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Social-ecological traps link food systems to nutritional outcomes

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ABSTRACT

Recognized as an emerging global crisis in the mid-1990s, the "nutrition transition" is marked by a shift to Western diets, dominated by highly processed, sugar-sweetened, and high caloric foods. Occurring in parallel to these health transitions are dramatic shifts in the natural systems that underlie food availability and access. Traditionally, environmental degradation and ecosystem change, and processes of nutritional transition, though often collinear and potentially causally linked, have been addressed in isolation. Food systems represent an emblematic social-ecological system, as both cultivated and wild foods are directly reliant on natural ecosystems and their processes. While healthy ecosystems are a necessary precondition of food production, they are not themselves sufficient to ensure continued benefits from local food systems. Mediating between food production and nutritional security are myriad governance and market institutions that shape differential access to food resources. Moreover, globalization and urbanization may shift communities from non-market to market-based economies, with profound implications for local environments and food systems. Specifically, we argue that it is this feedback between coupled socioeconomic and natural dynamics within food systems that reinforces specific nutritional outcomes, and may result in a social-ecological trap. Here, we use the case of reef-based food systems globally, paying particular attention to the Pacific to showcase social-ecological traps present in global food systems, and to illustrate how such traps lead to the acceleration of the nutrition transition. Improving both nutritional and environmental outcomes of food systems requires understanding the underlying drivers of each, and how they interact and reinforce each other. Only in recognizing these interactions and coupled dynamics will economic, governance, and environmental policies be positioned to address these food system challenges in an integrated fashion.

1. Introduction

Achieving global food and nutrition security requires addressing both nutritional deficiencies and confronting the growing prevalence of obesity and metabolic disease. Recognized as an emerging global crisis in the mid-1990s, the "nutrition transition" is marked by a shift to Western diets, dominated by highly processed, sugar-sweetened, and other high caloric foods (Popkin et al., 2020). This phenomenon shifts populations from nutritional deficiencies, often driven by food scarcity or lack of dietary quality, to a cluster of associated conditions including high blood pressure, high blood sugar, excess body fat, and abnormal cholesterol or triglyceride levels. These conditions often co-occur, leading to an increased risk of heart disease, stroke and diabetes.

While the nutrition transition was initially identified as a problem affecting urban areas of developing countries, it is apparent that it now affects all segments of society across the Global North and South (Black et al., 2013). In the past 25 years, increases in these types of non-communicable diseases have been substantial enough to compensate for declines in communicable diseases, such that the global burden of disease has remained largely unchanged (Global Burden of Disease

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2016 DALYs and HALE Collaborators, 2017). Undernutrition and overnutrition can affect different households within the same community and can even coexist within an individual (Black et al., 2013). The simultaneous occurrence of undernutrition and overnutrition, commonly described as the double burden of malnutrition, is a predictable but unfortunate result of this transition, and particularly affects lower-income countries, as food markets become increasingly globalized (Popkin et al., 2020).

Occurring in parallel to these health transitions are dramatic shifts in the natural systems that underpin food availability and access. Growing food demand and dietary shifts toward more resource intensive foods are straining the natural systems that support food production through increased freshwater scarcity, reductions in arable land, soil erosion, seawater intrusion, deforestation, biodiversity loss, and overfishing (Steffen et al., 2015). Climate change is also reshaping food production systems by shifting crop productivity, reducing the nutrient content of some foods, limiting or displacing wild fishery potential, and increasing the frequency of extreme events that disrupt the production and distribution of food (Myers et al., 2017). Environmental change has transformed the current food system, and will continue to shape our prospects for sustainable food availability and access.

Improving both nutritional and environmental outcomes of food systems requires understanding the underlying drivers of each, and how they interact and reinforce each other. Traditionally, processes of environmental degradation and ecosystem change, and processes of nutritional transition, though often collinear and potentially causally linked, have been addressed in isolation. We contend that the interaction of these—wherein shifts in markets and institutions drive environmental change, and the environmental condition influences those same markets and institutions that shape wild and cultivated food production—is itself critical to understand in addressing the ongoing nutrition transition. Specifically, we argue that it is this feedback between coupled socioeconomic and natural dynamics within food systems that reinforces specific nutritional outcomes and may result in a social-ecological trap, a condition in which feedbacks within and between social and ecological domains drive the system toward, or keep it in, an undesirable state from which it is difficult or impossible to escape.

Food systems represent an emblematic social-ecological system, as both cultivated and wild foods directly rely on natural ecosystems and their processes. While healthy ecosystems are a necessary precondition of food production, they are not themselves sufficient to ensure continued benefits from local food systems. Mediating between food production and nutritional security are myriad governance and market institutions that shape differential access to food resources. Healthy diets do not follow simply from food availability, but also complex social and economic dynamics that are contextual and historically embedded (Sen, 1982). For example, colonization and economic development may act to reinforce or dismantle traditional structures of property and access governing natural resources and diets (Weerasekara et al., 2018). Similarly, globalization and urbanization may shift communities from non-market to market-based economies, with profound implications for what and how people eat (Hawkes, 2006).

To consider the potential influence of these critical factors—albeit in a simplifying way—we conceptualize dietary archetypes arising from social-ecological traps that can lead to divergent nutritional outcomes. Preventing or escaping a social-ecological trap can improve peoples' nutritional state, but requires understanding the processes reinforcing healthy or unhealthy outcomes. Navigating these traps is urgent to avoid or reverse ecological and public health crises, and requires interdisciplinary research and intersectoral intervention. Using insights from social-ecological trap theory and analysis, we use the growing literature on food systems to provide a grounded framework connecting research to policy and interventions.

Below, we describe coral reef-based food systems as an exemplar of the process interdependencies and consequences of a social-ecological trap, paying particular attention to the alternate pathways leading to various nutritional outcomes. We focus on reef-based food systems in Small Island Developing States (SIDS) because populations are often highly reliant on seafood and the nutrition transition has been definitional to the health challenges faced by local people (McIver et al., 2016).

2. Social-ecological traps in coral reef food systems

Seafood serves as a key dietary resource to protect against both forms of malnutrition (undernutrition; Golden et al., 2016; Béné et al., 2016 and overnutrition; Zhao et al., 2015). It is a critically important source of nutrition in much of the developing world, providing key micronutrients and vitamins such as iron, zinc, vitamin A, vitamin B12, and fatty acids (Golden et al., 2016; Béné et al., 2016). Although broadly relevant to all SIDS, we focus our case study discussion on Pacific Island Countries and Territories (PICTs) where these phenomena are particularly acute. In PICTs, seafood provides an average of 36% (range 14–65%) of animal-source protein, in comparison to a global average of 17% (FAO, 2019). However, Pacific food systems are under threat from both natural and anthropogenic forces, and coastal fisheries may only provide adequate seafood for 6 of the 22 countries and territories by 2030 (Bell et al., 2009). In addition to the nutrient provision of seafood, in PICTs this traditional mainstay also reduces dependence on less healthy market-associated alternatives such as spam, tinned corned beef, turkey tails, mutton flaps, noodles, and processed foods common in the Pacific diet (Gewertz and Errington, 2010).

Healthy reef ecosystems and robust, locally appropriate markets and institutions are both necessary to ensure the continued benefits of coral reef food systems (Cinner, 2011). In theory, healthy reefs maintain the potential for seafood access and traditional diets, preventing a shift toward less healthy market-based food alternatives (Fig. 1). Whether a reef-based food system supports a healthy or unhealthy diet depends on reinforcing social and ecological processes, especially the transition between a healthy, coral-dominated reef and a degraded, macroalgal-dominated reef and the transition from traditional subsistence to cash-based economies (Fig. 1). These transitions are linked and reinforced through governance and resource access structures, offering opportunities to intervene and escape the trap.

3. Transition from healthy to degraded reefs

Coral reefs, the most biologically diverse marine ecosystem, are deteriorating in many locations as a consequence of human activities. Climate change and the associated impacts of coral bleaching, ocean acidification, and large-scale storm events have resulted in reefs that are less diverse, making them more susceptible to regime shifts (Hughes et al., 2017). Similarly, local effects such as overfishing, land use changes, sedimentation or nutrient runoff may accelerate a transition to undesirable states (Robinson et al., 2018). The transition from a coral-dominated reef to a degraded, macroalgal-dominated reef is typically marked by these long-term anthropogenic stressors, compounded by a short-term disturbance event (Norström et al., 2016). Coral reefs can change, sometimes quickly, from having a diverse, abundant, and functionally rich fish and invertebrate assemblage with high coral cover, to a state with a functionally depleted community assemblage and high abundances of fleshy macroalgae and turf algal overgrowth (Richardson et al., 2018). With recent increases in the frequency and severity of rapid and unexpected ecosystem shocks, coral reefs are increasingly vulnerable to alternative stable states, including depleted fisheries (Cinner, 2011). Thus, fishers in these systems are often forced to increase fishing effort, travel further, fish deeper, change gear, or target different species to maintain catches for local markets, income, and food production (Belhabib et al., 2016). With this increased or shifted fishing effort, resources are often further diminished, reducing catch stability (Robinson et al., 2018), and resulting in a negative feedback loop that pulls the system deeper into the social-ecological

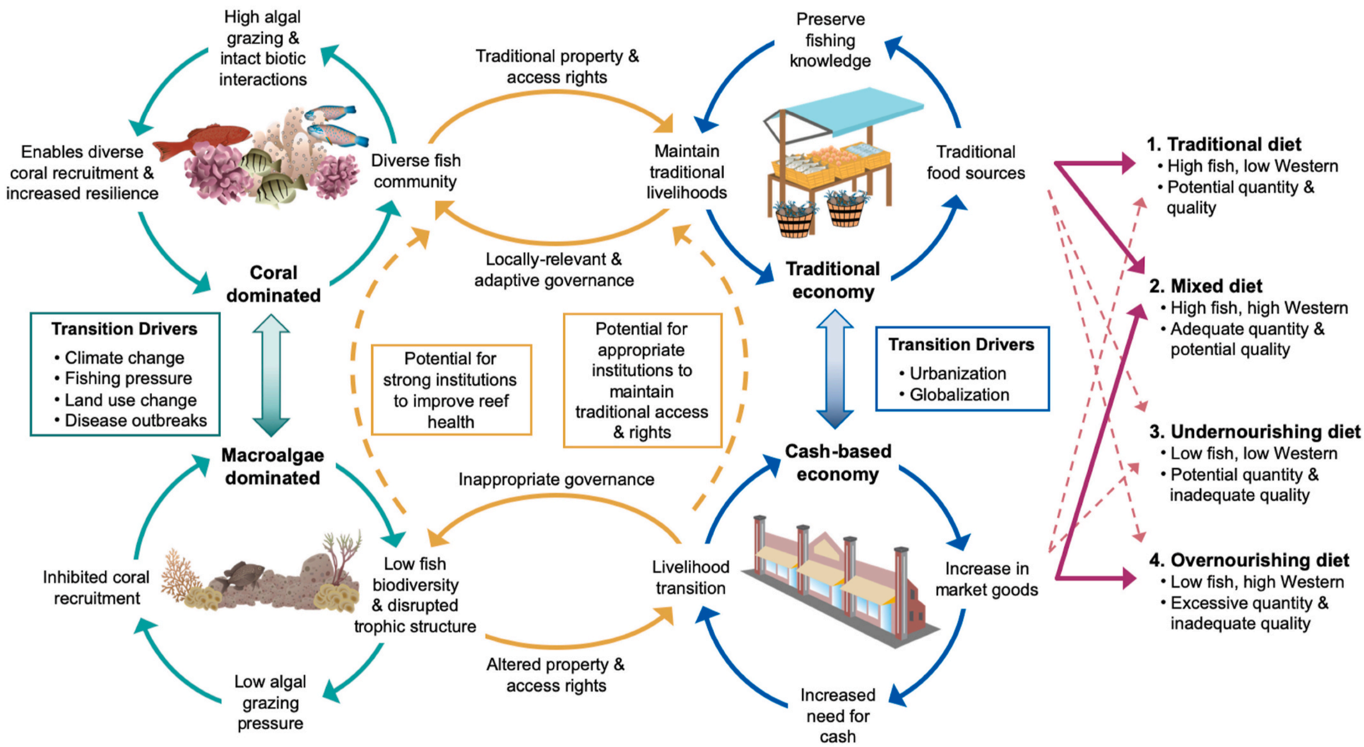

Fig. 1. Conceptual diagram of social-ecological traps in a reef-based food system where the natural system (teal) and socioeconomic system (blue) interact through the support of local institutions or the implementation of effective management strategies (yellow) to reinforce specific human dietary and nutritional outcomes (purple). Transitional drivers into social-ecological traps include factors that directly influence the environmental state of a coral reef (left) or factors that alter socioeconomic development and food availability in an economy (right). These drivers impact the ecological or economic alternative stable state by reinforcing positive (top) or negative (bottom) feedback loops, both directly (bold) or indirectly (dotted). Strong institutions and management can assist in changing the directionality of these feedbacks (bidirectional arrows). The pathways of this social-ecological trap (whether avoiding it, escaping it, or falling into it) reinforce specific dietary and nutritional outcomes (bold arrows indicating major dietary inputs; dotted arrows indicating minor dietary inputs).

trap.

4. Transition from traditional to cash-based economies

Increasing market-oriented production, along with income opportunities in population centers, can drive a shift away from subsistence fisheries-based livelihoods. Nearly half of all PICTs have more than 50% of their population currently located in urban areas, with expectations of significant urban growth by 2050 (Campbell, 2019). In recent decades, many small-scale fishing communities in PICTs have shifted from exploitation based on subsistence or local exchange to more commercial fishing, or have left the fishing sector entirely (Turner et al., 2007). For example, from 2012 to 2016, approximately 41% of fish consumed in PICT households came from home production (ranging from 11% in Tonga to >50% in Solomon Islands, Tokelau and Niue), representing an average 18% decline in subsistence fishing from the previous decade (59%) (Bell et al., 2009). While fish caught for subsistence purposes remain important in many places, fish for commercial sale is increasing.

The transition to cash-based economies not only transforms livelihoods in small-scale fishing communities, but the commodification of fishery resources can also increase pressure on ecosystems when appropriate management structures are lacking. Increased demand can generate strong economic incentives to intensify fishing effort and export-oriented fisheries often attract investment in fishing and processing technologies, which can contribute to an increase in resource exploitation (Crona et al., 2016). Consistent with this hypothesis, proximity to large population centers has been shown to be a strong predictor of reef biomass (Cinner et al., 2018). Declining fish biomass can lead to greater fishing effort to maintain catch levels or cause fishers to exit the fishery, both of which further the social-ecological trap.

5. Nutritional outcomes resulting from social-ecological traps

We contend there are four dietary archetypes arising from social-ecological traps in food systems: 1) Traditional Diets; 2) Mixed Diets of traditional and market-based foods contingent on preference, cultural attitude, and price; 3) Undernourishing diets with a lack of access to adequate traditional and/or market-based foods; and 4) Overnourishing diets with an over-reliance on less healthy market-based foods (Fig. 1). To exemplify the dietary and nutritional typologies, we zoom out from a focus on PICTs and use coral reef food systems drawing on an array of global country contexts, where the potential nutritional repercussions of social-ecological traps relate specifically to the degree of market integration into the food system and the extent to which market foods do or do not replace traditional seafood.

The first two archetypes, the Traditional Diet and the Mixed Diet, assume the preservation of traditional property and access rights, locally relevant and adaptive management of natural resources, and the maintenance of traditional livelihoods such that local food sources remain available. In a context of low market integration, the resulting Traditional Diet consists of high subsistence and wild food consumption and low consumption of Western foods, providing overall positive nutritional and health outcomes (Fig. 2). This diet is characterized by potentially adequate *quantity* and *quality* of foods to sustain nutrition. An example of a reef-based Traditional Diet are the outer islands of Kiribati, where the population subsists on a diet of taro, pandanus, breadfruit, coconut, and seafood, which can provide a healthy combination of protein, energy, micronutrients, vitamins, and fats. The dietary archetype of rural I-Kiribati is consistent with a Traditional Diet, representing a high per capita reef fish catch of 16.5 kg/year, a relatively low import dependency ratio (IDR) of 23% (representing self-sufficiency and low

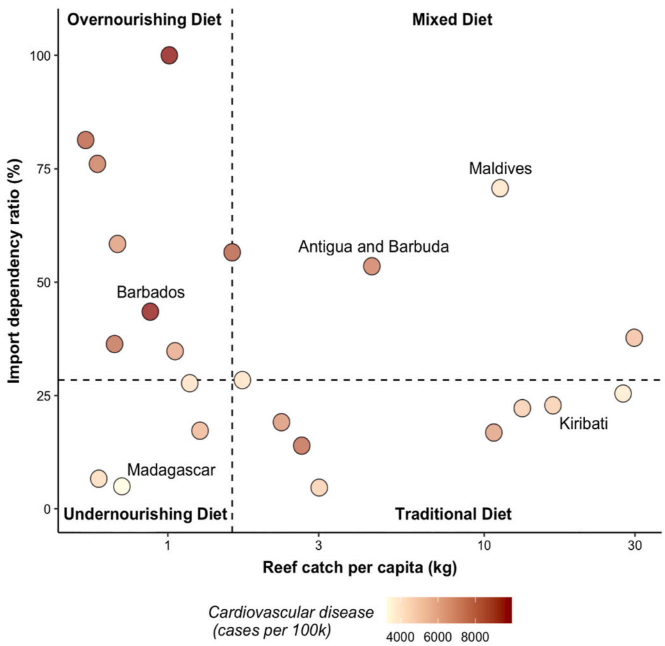

Fig. 2. Four illustrative nutritional archetypes resulting from a reef-based social-ecological trap. Reef catch represents the provision of reef-based foods through ecological health and governance success (x-axis) and the import dependence ratio represents the dominant economic system most relevant to market integration and diets (y-axis). Dotted lines are variable medians, with each quadrant representing a dietary archetype and nutritional outcome: 1) *Traditional Diet* (lower right)- consists of high seafood consumption and low consumption of Western food items; 2) *Mixed Diet* (upper right)- depends on preferences, culture, and prices, with many potential outcomes given the availability of both traditional and Western foods; 3) *Undernourishing Diet* (lower left)- when traditional food sources are no longer sufficiently available and a lack of market food access cannot provide nutritious substitutes; and 4) *Overnourishing Diet* (upper left)- a replacement of traditional seafood rich diets with highly processed energy dense foods. Each scenario assumes the "market" provides access to foods characteristic of Western diets, dominated by highly processed, sugar-sweetened, and other high caloric foods. These two variables interact and influence the resulting system trajectory towards a specific nutritional and dietary outcome. Chronologically, diets can be considered to begin in the lower right and shift to the lower left; or, begin in the lower right and shift to the upper right and then potentially to the upper left. All circles represent a nation with over 0.5 kg of reef-based food consumption per capita per year and do not exhibit permanence in any of their respective quadrants. We assume that the vast majority of reef catch is retained for domestic consumption. Per capita subsistence reef associated fish and invertebrate catch (Pauly et al., 2020), import dependency ratio (100*imports/supply) for all FAO Food Balance Sheet items other than oil crops, vegetable oils, alcohol, stimulants, and spices (FAOSTAT, 2020), and cardiovascular disease (CVD) prevalence (Global Burden of Disease Collaborative Network, 2018) represent 2014 values.

dependence on foreign food), and a relatively low incidence of cardiovascular disease (4667 cases of CVD per 100,000 people. However, more recently, and particularly in places with higher market integration, some populations of Kiribati increasingly subsist on highly Western diets and are beginning to transition (Eme et al., 2019) to a Mixed Diet.

In a context of high market integration, the resulting Mixed Diet represents broad access to an abundance of traditional and Western food items. Depending on taste preferences, cultural attitudes, and price elasticities among food items, this typology could result in a spectrum of individual diets ranging from highly traditional to highly Western, with resulting nutritional and health outcomes in a similar range. This diet is characterized by adequate *quantity* and potentially adequate *quality* depending on affordability and the dietary choices that are made. For example, the Maldives is heavily reliant on seafood with a very high per capita reef catch of 11.2 kg/year, and shows significant dependence on foreign food, with a very high IDR of 71%. However, trade regulations and food policy interventions within the country have restricted the penetration of Western foods (World Health Organization, 2017), leading the market to direct the Mixed Diet to a healthier outcome (3985 cases of CVD per 100,000 people). In contrast, Antigua also has a Mixed Diet, but a lower reef catch combined with high market products availability and limited policy intervention (Dorodnykh, 2017) lead to a significant nutrition transition (7134 cases of CVD per 100,000; Fig. 2).

The other archetypes, the Overnourishing Diet and the Undernourishing Diet, assume that traditional food sources are no longer sufficiently available, frequently due to the breakdown of traditional property and access rights and a shift to more centralized, less context-specific reef management. In a context of high market integration, the resulting Overnourishing Diet substitutes shortfalls in traditional subsistence and wild foods with highly processed, cheaply accessible market foods, shifting consumption toward less expensive Western diets, and increasing the risk of obesity and metabolic diseases (McIver et al., 2016; Campbell, 2019). This diet is characterized by excessive *quantity* of overall food, and insufficient *quality* of micronutrient rich and nutritious foods. For example, a very low per capita reef catch (0.9 kg/year) in Barbados, combined with open trade policies (Ford et al., 2007), has led to a high IDR of 44% (representing major dependence on foreign food). This high IDR corresponds with reduced the availability of healthy local foods, accelerating the nutrition transition (Sobers et al., 2019), and enabling a very high incidence of cardiovascular disease (9798 cases per 100,000 people; Fig. 2).

In a context of low market integration, Undernourishing Diets occur when market food access fails to provide sufficient nutritious substitutes for shortfalls in traditional subsistence and wild foods. This diet is characterized by an inadequate *quality* and potentially inadequate *quantity* of foods. In this case, increased consumption of locally available roots, tubers, starches, and other easily accessible and affordable foods are also unlikely to replace nutritionally rich wild food resources, and thus populations may face micronutrient, vitamin, and fatty acid deficiencies (Turner et al., 2007). In Madagascar, for example, the majority of the population of 25 million people face a high poverty rate and degrading coral reef systems. This is consistent with very low per capita reef catches of 0.7 kg/year, very low dependence on foreign food (IDR = 5%), and overall food insecurity that leads to low incidence of cardiovascular disease (3255 cases per 100,000 people; Fig. 2), but high undernutrition that stunt the growth of more than half the population (Rakotomanana et al., 2016).

These archetypes of nutritional outcomes arising from social-ecological traps have been demonstrated in a broad array of ecological and cultural systems, including but not limited to: deforestation and the rise of undernutrition in Malawi (Johnson et al., 2013); unsustainable hunting and increases in undernutrition in Madagascar (Golden et al., 2011); and the replacement of traditional foods with market foods leading to overnutrition in the Amazon region (van Vliet et al., 2015).

6. Interventions to avoid and escape the trap

An inherent feature of social-ecological traps is that the feedbacks in the system make the transition from one state to another difficult to reverse, or in some instances situationally infeasible. Thus, efforts to escape traps are inherently more challenging than efforts to avoid traps. This proposition has parallels in the comparison between public health and medicine, or conservation and restoration. Both public health and conservation focus on the prevention of adverse state outcomes, rather than the treatment of an unhealthy state. We propose that avoiding or escaping a social-ecological trap requires addressing the reinforcing dynamics between the social and ecological systems. Specifically, we discuss some historical trends in governance and market systems that have contributed to the creation and perpetuation of social-ecological traps in reef food systems.

While market and governance structures may certainly be designed to optimize ecological or nutritional objectives individually, often these interventions can create perverse effects for coupled social-ecological systems. For example, if a management approach considers only ecological dimensions, but creates nutritional vulnerabilities, it may undermine not only local health outcomes, but also the success of ecological management (Lewis et al., 2020). Similarly, if a policy considers only nutritional outcomes, but results in detrimental environmental impacts, ultimately both the nutritional benefits and the environmental support systems that underlie them will be threatened (Brunner et al., 2008). Rather than focusing on either the potential to promote ecological outcomes at the expense of nutritional outcomes, or *vice versa*, we suggest that by specifically focusing on the coupled system, it becomes possible to find solutions that promote social-ecological health. Research is critical to delineate exactly how much local populations rely on aquatic foods for nutrition, outlining needs to broaden the scope of dietary intake research and the importance of recognizing social difference when evaluating dependency and vulnerability (Golden et al., in review).

6.1. Governance interventions

Broadly speaking, governance shapes who, when, and under what conditions people may access and utilize marine spaces and resources. As such, governance is equally important in shaping both reef health (e.g., through gear restrictions or closed areas) and food access (e.g., through catch sharing or marketing practices) (Fig. 1). A substantial body of literature has considered how various fisheries governance approaches shape resource harvest and allocate benefits to local populations, and the relative advantages and tradeoffs implicit within them (Béné et al., 2016). In the context of fisheries, dominant strategies over recent decades have emphasized sustainability and economic dimensions of fisheries, maximizing harvests using indicators such as maximum sustainable or maximum economic yield (Hilborn, 2007). These strategies are inextricably linked to notions of centralized government regulation and licensing, and effective monitoring, control, and enforcement. Such strategies have served to underpin fisheries in many jurisdictions, but their poor fit to many developing world contexts have been well-described in the literature (Béné et al., 2016).

Managing fisheries for food security and nutrition for local populations (Béné et al., 2016; Bell et al., 2009) requires governance structures that stress locally relevant and adaptive fisheries management over centralized rules and authorities (d'Armengol et al., 2018) (Fig. 1). Rather than reinforcing central government institutions that focus on regulation, monitoring, and enforcement, adaptive fisheries management refocuses support toward decentralized, community-based, or traditional institutions that employ flexible and contextual management approaches to emerging and dynamic challenges. Locally legitimate institutions such as community-based fisheries management councils, traditional councils, and elders may utilize a suite of locally appropriate management strategies ranging from gear restrictions, fishery closures and access rights to watershed management, other means of controlling reef utilization (Cinner and Aswani, 2007; Jupiter et al., 2014; Kennedy et al., 2013).

The virtues of locally relevant and contextual resource governance institutions are well known; however, they have not often been conceptualized as promising interventions in social-ecological traps. Recent research has begun to explore this potential, however, and has highlighted the foundational need for appropriate governance structures to safeguard both the social and the ecological components, and interrupt trap dynamics (Eriksson et al., 2021) (Fig. 1). For example, recent studies highlight the importance of: indigenous knowledge and tribal institutions in ensuring ecosystem health and continued cultural and food benefits in the Pacific Northwest (Eckert et al., 2018; Long and Lake, 2018); co-management institutions in sustaining *hilsa* populations and local livelihoods in Bangladesh (van Brakel et al., 2018); and community authorities in safeguarding marine conservation goals and ceremonial and food benefits in Indonesia (Steenbergen and Warren, 2018). Ultimately, both the health of natural ecosystems and the nutritional benefits that flow from them rely on robust and adaptive resource governance institutions that have evolved over time to the local social and ecological context.

6.2. Market and food environment interventions

Increasing urbanization, rising incomes, transitions to cash-based economies, and liberalization of global trade have driven westernization of diets (Popkin et al., 2020). Trade liberalization has reduced barriers to food trade, with a goal of lowering prices, increasing the diversity of available products and increasing market access. Yet, evidence for the benefits of liberalizing food trade for food security is mixed: a systematic review found food security outcomes to improve in about a third of studies, to decline in another third of studies, and mixed results in the remaining third (McCorriston et al., 2013). A review of the effects of global seafood trade on food security found similarly contradictory evidence (Béné et al., 2010). While the evidence for food security benefits from trade liberalization remains unclear, there is mounting evidence that trade liberalization is driving increased consumption of processed foods (Thow et al., 2011). This is especially an issue in remote locations with low levels of disposable income because the longer shelf life and low cost of processed foods is better suited for long-distance transport and unrefrigerated storage.

Nutrition-sensitive trade and food policies are necessary top-down interventions to prevent the health trap associated with the nutrition transition. Dietary intake of highly processed, sugar-sweetened, and energy dense foods leads to physical transitions from a healthy body mass index to overweight and then obesity. Obesity is often called a chronic relapsing progressive disease process (Bray et al., 2017) and can lead to an intractable, irrecoverable cluster of conditions, and a fixed physical state of ill health. These dietary patterns lead to a cluster of diseases, called metabolic syndrome, that includes obesity, diabetes, and hypertension. The onset of these conditions makes it more difficult to exercise, and leads to psychological impacts that delay satiation and can lead to overeating. This condition is exemplary of trap dynamics. Moreover, this trap is not limited to an individual; obesity provides an excellent example of an intergenerational trap whereby the physical health and stress of one's ancestors can lead to an increased risk of ill health in the present (Campión et al., 2009).

While international agreements can target malnutrition, such agreements are generally non-binding, whereas trade liberalizing agreements are legally binding (Friel et al., 2020). Furthermore, historical precedence has shown that aid, and particularly humanitarian relief, have focused on averting undernourishment, which can often induce a shift toward energy dense foods. To better coordinate nutrition and trade policy, some countries are currently establishing agencies that bridge health and trade policies, such as Thailand's International Trade and Health Programme (Friel et al., 2020). Going further, some countries have moved toward increased protectionism. In relation to food production, this has included import standards to reduce the influx of low-quality meats, and tariffs on processed and sugary foods, as has occurred in Ghana (Thow et al., 2014) and several Pacific Islands including Fiji and Samoa (Thow et al., 2011). Additionally, some countries have established food self-sufficiency targets and food sovereignty movements have gained momentum. For example, La Via Campesina, formed in Uruguay in 1993, now has branches around the world promoting agrarian reform, natural resource protection, a reorganization of food trade, an end to hunger, and general democratic control of food (Chaifetz and Jagger, 2014).

6.3. Social-ecological interventions

Developing appropriate interventions in governance, economies, and ecosystems in the present may, in the face of future social and environmental change, prevent populations from becoming entrenched in social-ecological traps in the future. Furthermore, by aligning ecological and social interventions, we may identify particular opportunities for co-beneficial outcomes. We suggest that adopting a lens explicitly focused on the coupled system can reveal opportunities for intervention that improve both social and environmental outcomes. For example, governance interventions that prioritize local food security and nutrition over short-term revenue generation may produce co-benefits by increasing local food access while simultaneously reducing profit-oriented overexploitation of reef fisheries. This is in line with recent recommendations to ensure a just space for small-scale fishers within the growing number of blue economy initiatives (Cohen et al., 2019; Bennett et al., 2021). Similarly, support for local rules and authorities over centralized government regulations and institutions has the potential to improve responsivity to both local nutritional needs as well as potential declines in reef health (Jupiter et al., 2014). While tradeoffs certainly exist between some social and environmental management objectives, often interventions that seek to promote local access to seafood resources simultaneously work to promote overall ecosystem health (McClenachan et al., 2014).

As an example, marine protected areas have been hypothesized to simultaneously benefit ecosystems and human nutrition and wellbeing, particularly in overfished areas (Cabral et al., 2020). Empirical research has demonstrated these benefits where there is successful governance of diverse reef-based food systems, including marine protected areas of the Roviana Lagoon in the Solomon Islands (Aswani and Furusawa, 2007), North Sulawesi, Indonesia (Gurney et al., 2014), and Kenyan coastal communities (Darling, 2014). All of these case studies present complex dynamics and mechanisms for impact, and highlight important enabling conditions to integratively advance progress in both natural and social systems. To further demonstrate how a coupled system lens may highlight opportunities for co-beneficial intervention, we draw on social-ecological health interventions in the Philippines (Box 1).

Box 1
Social-ecological health interventions in the Philippines

Globally, a model-simulated increase of marine protected area (MPA) coverage has been estimated to deliver a 20% increase in fish catch due to the spillover effect (Cabral et al., 2020); an increase that could lead to major nutritional benefits. Of the more than 16,000 MPAs globally, over 1000 can be found in the Philippines (Weeks et al., 2010). These MPAs have varying governance strategies, including strict no-take zones and multiple use conditions and occur at diverse scales. Although MPAs do not always achieve their stated ecological objectives in the Philippines (Weeks et al., 2010), there is increasing evidence of MPAs enhancing social benefits, human welfare and equity in this ecological and cultural setting (Yang and Pomeroy, 2017; Mascia et al., 2010), making design adaptations and increased coverage a hopeful prospect. In a national study, Alva and colleagues demonstrated that children within a 2 km proximity of MPAs had substantially higher dietary diversification and consumed more fish than children not adjacent to a MPA (Alvaet al., 2016). The proximity of MPAs and type of governance strategy are important determinants of the degree of impact, demonstrating the nutritional benefits of MPA presence (Alvaet al., 2016). Time since MPA establishment is also a core factor implicated in social-ecological success, underscoring potential tradeoffs inherent in the temporal dynamics of MPAs- often exhibiting higher costs at onset with options for long-term benefits (Mascia et al., 2010). Though impacts have been found on food security (Mascia et al., 2010) and dietary diversity (Alvaet al., 2016), there is no current evidence on objective measures of health, such as rates of undernutrition (Gjertsen, 2005). While no evidence directly links MPAs to enhanced nutritional outcomes, the marine management interventions in the Philippines have resulted in tangible ecological and human health benefits – an escape from a social-ecological trap.

Social-ecological interventions, such as Population Health and Environment interventions (Lopez-Carr and Ervin, 2017), or Integrated Conservation and Development Programs (Garnett et al., 2007), can be leveraged to touch on all components of the social-ecological system, and better ensure avoidance of social-ecological traps prior to entrapment. For example, the PATH Foundation (a Filipino non-profit organization) created a Population Health and Environment initiative in Palawan that paired coastal marine management and health services around a central theme of food security. This initiative only delivered positive change on all measured food security indicators when health and resource management interventions were provided together, and not when either intervention was provided in isolation (D'Agnes et al., 2010). Similarly, Rare's Fish Forever Philippines program has used behavior change and communication methods to weave together social and environmental objectives, thereby intervening into social-ecological system dynamics, leading to increased fishery productivity and improved livelihoods (Karr et al., 2017). For MPAs to reach their full potential, they must be networked both socially and environmentally, creating institutional mechanisms of support and ecological connectivity, allowing for local processes to scale at national, regional, and even global levels (Lowry et al., 2009). Furthermore, MPAs need to be linked to longer-term multi-scale efforts to reform fisheries management to reduce or eliminate overfishing. The Philippines natural and human systems have been widely studied, with research documenting the individual connections between the two systems. Still, each of the links within the social-ecological system is typically studied in isolation, without paying attention to the coupled dynamics and the relationships among all links within the system. While the Philippines social-ecological interventions have displayed tangible health benefits and provide an example of social-ecological trap escape, future research capturing these complex social-ecological system dynamics represents a critical frontier for avoiding social-ecological traps altogether and realizing potential human-environmental health co-benefits.

7. Conclusion

Social-ecological traps within food systems have potentially dire ecological and public health consequences and have led to skyrocketing rates of undernutrition, obesity and metabolic disease. Indeed, reef-based food systems illustrate this exact dynamic. Understanding the internal dynamics and system feedbacks of this type of social-ecological trap will position decision-makers to better design management strategies to prevent, avoid, and escape them. This is particularly true in responding to the ongoing COVID-19 pandemic, a shock that could tip systems into a social-ecological trap, but also presents an opportunity to shift internal system dynamics toward more favorable food system outcomes (Farrell et al., 2020; Love et al., 2021). Trap escape or reversal through system recovery is inherently difficult and may be impossible if actions are not taken in the short term to rehabilitate coral reefs and ensure access to seafood. On a generational timescale, once livelihoods are shifted away from the reef, it is possible that fishing knowledge will be lost, and an effective return to the reefs for sustained nutritional benefit will be challenging. Other slow-moving variables, such as climate change-induced sea temperature rise, coral bleaching, and ocean acidification will continue to degrade reefs, further entrapping or eroding social-ecological system resilience (Hughes et al., 2017).

However, social-ecological traps are not inevitable for reef-based food systems. Above we outline several governance, market and food environment, and social-ecological interventions with the potential to interrupt trap dynamics. We stress the need for a focus on the coupled system itself, through approaches, such as nutrition-sensitive trade policies and local adaptive fisheries management, to find solutions for social-ecological health. An essential first step is to conceptualize food systems within broader social-ecological frameworks, in order to center cohesive policies across different sectors. This conceptualization subsequently has the potential to align co-beneficial outcomes across a wide range of policy goals, for example the UN Sustainable Development Goals (SDGs), including SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 13 (climate action) and SDG 14 (life below water). In this way, it is possible that conservation and fisheries management efforts could contribute to the persistence of traditional diets and stabilization of food security.

In addition to the imperative high-level need to better recognize the interconnectedness of ecological health, food systems, and nutrition, we recommend a host of more specific pathways for action. In the realm of governance, we must encourage increased collaboration and communication between too often siloed public health and environmental agencies at multiple scales of government. Together these agencies should embark on more co-designed data collection programs that can serve as intra-national surveillance platforms for the progression of these social-ecological trap dynamics. They should also collaborate on interventions to arrest or reverse such dynamics. Environment and public health agencies must similarly engage in active dialogue with their counterparts in trade to leverage more understanding for how market forcings may contribute to negative outcomes and how such systems can be adjusted to sidestep traps. We must specifically elevate conversations about social-ecological trap dynamics in key upcoming intergovernmental dialogues where little to no recognition is given to their importance; for example, at the Convention on Biological Diversity Conference of the Parties meetings, alongside discussions of protected area target ambition at the International Union for Conservation of Nature's World Conservation Congress, or at the UN Food Systems Summit. In the realm of research, we must invest seriously in research in the intersectional areas of human health and environment. Such interdisciplinary programs arguably are best situated in better funded health research programs versus their counterpart agencies for fundamental science. Programs such as the US National Science Foundation's "Dynamics of Integrated Socio-Environmental Systems" serve as exemplary models, but are under-resourced relative to the complexity of the science involved, and the significant societal benefit to be derived from potential research outputs. Collaborations for research funding and the execution of research must not only include social, ecological, and public health researchers - but also medical researchers, given the connectedness of these dynamics to disease treatment and care. For example, current efforts by the government of Kiribati (in partnership with academic institutions and the Pacific Community) to couple nationally representative household income and expenditure surveys with the collection of health, fisheries and local ecological data will facilitate novel integrated analyses; these co-designed programs are currently serving as a model for other island states in the Pacific and elsewhere.

Research on social-ecological traps should also be accelerated such that it can mature from simply understanding trap dynamics to forecasting and creating early warning systems to detect the onset of trap dynamics. The Lancet and Rockefeller Foundation joined forces on an official commission on Planetary Health, a field dedicated to understanding the human health impacts of environmental change. The Commission Report detailed the planetary boundaries and environmental tipping points that had been exceeded, and the consequent impacts on infectious disease, mental health, and nutrition (Whitmee et al., 2015). Within the Commission Report, the nutritional consequences of unsustainable fishing and coral reef degradation were specifically mentioned as a key area requiring further research.

In the realm of international finance, we must encourage international funding agencies (e.g. The Global Environment Facility) to design their funding prioritization schemes such that their investments can be directed specifically to reversing social-ecological trap progression. This could include enhancing funding for programs such as those that help situate new marine protected areas in regions that maximally enhance nutritional security, programs that build local marine science capacity that can effectively detect coral reef state shifts, or programs that bolster secure community access rights to marine resources.

Understanding the relevant tipping points of coral reefs and associated habitats and preventing them or their impacts on human food security should be seen as a primary objective for those committed to stabilizing food security in the developing world. Coral reefs are just one example. Temperate and tropical forests (Johnson et al., 2013), freshwater lakes (Fiorella et al., 2014), and other critical ecosystems provide the underlying support for food systems to flourish, highlighting the importance of social-ecological trap dynamics. This imperative begs for greater coordination among sectors including economics, public health, terrestrial conservation, marine and coastal management, and agriculture, among others, to ensure thriving societies grounded in healthy and functioning ecosystems.

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