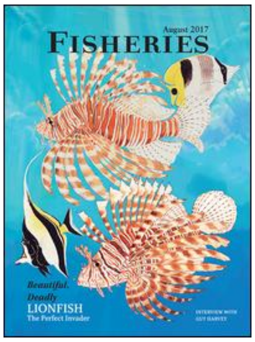

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The Telecoupling Framework: An Integrative Tool for Enhancing Fisheries Management

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What do telephones, televisions, and telescopes have in common? They are devices for transmitting sounds or images over distances. In much the same way, a new scientific paradigm—the telecoupling framework—enables simultaneous assessment of socioeconomic and environmental interactions among local and distant locations (Liu et al. 2013). The framework is revolutionizing the way social and natural scientists understand and provide for sustainable resource management over space and time in our increasingly connected world. The telecoupling framework was developed from the integration of two different but related concepts: teleconnections (i.e., environmental interactions among natural systems over geographic space and time) and globalization (i.e., socioeconomic interactions among human systems over distances). The framework focuses on the structure, functioning, dynamics, trade-offs, and synergies of "telecouplings": socioeconomic and environmental interactions among human and natural systems over distances. Because fish promote global food and nutrition security and support a growing aquaculture sector and commercial, recreational, and subsistence industries (Taylor et al. 2016), fisheries are ideal systems in which to apply the telecoupling framework to better understand the impacts of local and more distant socioeconomic and environmental interactions that alter fisheries productivity, thereby yielding insights for fisheries management.

The telecoupling framework has five principal attributes: systems, flows, agents, causes, and effects (Figure 1). In the telecoupling framework, systems are social-ecological entities that are categorized as sending, receiving, or spillover based on their association with flows (e.g., movement of fish, fish products, money, fisheries stakeholders, fish harvest equipment). Sending systems are those *from* which flows move, whereas receiving systems are those *to* which flows move, such as nations that import fish or fish products. Spillover systems are those that affect, or are affected by, local, regional, or international interactions between sending and receiving systems (Figure 1). For instance, when two countries harvest fish from the same common stock, a policy change that favors increased fish harvest and trade in one nation may produce effects such as reduced fish landings and exports in the other country. Flows are produced by one or more causes (e.g., economic, political, social, cultural, ecological) and facilitated by one or more agents (e.g., individuals, organizations, governments) with resultant effects (Figure 1). For example, international trade of fishmeal can be caused by a sending nation's desire for economic growth and a receiving nation's demand for fish products. In turn, trade can cause a sending nation to have increased revenue and employment concurrent with a receiving nation's growing demand for fish products.

The telecoupling framework is a promising tool for investigating short- and long-distance fisheries interactions and thereby developing a knowledge base for sustainable fisheries management that is ecologically and socioeconomically informed. For instance, the commercial fishery for Peruvian Anchoveta *Engraulis ringens* is the largest single-species fishery in the world. It supports approximately 50 percent of fishmeal production and 33 percent of fish oil production worldwide, making Peru the largest global exporter of products important for the global aquaculture and animal agriculture industries (Avadí et al. 2014). The Anchoveta fishery is situated in the Pacific Ocean off the coast of Peru and Chile. During El Niño years, westerly winds move warm surface waters toward Peru, which deepens the thermocline and prevents the upwelling of nutrient-rich cold water from the ocean depths, thereby decreasing phytoplankton abundance and thus Anchoveta production in the euphotic zone (Orlic 2011). In contrast, upwelling during La Niña years amplifies nutrient flux and

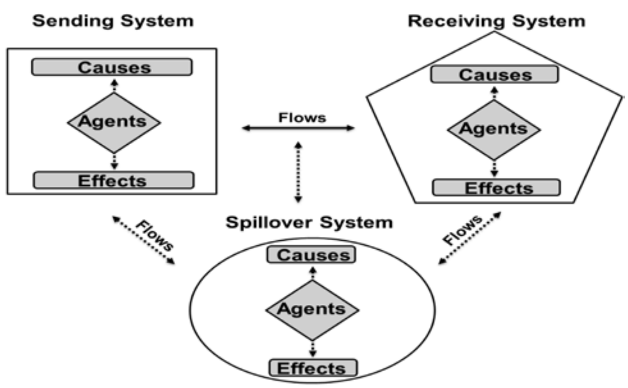

Figure 1. Five major and interrelated components of the telecoupling framework: systems, flows, agent, causes, and effects. The framework conceptualizes coupled human and natural systems in terms of flows (e.g., movement of materials, energy, knowledge) among them, which are produced by causes and facilitated by agents (e.g., individuals, organizations, governments) with resultant effects. Systems are defined as sending, receiving, and/or spillover, defined by the directional movement of the flow considered. Modified from Liu et al. (2013).

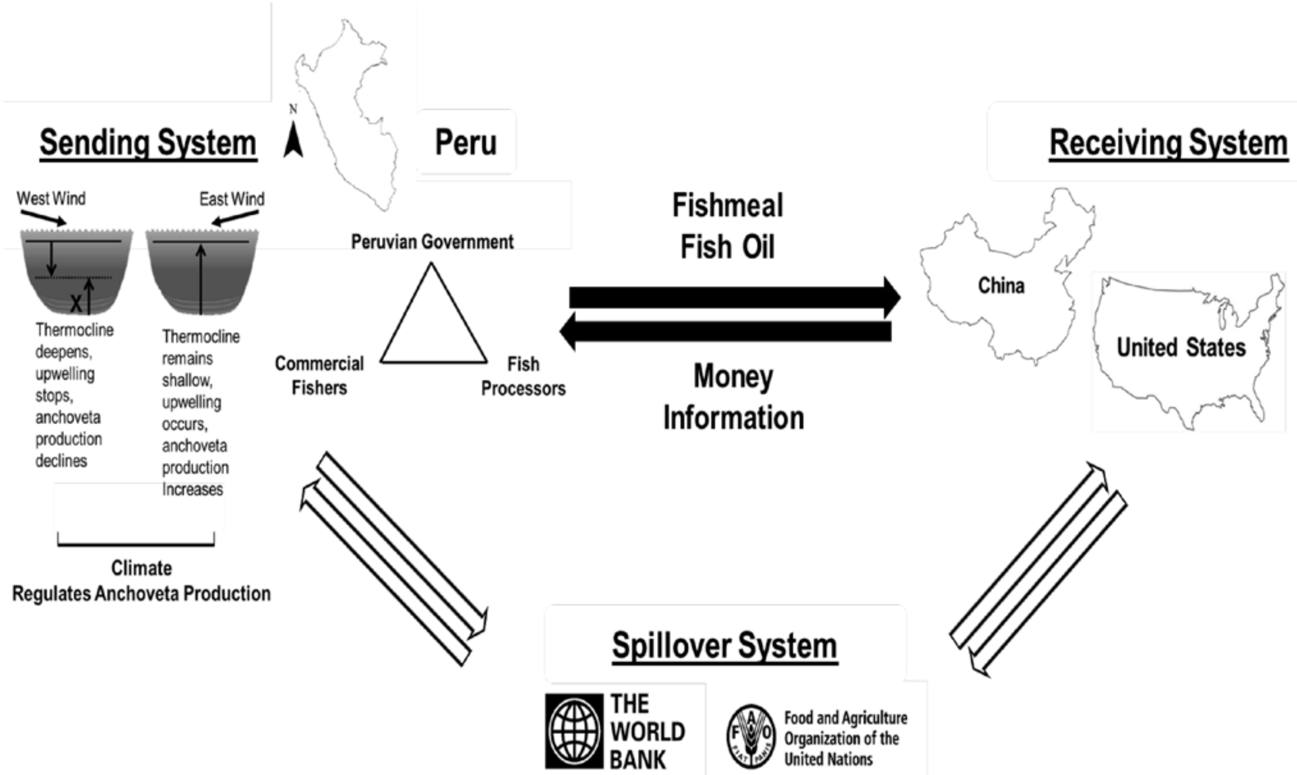

Figure 2. Examples of natural and human components of the Peruvian Anchoveta fishery conceptualized using the telecoupling framework. Telecouplings are long-distance environmental and socioeconomic interactions among sending, receiving, and spillover systems. Climate, particularly the El Niño/La Niña cycle, regulates the environmental conditions that govern Anchoveta production, which influences Anchoveta harvest and associated telecouplings such as global trade of fishmeal and fish oil and international movement of money and information.

increases Anchoveta production. Climate regulates Anchoveta biomass and controls the magnitude and timing of fish harvest by fishing nations such as Peru, setting the conditions in which telecouplings occur (Figure 2).

An example of a Peruvian Anchoveta telecoupling is the trade of fishmeal and fish oil (FMFO) from Peru to receiving systems (e.g., China, United States, Germany, Spain, Norway, Denmark). Trade of FMFO is caused by the desire of various agents in Peru (e.g., Peruvian government, commercial fishers) to gain economic revenue from production of anchoveta products (Figure 2). Trade of FMFO is also caused by demand for fishmeal and fish oil to support growing aquaculture and animal agriculture industries in receiving systems. In turn, this trade causes money to flow from FMFO-receiving systems to Peru, a sending system. In the 1960s, FMFO trade was facilitated by monetary subsidies from the World Bank and the United Nations Food and Agriculture Organization for development and modernization of the Peruvian Anchoveta fishery (Orlic 2011). As such, these organizations were agents in spillover systems because they provided financial resources necessary for FMFO trade between sending and receiving systems (Figure 1, 2). Growing revenue from the Anchoveta fishery in the 1960s caused Peruvian fishing companies to continually add fishing vessels and fish processing machinery to their operations without regard for the finite availability of Anchoveta. Such overcapitalization, combined with social instability and unfavorable El Niño climatic conditions, caused an historic Anchoveta stock collapse in 1972. To avoid future stock collapses, Peru participated in global conferences to learn and implement more sustainable techniques for fish harvesting, processing, and marketing from around the world (Orlic 2011). This international flow of information from sending systems such as the United States and the Soviet Union (Figure 1, 2) to Peru was a telecoupling that allowed Peru to preserve the long-term viability of Anchoveta populations and enhance the fishery's sustainability (Mondoux et al. 2008). In addition, international knowledge transfer about sustainable fisheries management strategies was a telecoupling that equipped Peruvian fishing companies with the information base for creating programs to provide employees education assistance for children, financial incentives for quality work, and pensions for early retirement (IFFO 2009). These programs engendered a culture of corporate responsibility that increased public support for the Anchoveta fishery and allowed Peru to become a global leader in ecologically and socially sustainable fisheries management (Mondoux et al. 2008).

All fisheries systems involve telecouplings (Figure 1). For instance, as the economic viability of commercial fishing declined in the Great Lakes due to overfishing, habitat degradation, and Sea Lamprey *Petromyzon marinus* invasion, Coho Salmon *Oncorhynchus kisutch* and Chinook Salmon *O. tshawytscha* were stocked to create a productive recreational fishery (Tanner and Tody 2002). In the mid-1960s, fish hatcheries in Oregon, Washington, and Alaska (i.e., sending systems) delivered millions of Coho Salmon and Chinook Salmon eggs to Michigan, a receiving system (Crawford et al. 2001). After eggs were reared to fry, Michigan hatcheries functioned as sending systems, delivering salmon smolts to recipient tributaries in lakes Michigan and Superior. Spillover systems included the other Great Lakes (Huron, Erie, and Ontario) and the coastal communities and economies that received Coho Salmon and Chinook Salmon—and associated angling-related revenue—following stockings in lakes Michigan and Superior. Effects of stocking included greater abundance of Coho Salmon and Chinook Salmon, increased angler catch and harvest rates, information sharing about angling among fisheries stakeholders (e.g., anglers, retailers, managers), public enthusiasm for recreational fishing, and, ultimately, development of vibrant angling-based economies in coastal communities of the Great Lakes basin (Tanner and Tody 2002; Mueller et al. 2008).

Why is the telecoupling framework important for enhancing fisheries sustainability? How does it contribute to fisheries management? First, the telecoupling framework is a useful tool for understanding socioeconomic and environmental complexity in fisheries. For instance, the framework can be used to analyze intricate social-ecological interactions among local and distant places and thereby promotes the study of fisheries as coupled human and natural systems that are impacted by events occurring across a range of spatial extents. In the Peruvian Anchoveta fishery, the promise of economic revenue engendered a philosophy of export-led growth that exposed Peru to the benefits and costs of globalization. For example, using the telecoupling framework, it is evident that economic growth, employment, and coastal development—short-term effects of international FMFO trade—were causes of overcapitalization, social instability, and, ultimately, overfishing, which contributed to a stock collapse in 1972. Amid social and political upheaval resulting from the stock collapse, the Peruvian government worked with the international community to change the course of Anchoveta management in ways that ensured sustainable fisheries management outcomes that continue today. In particular, economic globalization of the fishery caused ideational globalization through international collaboration, knowledge transfer, and technological advancement, which ultimately caused Anchoveta management to become more ecologically and socially sustainable (Mondoux et al. 2008).

Use of the telecoupling framework also illustrates important similarities and differences between different types of fisheries. For instance, the telecoupling framework is valuable for understanding how the success of salmonine stocking in the Great Lakes was an effect of information flow among fisheries stakeholders, which promoted public support and enthusiasm for enhanced salmonine management. In much the same way, information exchange regarding sustainable fisheries management caused some Peruvian fishing companies to increase the ecological and social sustainability of their operations, which engendered a culture of corporate responsibility that made Peruvian Anchoveta one of the most sustainable fisheries in the world today (Mondoux et al. 2008). In all fisheries, flows of information among people and fisheries organizations are critical causes that increase social capital and foster public acceptance and legislative support for fisheries management (Mueller et al. 2008), which is often as focused on humans as it is on fishes and their habitats. Moreover, fisheries flows are often similar for different types of fisheries, but the agents, causes, and effects of these flows may be vastly different, as illustrated by the Peruvian anchoveta and Great Lakes salmonine fisheries. These fisheries systems also demonstrate how fisheries have the potential to grow into large-scale industries that support local, regional, national, and international markets and economies – a life cycle for which the telecoupling framework is a useful research, management, and policy-making tool.

The telecoupling framework is a highly valuable paradigm for fisheries professionals because it enables one to simultaneously conceptualize the spatiotemporal dynamics of fisheries flows, understand short- and long-distance interactions among fisheries systems, and develop sustainable fisheries management strategies that are socioeconomically and ecologically informed. The framework advances previous research approaches that focus on either social or ecological aspects of fisheries because it integrates these dimensions, enabling assessment of socioeconomic and environmental interactions that may go unnoticed when traditional monothematic approaches are employed. The telecoupling framework is applicable in all types of fisheries because flows of fish, money, information, people, and materials are intrinsic components of all fisheries systems. In summary, the telecoupling framework provides fisheries professionals with a systematic methodology for simultaneously assessing the integrated outcomes of socioeconomic and environmental interactions in fisheries over space and time given changes at the local, regional, and global levels. Although the telecoupling framework is fledgling in fisheries science and practice, it has great promise as a tool for developing more sustainable fisheries policy and management approaches in the context of a globalized, interconnected world wherein local conditions are impacted by decisions in distant places.

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