1-1-2015

Contagious exploitation of marine resources

Hampus B. Eriksson
University of Wollongong

Henrik Osterblom
Stockholm University

Beatrice Crona
Stockholm University

Max Troell
Stockholm University

Neil L. Andrew
WorldFish Centre, nandrew@uow.edu.au

See next page for additional authors

Contagious exploitation of marine resources

Abstract

Global seafood sourcing networks are expanding to meet demand. To describe contemporary fishery expansion patterns, we analyzed the worldwide exploitation of sea cucumber (Echinodermata: Holothuroidea) traded via Hong Kong for consumers in China. In just 15 years (1996-2011), the sea cucumber sourcing network expanded from 35 to 83 countries; sea cucumber fisheries serving the Chinese market now operate within countries cumulatively spanning over 90% of the world's tropical coastlines. The emergence of such fisheries in nations where they were previously absent could not be explained either by their national governance capacity or by their distance from Hong Kong. Surging imports from these new fisheries have compensated for declines in long-standing fisheries elsewhere. The case of commercial sea cucumber trade for the Chinese market exemplifies a new global extraction phenomenon that we call contagious resource exploitation - A fast-moving system resembling a disease epidemic, where long-distance transport expedites largescale expansion followed by diffusive local spread into neighboring areas. Multi-level and multi-scale decision making is urgently needed to control and mitigate the effects of contagious exploitation.

Keywords

marine, exploitation, resources, contagious

Disciplines

Arts and Humanities | Law

Publication Details

Eriksson, H. B., Osterblom, H., Crona, B., Troell, M., Andrew, N. L., Wilen, J. and Folke, C. (2015). Contagious exploitation of marine resources. Frontiers in Ecology and the Environment, 13 (8), 435-440.

Authors

Hampus B. Eriksson, Henrik Osterblom, Beatrice Crona, Max Troell, Neil L. Andrew, James Wilen, and Carl Folke

Contagious exploitation of marine resources

Hampus Eriksson[1,2*], Henrik Österblom[3], Beatrice Crona[3,4], Max Troell[3,4], Neil Andrew[1,2], James Wilen[5], and Carl Folke[3,4]

Global seafood sourcing networks are expanding to meet demand. To describe contemporary fishery expansion patterns, we analyzed the worldwide exploitation of sea cucumber (Echinodermata: Holothuroidea) traded via Hong Kong for consumers in China. In just 15 years (1996–2011), the sea cucumber sourcing network expanded from 35 to 83 countries; sea cucumber fisheries serving the Chinese market now operate within countries cumulatively spanning over 90% of the world's tropical coastlines. The emergence of such fisheries in nations where they were previously absent could not be explained either by their national governance capacity or by their distance from Hong Kong. Surging imports from these new fisheries have compensated for declines in long-standing fisheries elsewhere. The case of commercial sea cucumber trade for the Chinese market exemplifies a new global extraction phenomenon that we call *contagious* resource exploitation – a fast-moving system resembling a disease epidemic, where long-distance transport expedites large-scale expansion followed by diffusive local spread into neighboring areas. Multi-level and multi-scale decision making is urgently needed to control and mitigate the effects of contagious exploitation.

Front Ecol Environ 2015; 13(8): 435–440, doi:10.1890/140312

The expansion of seafood production to meet increasing global demand entails both intensification of fishing in existing locations and continued expansion of resource extraction and production into previously unexploited areas (Troell *et al.* 2014). Over the past century, the global geographical spread of wild capture fisheries has generally followed a pattern of sequential exploitation into new areas (Berkes *et al.* 2006; Swartz *et al.* 2010; Anderson *et al.* 2011a; Norse *et al.* 2012). Observed global patterns associated with marine resource exploitation have been described as "roving" (Berkes *et al.* 2006), "serial" (Anderson *et al.* 2011a), "opportunistic" (Branch *et al.* 2013), and "profit driven" (Sethi *et al.* 2010). Here, we suggest that an additional pattern, which we term *contagious* resource exploitation, has emerged.

In a nutshell:

- Rising global demand for seafood presents challenges for managing marine resources, many of which are declining or threatened
- We describe a new and rapid pattern of contagious marine resource exploitation, which spreads via global sourcing networks to satisfy rising demand
- We use sea cucumbers to illustrate the concept, given their wide geographic distribution but specific market for consumption in China
- Neither distance from the source to the recipient market nor the strength of government authority in the source country can explain the pattern of exploitation
- We suggest that international cooperative initiatives, modeled on global-health-sector experiences in managing contagious diseases, could help to ensure the future sustainability of fisheries

[1]*WorldFish, Penang, Malaysia* [*]*(H.Eriksson@cgiar.org);* [2]*Australian National Centre for Ocean Resources and Security (ANCORS), University of Wollongong, Wollongong, Australia;* [3]*Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden;* [4]*Beijer Institute of Ecological Economics, and the Global Economic Dynamics and the Biosphere Program, Royal Swedish Academy of Sciences, Stockholm, Sweden;* [5]*University of California, Davis, Davis, CA*

We define contagious resource exploitation as the rapid spread of exploitative practices across marine ecosystems, facilitated by increasingly efficient connections between metropolitan areas of demand and remote resource-rich sources of supply. The contagion concept has analogs in disease epidemics, where models have shown how contagions can spread quickly as a result of increasing globalization (Brockman and Helbing 2013). The concept has also been used to describe other rapidly spreading processes, such as the propagating spread of "infectious" attitudes or behaviors (Ugander *et al.* 2012; Brockman and Helbing 2013). Containment and mitigation strategies for such complex, network-driven processes are impeded by the speed at which these diseases or behaviors can spread through contemporary global networks (Balcan *et al.* 2009; Helbing 2013). Contagious resource exploitation is characterized by a rapid response to escalating demand, facilitated by an ever more interlinked communication infrastructure and by reduced shipping costs. We propose that contagious resource exploitation will become a more common attribute of natural resource extraction in the globalized world, and a key question, therefore, is how this phenomenon can be addressed, to limit unsustainable extraction of marine resources. We use the commercial trade in sea cucumber (Echino-

Figure 1. *(a) Scuba diver's catch in Zanzibar, Tanzania, consisting of (from top to bottom)* Thelenota anax, Holothuria fuscopunctata, Actinopyga miliaris, Holothuria fuscogilva, *and* Thelenota ananas *(vertical). (b) Dried sea cucumbers for sale in Hong Kong. (c) Shoppers in Hong Kong selecting* bêche-de-mer *from a range of species.*

dermata: Holothuroidea) for the Chinese dried seafood market as a case study to examine this concept.

Sea cucumbers and the globalization of the Chinese seafood trade

Sea cucumbers are sedentary invertebrates that exist in all of the world's oceans. Common in tropical coastal waters, sea cucumber species contribute to nutrient recycling by feeding on both detritus and live organic material (Uthicke 2001); they also increase calcium bioavailability and help to buffer acidification on coral reefs through the partial dissolution and excretion of large quantities of ingested carbonate sands (Schneider *et al.* 2011). These echinoderms represent an important source of livelihood, most often among impoverished communities, and over 3 million people are engaged in their harvesting (Purcell *et al.* 2013). Overfishing of sea cucumbers is prevalent throughout their respective ranges, with 16 species considered to be vulnerable or endangered (Purcell *et al.* 2014).

Sea cucumbers have long been an element of traditional Chinese cuisine (Fabinyi and Liu 2014). They are harvested predominantly to produce *bêche-de-mer*, the dried bodywall (Figure 1) that is later rehydrated by soaking and boiled to prepare meals. The low-technology dried product-form has facilitated export to China from undeveloped and remote areas. The liberalization of the Chinese economy in the 1980s and the recent increase in wealth in China have accelerated harvesting and trade in wildlife and seafood, including sea cucumbers (Anderson *et al.* 2011a; Purcell *et al.* 2013) throughout the world (Graham-Rowe 2011).

We mapped the recent worldwide scale and expansion dynamics of sea cucumber fisheries by analyzing trade statistics from Hong Kong (1996–2011), a global seafood hub in Asia, where imports of sea cucumbers are recorded by country of origin (To and Shea 2012). Sea cucumbers traded through Hong Kong are mostly destined for consumers in China. We used the World Governance Index (WGI; Kaufmann *et al.* 2010) to test whether expansion of the sea cucumber trade into countries where such commerce was previously absent (hereafter, "new countries") – to satisfy China's rising demand – is linked to national governance dimensions and examined the influence of distance from the source country to Hong Kong, which is the recipient market (for details, see WebPanel 1 and WebTable 1).

Rapid expansion of the global sourcing network

Our analysis illustrates the global scale of the impact and expansion patterns of the contemporary Hong Kong trade in sea cucumbers (Figure 2). Many tropical sea cucumber fisheries across the Indo-Pacific have been operating since at least 1996, but notable recent expansion of such fisheries has been occurring off the coasts of West Africa and Latin America. Due to insufficient data, species from these regions were excluded from a recent appraisal of sea cucumber extinction risk (Purcell *et al.* 2014). The rapid spread into these areas, characterized by mostly undocumented extraction rates, indicates elevated risk to those species with local distributions, and illustrates a temporal mismatch between risk awareness and institutional response, as documented in several other types of fisheries unrelated to sea cucumber fisheries (Berkes *et al.* 2006; Norse *et al.* 2012).

On average, more than three countries have been added to the sourcing network each year, increasing from 35 countries to 83 countries between 1996 and 2011 (Figure 3a), with a trend that follows a linear model (slope = 3.50). This marked rate of fishery expansion into new countries has coincided with declining catch volumes from the 10 largest exporting countries in 1996 (Figure 3b). These 10 countries exported only 43% of the total traded volume in sea cucumbers in 2011, as compared with 92% in 1996, declining from 4481 to 2445 metric tons. However, this reduction was offset by 48 new countries added since 1997 and by increased exports from 25 other countries that were operating in 1996. As a result, the total traded volume has remained relatively stable over this period, with a notable dip in the late 1990s, most likely attributable to the 1997 Asian financial crisis. Global sea cucumber production also fell during this period (Anderson *et al.* 2011a). It is unclear whether the downturns in trade and production were a result of reduced demand as incomes fell in China, or

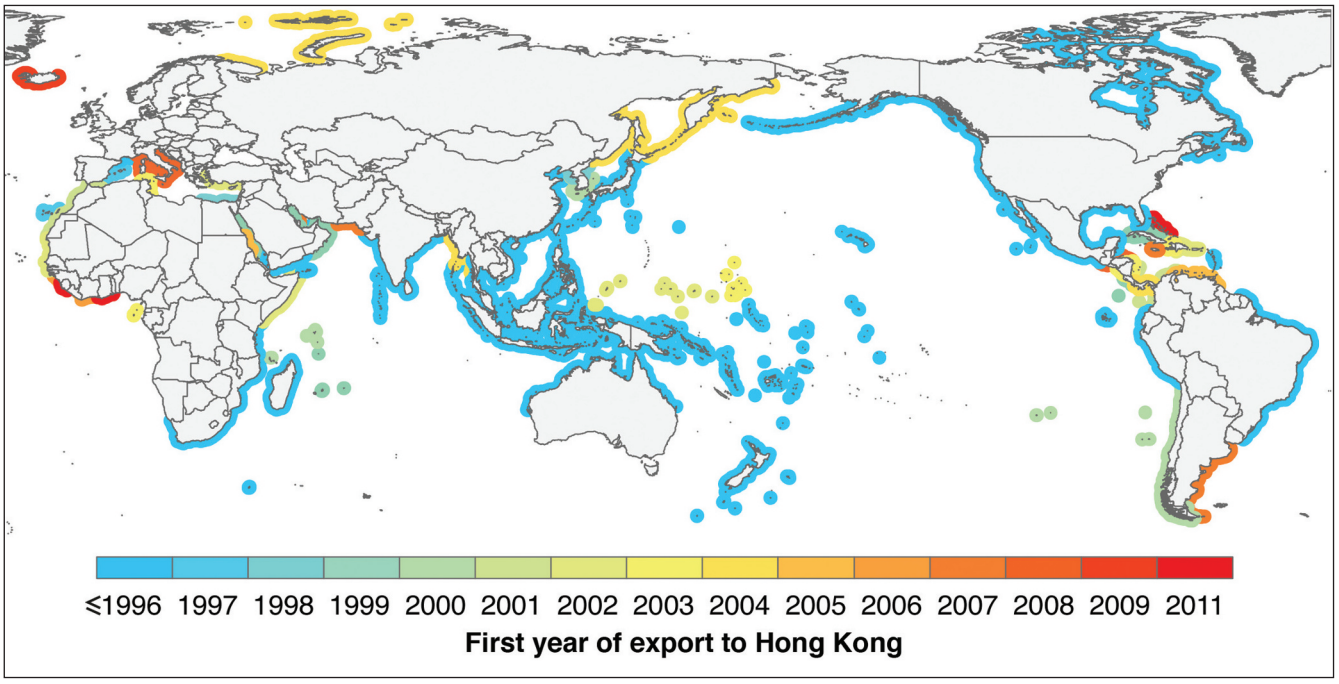

Figure 2. *Color-coded map depicting the year that countries first began exporting sea cucumbers to Hong Kong. For large countries, coastlines have been reduced to match fishing areas or target species distribution, in accordance with available information (for details, see WebPanel 1). Note: there were no new countries that started exporting sea cucumbers during 2010.*

whether the financial crisis adversely affected exchange rates so that such commerce became unattractive to merchants. If the dip was due to waning consumer demand associated with the economic crisis, then it could be anticipated that demand will slow yet again if growth in the present-day Chinese economy stalls.

Concealed within these trade data are compensating processes, such as the well-documented phenomenon of sequential species substitution to replace declining stocks (Branch *et al.* 2013) and the recent contribution of burgeoning sea cucumber aquaculture production (Purcell *et al.* 2013).

Between 1996 and 2011, the total tropical coastline of countries appearing in Hong Kong trade statistics associated with sea cucumbers increased by 30% (60 760 km) and by 2011, over 90% of the world's tropical coastline lay within countries that operate sea cucumber fisheries (Figure 3c). These data provide a clear example of how expansive the reach and spatial impact of modern seafood sourcing networks can be to satisfy increasing demand, such as that in China. More coastline lies within temperate areas (Figure 3d), but there are fewer species with commercial potential in these regions and they are less accessible as compared with those in tropical shallow waters; thus, the possibility of commercializing these temperate stocks is unclear.

Potential predictors of expansion

Proximity to market

To assess historical expansion, Anderson *et al.* (2011a) analyzed data for 19 countries over the period 1950–2002 and showed that sea cucumber sourcing networks experienced a delayed expansion with increasing distance from Hong Kong. Berkes *et al.* (2006) illustrated a similar pattern of geographical expansion using sea urchin fisheries (1945–1995), primarily for the Japanese market. Conversely, we found that the modern expansion of the sea cucumber sourcing network was not influenced by distance from Hong Kong (r^2 = 0.05, P = 0.11; Figure 4a), based on data from the 48 countries that developed new fisheries between the years 1997 and 2011. The pattern over time closely resembles models of disease epidemics, where long-distance travel leads to worldwide disease spread into a new region but short-range coupling creates a diffusive pattern into neighboring subpopulations (Balcan *et al.* 2009). These data indicate that the sea cucumber sourcing network has moved into an era of rapid expansion, building on networks initiated over the past century (WebAnimation 1).

Governance capacity

Fisheries expansion has previously been attributed to a lack of governance capacity (Berkes *et al.* 2006). For instance, illegal fishing operations in the Southern Ocean are adapting to increased regulation by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) by deregistering vessels from CCAMLR member states to countries characterized by weak governance (Österblom *et al.* 2010). For sea cucumber fisheries, the opposite trend might be expected, such that stocks in countries with weak governance are exploited first, followed by stocks in countries with stricter controls. Yet our

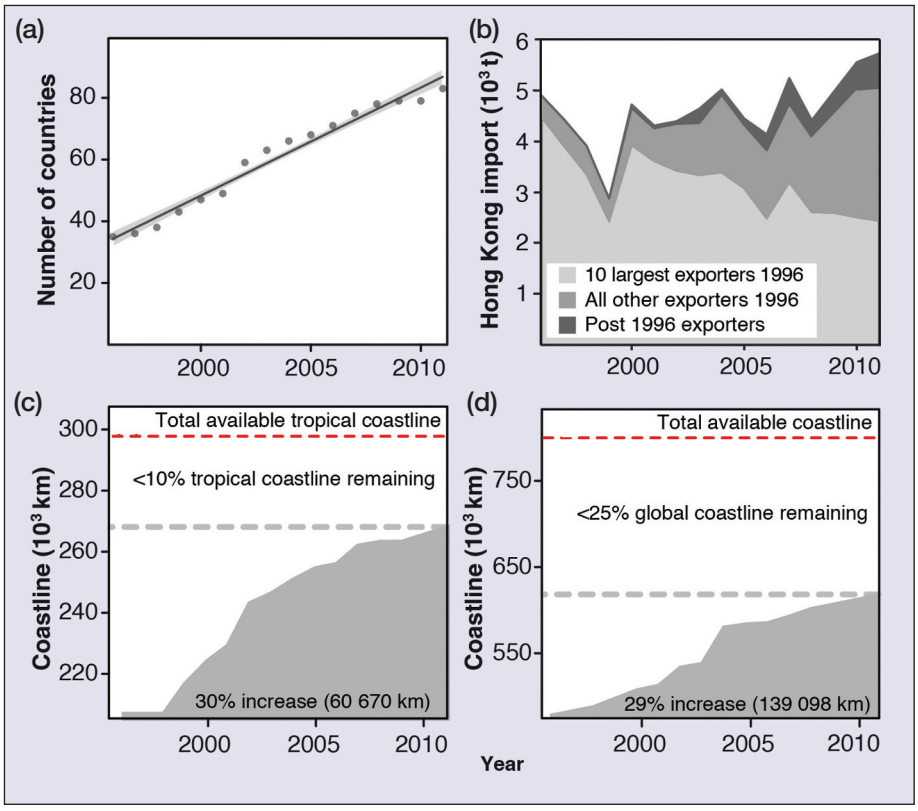

Figure 3. *Expansion of the sea cucumber sourcing network for imports into Hong Kong, 1996–2011. (a) Cumulative count displaying increasing numbers of countries entering the market over time. Fitted line is a linear model with 95% confidence intervals (slope = 3.50). (b) Traded quantities of sea cucumber by the 10 largest exporting countries in 1996, other countries exporting in 1996, and those that began exporting after 1996. (c) Coastline of tropical countries (between the latitudes of 23°N and 23°S) and (d) total world coastline where sea cucumbers are harvested for export to Hong Kong.*

analysis of the expansion of the sea cucumber sourcing network into new countries reveals no influence by national governance capacity (r^2 = 0.01, P = 0.80; Figure 4b). On the other hand, countries in Europe, which have relatively strong governance capacity, are increasingly seeking to export sea cucumbers and are paying more attention to sea cucumber species in the Mediterranean (CUMFISH; www.ccmar.ualg.pt/cumfish).

Our results show that it cannot be assumed that only countries with weak governance will be future candidates for the global sea cucumber sourcing network described here, nor can it be assumed that countries with weak governance capacity are the only nations where unsustainable harvesting will occur. Thus, new fisheries that emerge rapidly in countries where they have not previously existed pose challenges for any institution to respond at an appropriate timescale.

Facilitation through global connectivity

Certain features of the global seafood trade have hampered rapid global exploitation in the past. When demand was lower and when available supplies were in close proximity to the recipient market, there was less incentive to expand. In addition, commercial and shipping networks were undeveloped, which restrained geographical expansion. In recent decades, however, increasingly efficient communication infrastructure, technological advancements, and reduced shipping costs (Dicken 2011) have combined with the rise in market demand and dwindling regional supplies to create favorable conditions for contagious resource exploitation. For sea cucumbers, the presence of Chinese communities in other countries may have facilitated this development. This case study demonstrates that the global scale of human actions, and the speed and connectivity of the global trade network, is severely challenging the capacity of existing regulatory institutions, as the effects of exploitation propagate and cascade across countries and regions. Analogous patterns of global change effects have been described elsewhere (Young *et al.* 2006; Adger *et al.* 2009), but rarely with similar speed. Not only has exploitation developed more rapidly than local institutions can react to but it has also in some cases resulted in overfishing before the resource is perceived as threatened or has even been taxonomically described.

The scale, speed, and connectivity of human activities now provide a novel context for global resource exploitation patterns beyond those previously witnessed. We theorize that contagious exploitation is more likely to occur in connection with widespread "lootable" natural resources – that is, those that are highly profitable, have low extraction costs, and are weakly regulated (Snyder 2006). In the marine domain, other highly priced invertebrates (Anderson *et al.* 2011b) as well as species in the live reef fish trade (Scales *et al.* 2006) demonstrate similar patterns of spread; they too are widespread and exhibit lootable properties. Patagonian toothfish (*Dissostichus eleginoides*) is an example of a remote and valuable fishery resource where exploitation has expanded rapidly across Southern Ocean jurisdictions since it emerged in the 1990s to supply global markets, following the collapse of cod (*Gadus morhua*) stocks in the North Atlantic. Increased UK enforcement in the Southwest Atlantic and discovery of toothfish stocks farther eastward resulted in the quick expansion of fisheries to South Africa's Prince Edward Islands, where stocks collapsed after only a few years of fishing, and subsequently to the French

islands of Crozet and Kerguelen and later to the Australian islands of Heard and McDonald in the mid-2000s. In recent years, stricter enforcement of fishing regulations by France and Australia has resulted in increased illegal fishing for Antarctic toothfish (*Dissostichus mawsoni*) closer to the edge of Antarctic sea-ice extent, as well as relocation of illegal fishing vessels to Madagascar (Agnew 2000; Österblom *et al.* 2010; Österblom and Sumaila 2011). The fishing grounds for both species of toothfish now encircle the Antarctic continent.

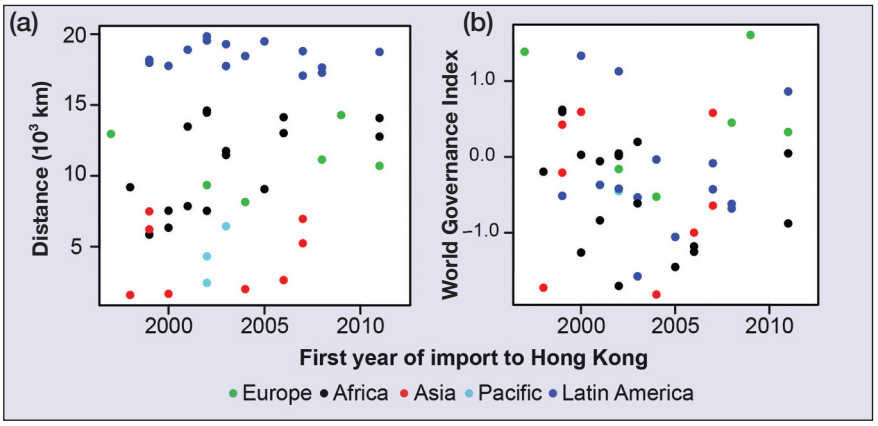

Figure 4. *Distance from Hong Kong to exporting countries and World Governance Index (WGI) by year of first Hong Kong import record. (a) No correlation was found between distance from Hong Kong and first year of import ($r^2 = 0.05$, $P = 0.11$). (b) No correlation was found between WGI and start year ($r^2 = 0.01$, $P = 0.80$).*

Worldwide linkages of social–ecological systems are becoming more prevalent (Young *et al.* 2006; Dicken 2011), an indication that contagious exploitation may also be affecting several other types of resources associated with hunting, farming, or logging. For example, shrimp and salmon aquaculture have spread across regions in just a few decades, and now form a global production system that supplies markets and consumers worldwide (Deutsch *et al.* 2007). More than 50% of species' threats in the iconic biodiversity locations of Madagascar and Papua New Guinea are linked to international trade that satisfies global demand (Lenzen *et al.* 2012) – showcasing that affluent markets have considerable broad ecological impact. The speed at which markets emerge and expand in today's global economy can overwhelm even well-performing institutions (Walker *et al.* 2009), adding a dimension of urgency in protecting global biodiversity and the functionality of ecosystems.

Global governance requires new institutions

Innovative international approaches to governance are needed to address the challenges presented by contagious exploitation. Such efforts must be broad in scope, given that the processes that underpin the phenomenon of contagious exploitation are complex and occur at many different levels. Industry intelligence on fishing operations has previously proven useful in understanding sourcing links across countries and regions (Österblom and Sumaila 2011). This type of information could support regional sea cucumber fishery management partnerships, such as one that was recently initiated in the Pacific (IUCN 2014), which aspires to bring about formalized cooperation between countries to share information and build capacity to better control and manage market pressures. However, initiatives are confounded by the secretive and illegal trade in dried seafood (Purcell *et al.* 2013), which obscures exploitation and trade patterns. Improved resolution of trade data would help support trend appraisals and guide management responses. This has been achieved for some highly migratory species and fish stocks in international waters through several transparent trading schemes at the species level (Agnew 2000).

When confronting contagious resource exploitation, there may be lessons to be learned from other sectors. For example, the global health community (eg the World Health Organization) has developed reasonably effective global coordination systems to mitigate and control the spread of disease. Existing international initiatives aimed at policing global seafood trade and global fishery operations are limited, but include CCAMLR (Agnew 2000), the Convention on International Trade in Endangered Species of Wild Fauna and Flora, and Parties to the Nauru Agreement. Nevertheless, these organizations have varying levels of authority in terms of implementing coordinated actions, and all are constrained by relatively slow decision-making processes.

Until now, there has been a limited international institutional response to sea cucumber overharvesting. These sedentary animals are mostly collected by people with few other livelihood options; international efforts to coordinate sustainable use must be compatible with national policies as well as responsive to local needs and objectives. Any international control initiatives, including catch documentation schemes, will require substantial human and financial capacity at both global and local levels. Encouragingly, the combination of formal institutional structures at multiple levels led by nation states – coupled with informal global, regional, and community-based networks of diverse actors – has shown potential as a means of effectively tackling some of the most complex challenges associated with both pandemics and natural resource use (Galaz *et al.* 2014), including fisheries exploitation (Österblom 2014). Such multi-level institutions with multiple centers of governance are needed to mitigate contagious exploitation of species.

Acknowledgements

We thank A To at WWF Hong Kong for trade statistics, J Benedict at WorldFish for GIS analysis, and S Clarke for discussions. This study was supported by the Australian Centre for International Agricultural Research (ACIAR) project FIS/2012/074 "Improving Community-based Fisheries Management in Pacific Island Countries" and the CGIAR Research Program on Aquatic Agricultural Systems. HE and NA were funded through these sources; HÖ was funded by BEAM (Baltic Ecosystem Adaptive Management) and the Nippon Foundation; BC, JW, and CF were funded by the Erling-Persson Family Foundation; HÖ, BC, CF, and MT were supported by Mistra, through a core grant to the Stockholm Resilience Centre. For author contributions, see WebPanel 2.

References

Adger WN, Eakin H, and Winkels A. 2009. Nested and teleconnected vulnerabilities to environmental change. *Front Ecol Environ* **7**: 150–57.

Agnew DJ. 2000. The illegal and unregulated fishery for toothfish in the Southern Ocean, and the CCAMLR catch documentation scheme. *Mar Policy* **24**: 361–74.

Anderson SC, Flemming JM, Watson R, and Lotze HK. 2011a. Serial exploitation of global sea cucumber fisheries. *Fish Fish* **12**: 317–39.

Anderson SC, Flemming JM, Watson R, and Lotze HK. 2011b. Rapid global expansion of invertebrate fisheries: trends, drivers, and ecosystem effects. *PLoS ONE* **6**: e14735.

Balcan D, Colizza V, Goncalves B, *et al.* 2009. Multiscale mobility networks and the spatial spreading of infectious diseases. *P Natl Acad Sci USA* **106**: 21484–89.

Berkes F, Hughes TP, Steneck RS, *et al.* 2006. Globalization, roving bandits, and marine resources. *Science* **311**: 1557–58.

Branch TA, Lobo A, and Purcell S. 2013. Opportunistic exploitation: an overlooked pathway to extinction. *Trends Ecol Evol* **28**: 409–13.

Brockman D and Helbing D. 2013. The hidden geometry of complex, network-driven contagion phenomena. *Science* **342**: 1337–42.

Deutsch L, Gräslund S, Folke C, *et al.* 2007. Feeding aquaculture growth through globalization: exploitation of marine ecosystems for fishmeal. *Global Environ Chang* **17**: 238–49.

Dicken P. 2011. Global shift: mapping the changing contours of the world economy (6th edn). New York, NY, and London, UK: Guilford.

Fabinyi M and Liu N. 2014. Seafood banquets in Beijing: consumer perspectives and implications for environmental sustainability. *Conserv Soc* **12**: 218–28.

Galaz V, Österblom H, Bodin Ö, and Crona B. 2014. Global networks and global change-induced tipping points. *Int Environ Agreements*; doi:10.1007/s10784-014-9253-6.

Graham-Rowe D. 2011. Endangered and in demand. *Nature* **480**: 5101–03.

Helbing D. 2013. Globally networked risks and how to respond. *Nature* **497**: 51–59.

IUCN (International Union for Conservation of Nature). 2014. Ministers of the Pacific Islands call for action on coastal fisheries and *bêche-de-mer*. Gland, Switzerland: IUCN. www.iucn.org/about/union/secretariat/offices/oceania/?18227/Ministers-of-the-Pacific-Islands-call-for-action-on-coastal-fisheries-and-beche-de-mer. Viewed 15 Jun 2015.

Kaufmann D, Kraay A, and Mastruzzi M. 2010. The Worldwide Governance Indicators: methodology and analytical issues. Washington, DC: World Bank. World Bank Policy Research Working Paper No 5430.

Lenzen M, Moran D, Kanemoto K, *et al.* 2012. International trade drives biodiversity threats in developing nations. *Nature* **486**: 109–12.

Norse EA, Brooke S, Cheung WWL, *et al.* 2012. Sustainability of deep-sea fisheries. *Mar Policy* **36**: 307–20.

Österblom H. 2014. Catching up on fisheries crime. *Conserv Biol* **28**: 877–79.

Österblom H and Sumaila UR. 2011. Toothfish crises, actor diversity and the emergence of compliance mechanisms in the Southern Ocean. *Global Environ Chang* **21**: 972–82.

Österblom H, Sumaila UR, Bodin Ö, *et al.* 2010. Adapting to regional enforcement: fishing down the governance index. *PLoS ONE* **5**: e12832.

Purcell SW, Mercier A, Conand C, *et al.* 2013. Sea cucumber fisheries: global analysis of stocks, management measures and drivers of overfishing. *Fish Fish* **14**: 34–59.

Purcell SW, Polidoro BA, Hamel J-F, *et al.* 2014. The cost of being valuable: predictors of extinction risk in marine invertebrates exploited as luxury seafood. *P Roy Soc B-Biol Sci* **281**: 20133296.

Scales H, Balmford A, Liu M, *et al.* 2006. Keeping bandits at bay? *Science* **313**: 612–13.

Schneider K, Silverman J, Woolsey E, *et al.* 2011. Potential influence of aspidochirotid sea cucumbers on coral reef $CaCO_3$ budget: a case study at One Tree Reef. *J Geophys Res* **116**: G04032.

Sethi SA, Branch TA, and Watson R. 2010. Global fishery development patterns are driven by profit but not trophic level. *P Natl Acad Sci USA* **107**: 12163–67.

Snyder R. 2006. Does lootable wealth breed disorder? *Comp Polit Stud* **39**: 943–68.

Swartz W, Sala E, Tracey S, *et al.* 2010. The spatial expansion and ecological footprint of fisheries (1950–present). *PLoS ONE* **5**: e15143.

To AWL and Shea SKH. 2012. Patterns and dynamics of *bêche-de-mer* trade in Hong Kong and mainland China: implications for monitoring and management. *TRAFFIC Bull* **24**: 65–75.

Troell M, Naylor RL, Metian M, *et al.* 2014. Does aquaculture add resilience to the global food system? *P Natl Acad Sci USA* **111**: 13257–63.

Ugander J, Backstrom L, Marlow C, and Kleinberg J. 2012. Structural diversity in social contagion. *P Natl Acad Sci USA* **109**: 5962–66.

Uthicke S. 2001. Nutrient regeneration by abundant coral reef holothurians. *J Exp Mar Biol Ecol* **265**: 153–70.

Walker BH, Barret S, Polasky S, *et al.* 2009. Looming global-scale failures and missing institutions. *Science* **325**: 1345–46.

Young O, Berkhout F, Gallopin GC, *et al.* 2006. The globalization of socio-ecological systems: an agenda for scientific research. *Global Environ Chang* **16**: 304–16.

