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The consequences of landscape change on fishing strategies

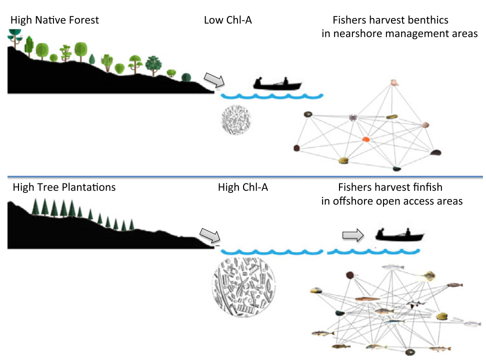
Tracy Van Holt [a,b,*], Beatrice Crona [a,b], Jeffrey C. Johnson [c], Stefan Gelcich [d]

[a] Royal Swedish Academy of Sciences, Global Economic Dynamics and the Biosphere Program, Stockholm 104-05, Sweden
[b] Stockholm University, Stockholm Resilience Center, Stockholm 114-19, Sweden
[c] University of Florida, Anthropology, Gainesville, FL 32611, United States
[d] Center of Applied Ecology and Sustainability (CAPES), Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Santiago, Chile

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/SeaWifs), 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.

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).

* Corresponding author at: Royal Swedish Academy of Sciences, Global Economic Dynamics and the Biosphere Program, Stockholm 104-05, Sweden.
E-mail addresses: tracy.vanholt@kva.se, tvanholt@gmail.com (T. Van Holt).

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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[1] 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 outside 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 subsides 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 ($8° \pm 5°$ average slope and $228\ \text{m} \pm 114\ \text{m}$ 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 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

[1] This FAO definition does not include palm trees (Penna, 2010).