can be explained by environmental variables that indicated that the management areas were affected by landscape change; technology and experience did little to explain variation in fisher-harvesting behavior.

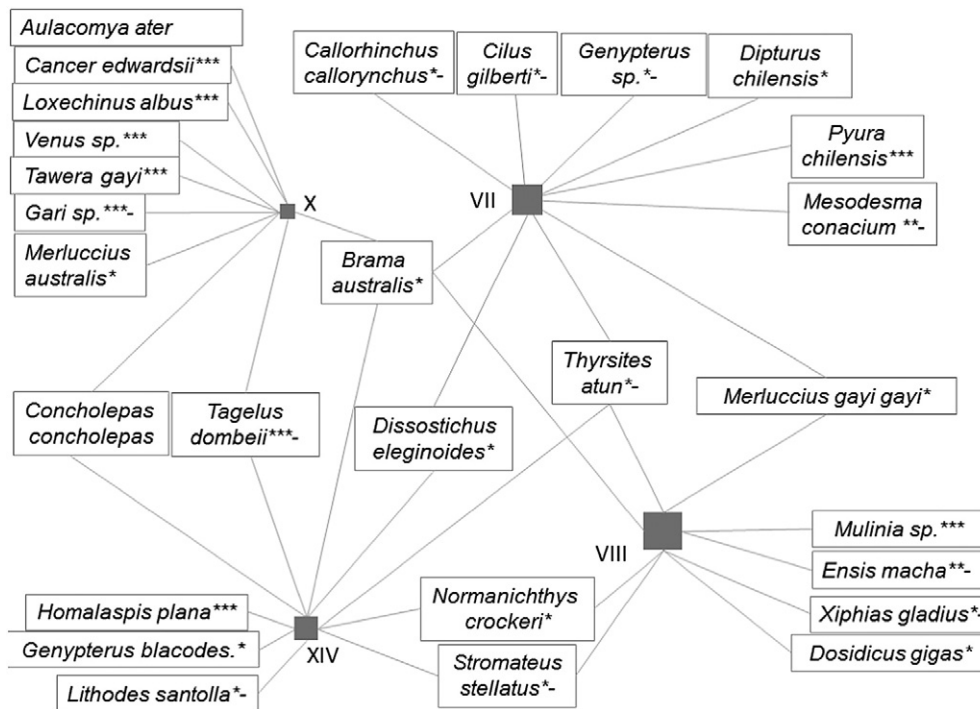
The harvesting behavioral communities had some striking differences. Harvesting behavioral communities 1 and 2 represented high plantation influence, while 4 represented low influence, and 3 represented medium influence (Table 2). The CFAM—the average chlorophyll-*a* values—were similar across communities 1, 2, and 3, with 4 markedly lower ( $1.2 \text{ mg}/\text{m}^3$ ). In communities 1 and 2, the average percentage of plantations (PPL\_CH) in associated watersheds had increased by 15.8% and 12.8% respectively from 1986 to 2001 and, on average, >25% of the loco shells were covered with phoronids and polychaetes

(POLFOR). Community 4 enjoyed a low increase of plantation cover (2.7%) and ~4% of the shells were covered. Community 3 had a modest average increase in plantations (6.9%) and 15% of the shells were covered. Experience in terms of AGE, and YEARS were similar across communities. Experience in terms of land-based activities (ALTLIV) and technology—having a boat (BOAT), did not appear to be related to landscape change—fishers with many alternative land-based livelihoods and those with many boats were associated with high and low plantation behavioral communities.

Fishers also exhibited high fidelity to their fishing syndicate since only 3.43% of the fishers from 2004 transferred to another syndicate within the Federación Interrregional de Pescadores Artesanales del Sur Federation in 2012 (the nine syndicates analyzed had 495 fishers in 2004 and 437 fishers in 2012).

##### 3.1.2. Finfish dominated harvesting behavioral communities in high plantation areas; benthics dominated in low plantation areas

Finfish dominated the harvesting profiles of fishers operating in management areas associated with a high increase in the percentage of plantation cover. In these communities (1 and 2) ~80% of species harvested were sourced from outside of benthic management areas (Table 3; Fig. 2). Marine benthic species of high economic importance normally harvested within management areas accounted for only ~20% of the top species harvested (Table 3; Fig. 2). Fig. 3a shows the behavioral profile of community 1, which shows pairs of species that were often harvested together. For example, *Cilus gilberti*, *Genypterus sp.*, *Callorhynchus callorynchus*, and *Thyrstites atun*, all fish, were often harvested in combination with other species and were core species harvested. In contrast, benthic species dominated the harvesting profiles of fishers operating in management areas with little influence from tree plantations (community 4). Eighty percent of the species in these fisher harvesting profiles were caught inside management areas and 20% were species harvested outside, primarily in rivers (Table 3; Fig. 2; Fig. 3b). Fig. 3b shows that *Pyura chilensis* was a key species harvested by many in



**Fig. 4.** Relationships among the top ten (by volume) species harvested from four adjacent administrative regions (grey squares). Size of squares indicates plantation influence in the region. Note: \*\*\* indicates that the benthic species is typically harvested in management areas, \*\* indicates that species are harvested in rivers, and \* indicates that species are harvested outside of management areas. A - indicates that the species did not have a management plan in place according to published government documents.

community 4. No fish species were ranked high enough to be included in the harvesting profiles of this low-tree plantation influenced community. In the medium plantation influenced community (community 3), fishers had a mixed profile, harvesting half of the species outside of the management areas and the other half from within management areas (Table 3; Fig. 2). Key benthic species include benthic invertebrates such as loco and limpets (*Fissurella* sp.) and key finfish include demersal species such as the elephant fish (*Callorhynchus callorhynchus*), corvina (*Cilus gilbert*), cusk eel (*Genypterus*) and Chilean sand perch (*Pinguipes chilensis*), and pelagic species such as snoek (*Thyrstites atun*) and Patagonian blennie (*Eleginops maclovinus*).

### 3.2. Regional analysis ~1200 km

#### 3.2.1. Harvesting patterns at regional scales were related to plantation influence

We found evidence of similar patterns in regions VII and VIII, which had the highest amount of tree plantations (15% and 24% cover, respectively); finfish dominated the catch. In region VIII, five pelagic finfish were among the top species harvested, whereas three demersal and only two benthic finfish appeared in the regional profile. The most valuable commercial benthic invertebrate species, loco, did not appear among the top ten species landed in regions VII or VIII (Fig. 4). In region VII loco catches have always been low because there are few rocky shorelines, but even the small loco catches had declined from 30 tons to 20 tons and then to 9 tons in 2007, 2008 and 2009, respectively; from 2010 to 2012 only 5 tons were reportedly caught annually (Supplementary 1)<sup>4</sup>. In region VIII, loco catches remained around 200 tons annually (2007–2012), which was a higher catch average compared to region XIV (moderate influence) despite having fewer rocky shorelines in region VIII; locos were not among the top ten species in region VIII because finfish were harvested at a higher volume. Region XIV, with a moderate influence of plantations (11% cover), shared many of the same finfish species harvested in the high influence regions but differed from these in that loco still ranked among the top ten species harvested. While fishers were harvesting offshore in region XIV, the offshore finfish fisheries were not as well developed as in regions VII and VIII and benthic invertebrates remained important. Region X was still heavily dependent on the loco fishery and benthic invertebrates in general and indeed it had the lowest influence of tree plantations (1%) compared to the other regions.

When examining catches over time, the volume of finfish dominated over invertebrate catches from 2007 to 2012 in regions VII and VIII, and XIV (Supplementary 1). Benthic invertebrate species declined for regions VII and VIII from 2007 to 2012 (Supplementary 1), whereas region XIV showed an increase in both benthic invertebrates and finfish harvests. Notably in region X, where there were few plantations, harvests were dominated by benthic invertebrate species and both benthic invertebrates and finfish maintained similar levels from 2007 to 2012. Thus we see a pattern that shows the dominance of benthic invertebrate resources decline and finfish increase, with some evidence that pelagics may be selected over demersal finfish in harvests as the influence of plantations increases, a pattern that mirrors that observed in the detailed examination of fisher behavior.

<sup>4</sup> At the aggregate scale, we can't rule out that shoreline type plays some role in species availability as four and 8% of the catch volume are benthic invertebrate species in regions VII and VIII whereas 36% of the catch is benthic species in region XIV and 70% of the catch is benthic species from 2007 to 2012. Of course, however, regions XIV and X both have rocky shorelines but region X has a much higher percentage of benthic species harvested, so shoreline type does not explain all. Likewise regions VII and VIII include sandy shore species such as macha, navajuela in their harvests, but also rocky shore species such as chorito, piure, and loco.

#### 3.2.2. Management of species in harvesting profiles

Of the finfish harvested in the fisher and regional profiles, ~50% were not formally managed (Supplementary 2). In both the sub-regional and regional analyses, *Gilus gilbert*, *Thyrstites atun*, and *Callorhynchus callorhynchus*, were top species harvested in common with other species, but no management was in place for these species; *Genypterus blacodes* was managed but not *Genypterus maculatus*. Only one out of the five species harvested in brackish rivers, *Mesodesma donacium*, was officially managed. Informal management systems were in place for the other species and *Mytilus chilensis* and *Choromytilus chorus* were sometimes harvested from concessions.

## 4. Discussion

### 4.1. Fisher-harvesting behavior was explained by landscape activities

In our study, fishers working in areas closer to tree plantations had distinct harvesting patterns and focused more on finfish than resources generally harvested in TURF management areas. Pelagic finfish appear to be particularly important. We find evidence that fisher-harvesting behavior could have changed as a consequence of landscape change because environmental variables indicative of landscape change — chlorophyll-*a* values (CFAM), the amount of polychaetes and phoronids on loco shells (POLFOR), and the percent change in tree plantations in nearby watersheds (PPL\_CH) — explained 32% of the variation in fisher behavior, while experience — age (AGE), years fishing, (YEARS), and alternative livelihoods (ALTLIVE) and technology — owning a boat (BOAT), did little to explain harvest profiles (Table 1). Previous work also has shown that landscape change can affect fisheries. Craig (2012) showed that hypoxia created by high nutrient input explained the spatial distribution of fish and fishers adapted by harvesting along the edges of hypoxic areas. Other studies have shown a dramatic decrease in the brown shrimp harvest and profits because of hypoxia, e.g. in North Carolina (Huang and Smith, 2010). Finally Van Holt showed that fisher success in nearshore management areas depended on the quality of the resource, which in turn was related to upland land use (Van Holt, 2012).

Fisheries models suggest that the ratio of pelagic planktivores to demersal species in landings should increase with increasing eutrophication because planktivores are more able to access enhanced prey production without experiencing the negative effects of hypoxia on lower water column and benthic habitat (Caddy, 2000; DeLeiva Motrno et al., 2000). We see evidence of this pattern in region VIII with the highest influence of plantations where 50% of the top ten species were pelagic finfish. The pelagic species were both plankton feeders, as well as higher trophic level predatory fish such as Patagonian toothfish (*Dissostichus eleginoides*), jumbo flying squid (*Dosidicus gigas*), and swordfish (*Xiphias gladius*), which can benefit if prey at lower trophic levels have increased food resources due to nutrient increases (Breitburg, 2002). Benthic invertebrates should be more affected by landscape change than demersal or pelagic species because they are less mobile than finfish.

### 4.2. Consequences of switching behavior

As land based activities change, the resources in the coastal management areas change too (Van Holt et al., 2012). This can leave fishers vulnerable if they are not able to adapt to the changing conditions. While land-based livelihoods may be one solution to reduce their vulnerability to changes in the management area, the relationship between these livelihoods and landscape change is unclear. Another solution is for fishers to switch to finfish. This requires experience and knowledge (human capital) and technology (access to boats and gear etc.), which requires financial capital and coordination with the seafood industry. Fishers with skills to harvest finfish appear to be less vulnerable to changes in the quality of the management areas because these fishers



can tap into new resources. Van Holt (2012) shows that those fishers who had more success in offshore fisheries were those with experience and technology whereas success for those working in the management areas did not depend on fisher experience or the amount of available boats—the quality of the loco resources explained higher prices and profit. Not all fishers will have the experience or technology to adapt to the influences of the landscapes on fisheries. For fishers who can move offshore where their experience counts, they place added pressures on other stocks, especially if these stocks are not managed, which risks transferring the vulnerability to this part of the system instead. With many finfish species in fisher's harvesting profile lacking official management documents, and these species taking on an increasingly important role in fisher profiles, the fishers and the marine resources may become more vulnerable.

In Chile, the government recently modified important aspects of environmental impact assessment policy to allow different compensation approaches (Gelcich and Donlan, 2015). A review and analysis of compensation and mitigation strategies of development projects in marine coastal areas (investments over US\$ 50 million within a total investment of US\$ 9000 million) shows that artisanal fisheries play an important role as marine compensation subjects (Gelcich et al., 2011). In fact, 63% of compensation aims at developing research intended to improve livelihoods and capacities in fishing communities (Gelcich et al., 2011). Unfortunately, there is still very little clarity on the future issues fishers will have to face associated to on-going marine and coastal impacts from landscape change. Results as the ones presented here, which link individual fisheries (TURFs) to other biosphere domains across scales can prove critical to inform marine compensation programs under voluntary and/or regulatory scenarios in ways that support the necessary adaptation needs associated to fishers' current and future livelihood shifts. Likewise, responsible seafood companies sourcing from fishers affected by landscape change will need to begin to consider how these changes can affect fishers, their catch, their livelihoods, and wellbeing (Van Holt et al., 2016b).

#### 4.3. Future work and conclusions

Here we provide an example of how sectors traditionally considered in isolation are in fact interconnected and influence resource extraction patterns. Commodity-driven landscape change, that is, pulp plantations for the global pulp market (terrestrial side), can be linked to fisher livelihoods and fisheries commodities (seascape). Still important challenges remain in this type of research and future efforts should focus on further isolating the natural biogeographic patterns from human induced patterns and identifying additional ways of linking together multiple systems and the social-ecological mechanisms which explain those linkages. While these types of cross-scale studies are challenging, behavioral networks offer a solution to link human behavior across components of the biosphere and multi-scale analyses can help confirm findings. Ruling out other potentially causal linkages are central to this work in Chile and elsewhere. This requires an understanding of how each system works and theory to build upon. Despite challenges in designing such cross-scale, social-ecological studies, we must continue to link these systems to build synergies between the different components so people can better plan to how work in a safe operating space for the planet.

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#### References

- Acker, J.G., Leptoukh, G., 2007. Online analysis enhances use of NASA earth science data. *EOS Trans. Am. Geophys. Union* 88, 14–17.
- Anderson, D.M., Glibert, P.M., Burkholder, J.M., 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries* 25, 704–726.
- Auty, R.M., 1993. *Sustaining Development in Mineral Economies: The Resource Curse Thesis*. Routledge, London.
- Berndes, G., Hoogwijk, M., van den Broek, R., 2003. The contribution of biomass in the future global energy supply: a review of 17 studies. *Biomass Bioenergy* 25, 1–28.
- Breitbart, D., 2002. Effects of Hypoxia, and the Balance Between Hypoxia and Enrichment, on Coastal Fishes and Fisheries.
- Caddy, J.F., 2000. Marine catchment basin effects versus impacts of fisheries on semi-enclosed seas. *ICES J. Mar. Sci.* 57, 628–640.
- Castilla, J.C., 1994. The Chilean small-scale benthic shellfisheries and the institutionalization of new management practices. *Ecol. Int. Bull.* 21, 47–63.
- Castilla, J.C., 1999. Coastal marine communities: trends and perspectives from human-exclusion experiments. *Trends Ecol. Evol.* 14, 280–283.
- Craig, J., 2012. Aggregation on the edge: effects of hypoxia avoidance on the spatial distribution of brown shrimp and demersal fishes in the Northern Gulf of Mexico. *Mar. Ecol. Prog. Ser.* 445, 75–95.
- Crona, B., Van Holt, T., Petersson, M., Daw, T.M., Buchary, E., 2015. Using social-ecological syndromes to understand impacts of international seafood trade on small-scale fisheries. *Glob. Environ. Chang.* 25, 162–175.
- Dekker, D., Krackhardt, D., Snijders, T.A.B., 2007. Sensitivity of MRQAP tests to collinearity and autocorrelation conditions. *Psychometrika* 72, 563.
- DeLeiva Motrono, J., Agostini, V., Caddy, J., Carocci, F., 2000. Is the pelagic-demersal ratio from fishery landings a useful proxy for nutrient availability? A preliminary data exploration for the semi-enclosed seas around Europe. *ICES J. Mar. Sci.* 57, 1091–1102.
- Diaz, R.J., Rosenberg, R., 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanogr. Mar. Biol. Annu. Rev.* 33, 245–303.
- Fernandez, M., Jaramillo, E., Marquet, P.A., Moreno, C.A., Navarrete, S.A., Ojeda, F.P., Valdovinos, C.R., Vasquez, J., 2000. Diversity, dynamics and biogeography of Chilean benthic nearshore ecosystems: an overview and guidelines for conservation. *Rev. Chil. Hist. Nat.* 73.
- Geist, H.J., Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical deforestation. *Bioscience* 52, 143–150.
- Gelcich, S., Donlan, C.J., 2015. Incentivizing biodiversity conservation in artisanal fishing communities through territorial user rights and business model innovation. *Conserv. Biol.*
- Gelcich, S., Hughes, T.P., Olsson, P., Folke, C., Defeo, O., Fernández, M., Foale, S., Gunderson, L.H., Rodríguez-Sickert, C., Scheffer, M., Steneck, R.S., Castilla, J.C., 2010. Navigating transformations in governance of Chilean marine coastal resources. *Proc. Natl. Acad. Sci. U. S. A.* 107, 16794–16799.
- Gelcich, S., Peralta, L., Gonzalez, C., Camano, A., Fernandez, M., Castilla, J.C., 2011. Scaling-up marine coastal biodiversity conservation in Chile: a call to support and develop ancillary measures and innovative financing approaches. In: Figueroa, E. (Ed.), *Successful and failed experiences in biodiversity conservation: lessons and policy recommendations from the American continent*. Editorial Universitaria, Santiago, Chile, pp. 199–220.
- Gelcich, S., Fernández, M., Godoy, N., Canepa, A., Prado, L., Castilla, J.C., 2012. Territorial user rights for fisheries as ancillary instruments for marine coastal conservation in Chile. *Conserv. Biol.* 26, 1005–1015.
- Girvan, M., Newman, M.E.J., 2002. Community structure in social and biological networks. *Proc. Natl. Acad. Sci. U. S. A.* 99 (12), 7821–7826.
- Gwynne, R.N., 1996. Direct foreign investment and non-traditional export growth in Chile: the case of the forestry sector. *Bull. Lat. Am. Res.* 15, 341–357.
- Halpern, B.S., Ebert, C.M., Kappel, C.V., Madin, E.M.P., Micheli, F., Perry, M., Selkoe, K.A., Walbridge, S., 2009. Global priority areas for incorporating land-sea connections in marine conservation. *Conserv. Lett.* 1–8.
- Heilmayr, R., Echeverría, C., Fuentes, R., Lambin, E.F., 2016. A plantation-dominated forest transition in Chile. *Appl. Geogr.* 75, 71–82.
- Huang, L., Smith, M.D., 2010. Management of an annual fishery in the presence of ecological stress: the case of shrimp and hypoxia. *SSRN Electron. J.*
- INFOR, 2004. *Estadística Forestales Chilenas 2003*. Boletín Estadístico.
- Kemp, W., et al., 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. *Mar. Ecol. Prog. Ser.* 303, 1–29.
- Lambin, E.F., Meyfroidt, P., 2010. Land use transitions: socio-ecological feedback versus socio-economic change. *Land Use Policy* 27, 108–118.

- Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. *Proc. Natl. Acad. Sci. U. S. A.* 108, 3465–3472.
- Lancellotti, D., Vasquez, J., 2000. Zoogeography of benthic macroinvertebrates of the Chilean coast: contribution for marine conservation. *Rev. Chil. Hist. Nat.* 73, 99–129.
- Moreno, C.A., Sutherland, J.P., Jara, H.F., 1984. Man as predator in the intertidal zone of southern Chile. *Oikos* 42, 155–160.
- Moreno, C.A., Lunecke, K.M., Lepez, M.I., 1986. The response of an intertidal *Concholepas concholepas* (Gastropoda) population to protection from man in southern Chile and the effects on benthic sessile assemblages. *Oikos* 46, 359–364.
- Nixon, S.W., 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia* 41, 199–219.
- Oyarzun, C.E., Pena, L., 1995. Soil-erosion and overland-flow in forested areas with pine plantations at coastal mountain-range, Central Chile. *Hydrol. Process.* 9, 111–118.
- Oyarzun, C., Aracena, C., Rutherford, P., Godoy, R., Deschrijver, A., 2007. Effects of land use conversion from native forests to exotic plantations on nitrogen and phosphorus retention in catchments of southern Chile. *Water Air Soil Pollut.* 179, 341–350.
- Penna, I., 2010. Understanding the FAO's wood supply. In: Lynch, A. (Ed.), *Planted Forests Projections*. University of Ballarat, Center for Environmental Management.
- Popp, A., Dietrich, J.P., Lotze-Campen, H., Klein, D., Bauer, N., Krause, M., Beringer, T., Gerten, D., Edenhofer, O., 2011. The economic potential of bioenergy for climate change mitigation with special attention given to implications for the land system. *Environ. Res. Lett.* 6.
- Rockstrom, J.E.A., 2009. A safe operating space for humanity. *Nature* 461, 472–475.
- Rudel, T.K., 2009. Tree farms: driving forces and regional patterns in the global expansion of forest plantations. *Land Use Policy* 26, 545–550.
- Sedjo, R.A., 1999. The potential of high-yield plantation forestry for meeting timber needs. *New For.* 17, 339–359.
- SERNAPESCA (Servicio Nacional de Pesca y Acuicultura), 2006–2012. *Anuarios Estadísticos*. [www.sernapesca.cl](http://www.sernapesca.cl) (Santiago, Chile).
- Sloan, N.A., Vance-Borland, K., Ray, G.C., 2007. Fallen between the cracks: conservation linking land and sea. *Conserv. Biol.* 21, 897–898.
- Smith, V.H., Tilman, G.D., Nekola, J.C., 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environ. Pollut.* 100, 179–196.
- Tallis, H., Ferdaña, Z., Gray, E., 2008. Linking terrestrial and marine conservation planning and threats analysis. *Conserv. Biol.* 22, 120–130.
- Thiel, M., et al., 2007. The Humboldt current system of northern and central Chile. *Oceanogr. Mar. Biol.* 45 (45), 195–344.
- Van Holt, T., 2012. Landscape influences on fisher success: adaptation strategies in closed and open access fisheries in Southern Chile. *Ecol. Soc.* 17.
- Van Holt, T., Moreno, C.A., Binford, M.W., Portier, K.M., Mulsow, S., Frazer, T.K., 2012. Influence of landscape change on nearshore fisheries in southern Chile. *Glob. Chang. Biol.* 18, 2147–2160.
- Van Holt, T., Binford, M.W., Portier, K.M., 2016a. A stand of trees does not a forest make: tree plantations and forest transitions. *Land Use Policy* 147–157.
- Van Holt, T., Weisman, W., Johnson, J.C., Käll, S., Whalen, J., 2016b. A Social Wellbeing in Fisheries Tool (SWIFT) to help improve fisheries performance. *Sustainability* 8 (8), 667.