Journal of Environmental Management 123 (2013) 14–25

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

A Value Chain Analysis of ghost nets in the Arafura Sea: Identifying trans-boundary stakeholders, intervention points and livelihood trade-offs

J.R.A. Butler [a,*], R. Gunn [b], H.L. Berry [c], G.A. Wagey [d], B.D. Hardesty [e], C. Wilcox [f]

[a] CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane, QLD 4001, Australia
[b] GhostNets Australia, PO Box 155, Karumba, QLD 4891, Australia
[c] Centre for Research and Action in Public Health, Faculty of Health, University of Canberra, ACT, Australia
[d] Arafura Timor Seas Ecosystem Action Program, Jakarta, Indonesia
[e] CSIRO Ecosystem Sciences, CES College Road, Sandy Bay, TAS 7005, Australia
[f] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7000, Australia

ARTICLE INFO

Article history:
Received 13 October 2012
Received in revised form
3 March 2013
Accepted 5 March 2013
Available online

Keywords:
Adaptive co-management
Indigenous rangers
Life Cycle Assessment
Marine debris
Social networks
Trans-boundary Diagnostic Assessment

ABSTRACT

Lost or discarded fishing nets are a significant component of marine debris which has trans-boundary impacts in large marine ecosystems. Such 'ghost nets' cause the by-catch of marine fauna and require retrieval from coastlines where they wash up. Identifying the causes of discarded nets and feasible intervention points requires analysis of a complex value chain and the stakeholders within it, yet no studies have attempted this. In this paper we combine Value Chain Analysis, commonly applied to understand value-adding for a commodity, with elements of Life Cycle Assessment and social network analysis to examine the drivers, stakeholders, economic, environmental and social costs and benefits in the life of a trawl net. We use the Arafura Sea as a case study, which is shared by Indonesia, Papua New Guinea and Australia, and is the focus of a Trans-boundary Diagnostic Assessment (TDA) within the Arafura–Timor Seas Ecosystem Action program (ATSEA). We follow a trawl net through four sub-systems: manufacture of webbing in South Korea, fishing and loss by an Indonesian vessel, retrieval as ghost net on the northern Australian coastline by Indigenous rangers, and disposal or re-cycling as 'GhostNet Art' by Indigenous artists. Primary stakeholders along the value chain incur economic and social benefits, and economic and environmental costs. There is an anomaly in the chain between Indonesian fishermen and Indigenous rangers, artists and communities due to the lack of market linkages between these primary stakeholders. The first 'nexus of influence' where reductions in net losses and environmental costs can be achieved is through interactions between GhostNets Australia, the World Wide Fund for Nature and the Australian Government, which can influence Indonesian fishery management institutions and fishing crews. The second nexus is via the international art market which by publicising GhostNet Art can raise awareness amongst fish consumers about the impacts of ghost nets, and hence influence Indonesian fishing companies. GhostNets Australia is a key bridging organisation in the network, linking stakeholders across scales and sub-systems. Feasible preventative interventions are discussed to rectify the anomaly in the value chain. The importance of GhostNets Australia and ATSEA in the evolving adaptive co-management and trans-boundary governance of fisheries is highlighted. However, the prevention of ghost nets will result in trade-offs in benefits for the livelihoods of primary stakeholders. The utility of the method for analysing marine debris in TDAs, and ATSEA in particular, is discussed.

1. Introduction

Plastic marine debris, including abandoned, lost or otherwise discarded fishing gear is of increasing global concern due to its environmental and economic impacts (Ryan and Maloney, 1993; Gregory, 2009; McIlgorm et al., 2008; Macfadyen et al., 2009; Ryan et al., 2009; Kaiser, 2010). In spite of international efforts to tackle

* Corresponding author. Tel.: +61 2 6776 1358; fax: +61 2 6776 1333.
E-mail addresses: James.Butler@csiro.au (J.R.A. Butler), riki.ghostnets@northerngulf.com.au (R. Gunn), Helen.Berry@canberra.edu.au (H.L. Berry), gabrielw@unops.org (G.A. Wagey), denise.hardesty@csiro.au (B.D. Hardesty), chris.wilcox@csiro.au (C. Wilcox).

0301-4797/$ – see front matter Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvman.2013.03.008

marine debris by communicating information about the abundance, impacts and probable sources of marine pollution and reinforcing regulatory instruments, the problem persists (Kiessling, 2003; Sheavly, 2011; Wurpel et al., 2011; UNEP, 2012). One of the primary challenges is the issue's complexity, which involves multiple stakeholders at different scales and across jurisdictional boundaries (Lee et al., 2006; McIlgorm et al., 2008; Macfadyen et al., 2009). Solving the problem requires methods which enable an understanding of the suite of drivers and linked stakeholders involved in the generation of marine debris, the identification of intervention points and design of appropriate policies and tools (Macfadyen et al., 2009; Thompson et al., 2011; Wurpel et al., 2011).

The evaluation and management of trans-boundary issues in international marine ecosystems is a focus of the United Nations Development Program (UNDP) and Global Environment Fund (GEF), which support Trans-boundary Diagnostic Analysis (TDA) and the development of Strategic Action Programs amongst partnering governments (Pernetta and Bewers, 2012). TDA is a participatory process involving government and technical stakeholders to identify and rank the root causes of environmental problems and threats in shared water bodies, and their national or international nature. Based on this, national or multi-national management interventions are implemented to address the causes of the problems and their implications for the environment and dependent livelihoods. However, the TDA approach has numerous shortcomings, including the lack of detailed analysis of livelihood trade-offs inherent in interventions (Pernetta and Bewers, 2012).

In 2010 the UNDP and GEF launched the Arafura–Timor Seas Ecosystem Action program, which aims to address trans-boundary issues in the Arafura and Timor Seas (ATSEA, 2010). This region, including the Gulf of Carpentaria in Australia, sustains fisheries which support livelihoods in the littoral nations of Indonesia, Timor Leste, Papua New Guinea and Australia (Stacey et al., 2011). Discarded, lost and abandoned fishing nets are a significant trans-boundary issue in the region, but have not yet been examined by the TDA. Such 'ghost nets' float into the Gulf of Carpentaria from the Arafura Sea, entangling large marine fauna of conservation concern, such as marine turtles and sharks (Kiessling, 2003; White, 2004; Gunn et al., 2010). Since 2004 a program of net retrieval has been coordinated by the non-governmental organisation GhostNets Australia, whereby government-employed Land and Sea Rangers from coastal Indigenous communities locate, retrieve and dispose of ghost nets. However, the source of nets, reasons for their loss and methods to identify potential intervention strategies remain largely undetermined (Kiessling, 2003; White, 2004; Gunn et al., 2010).

Value Chain Analysis (VCA) is one potential approach to the problem. It is a qualitative diagnostic tool applied to understand the flow of added values along a commodity's supply chain, key stakeholders in the chain and potential intervention strategies which can achieve economic efficiencies or more equitable outcomes (Wilkinson, 2006; Riisgaard et al., 2010; Coles and Mitchell, 2011). The method follows a commodity from its 'upstream' (i.e. production) to its 'downstream' conclusion (i.e. consumer). However, the environmental costs of such value chains are rarely considered (Clift and Wright, 2000; Riisgaard et al., 2010). Instead, these are the focus of Life Cycle Assessment (LCA) which evaluates the environmental impacts of products and production processes from 'cradle-to-grave' (Pelletier et al., 2007; Finnveden et al., 2009; Horne et al., 2009).

In this paper we apply VCA to analyse the relative economic, environmental and social benefits and costs of fishing nets in the Arafura Sea, the stakeholders concerned and their influence within the value chain. By integrating elements of LCA and social network analysis we identify sub-systems in the life cycle of a net, the 'nexus of influence' amongst key stakeholders and potential interventions to promote more sustainable fisheries in the region's trans-boundary waters. We highlight that the prevention of ghost nets will potentially result in complex trade-offs for the livelihoods of primary stakeholders. We discuss these and the utility of the approach to promote trans-boundary co-management, and the analysis of marine debris by TDAs in particular.

2. Study site and methods

2.1. Arafura Sea and the Gulf of Carpentaria

The Arafura Sea is a semi-enclosed shallow marine ecosystem of 650,000 km^2 (Fig. 1) which provides a highly productive habitat for a wide variety of fishery species (Resosudarmo et al., 2009; Alongi et al., 2011). Fisheries in the region include artisanal, subsistence and large commercial operations which directly employed approximately 200,000 people in the littoral nations of Indonesia, Timor Leste, Papua New Guinea and Australia in 2010 (Stacey et al., 2011).

To the south of the Arafura Sea within Australian territorial waters is the Gulf of Carpentaria ('the Gulf'), which provides important foraging, breeding and nesting grounds for five of the world's seven marine turtle species: green (*Chelonia mydas*), loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*), flatback (*Chelonia depressa*) and hawksbill (*Erectmochelys imbricate*). All are listed as vulnerable, endangered or critically endangered by international or Australian legislation (Kiessling, 2003). The Gulf also contains important seagrass habitat for the endangered dugong (*Dugon dugon*; Gunn et al., 2010). Turtles and dugong are 'cultural keystone species' which provide ecosystem services for coastal Australian Indigenous communities in the region, and have catalysed innovative co-management between these communities and government agencies due their local, national and international values (Butler et al., 2012).

The commercial fishing sector in Indonesian waters consists of four major legal activities: shrimp trawl, semi-demersal fish trawl, gill netting for sharks, and purse seining for small tuna and other pelagic species (Blaber et al., 2005; Gillett, 2008; Af-idati and Lee, 2009; Tull, 2009). Shrimp is the largest fishery due to the extensive shallow mud and sand seafloor, which provides abundant habitat for this species (Nurhakim et al., 2008; Af-idati and Lee, 2009; Stacey et al., 2011). In 2007 the estimated total shrimp catch was 36,670 tonnes (Af-idati and Lee, 2009), 47% of the total reported catch from the Arafura Sea (Wagey et al., 2009). The Gulf also supports legal gill net and trawl fisheries, but the total annual catch is much smaller (6740 tonnes; Stacey et al., 2011).

Together with the Timor Sea, the Arafura Sea and the Gulf form the North Australian Large Marine Ecosystem. The 3-year Arafura–Timor Seas Ecosystem Action program (ATSEA) was established in 2010 by the UNDP and GEF. ATSEA's objective is to provide 'a forum for bringing together the littoral nations of the Arafura–Timor Seas region to work on trans-boundary marine issues to ensure integrated, cooperative, sustainable, ecosystem-based management and usage of the living coastal and marine resources, through the formulation, inter-governmental adoption, and initial implementation of a regional Strategic Action Program' (ATSEA, 2010). The preliminary step in developing any action plan is to undertake a TDA (Pernetta and Bewers, 2012), which is currently ongoing in ATSEA.

Since the early 1990s increasing amounts of marine debris have been observed on the shores of the Gulf, with 70–80% consisting of discarded nets (Kiessling, 2003; Gunn et al., 2010; Heathcote et al., 2011). Because they are constructed from polyethylene, such 'ghost nets' are buoyant and consequently float into the Gulf from the Arafura Sea, driven largely by the north-western monsoonal winds

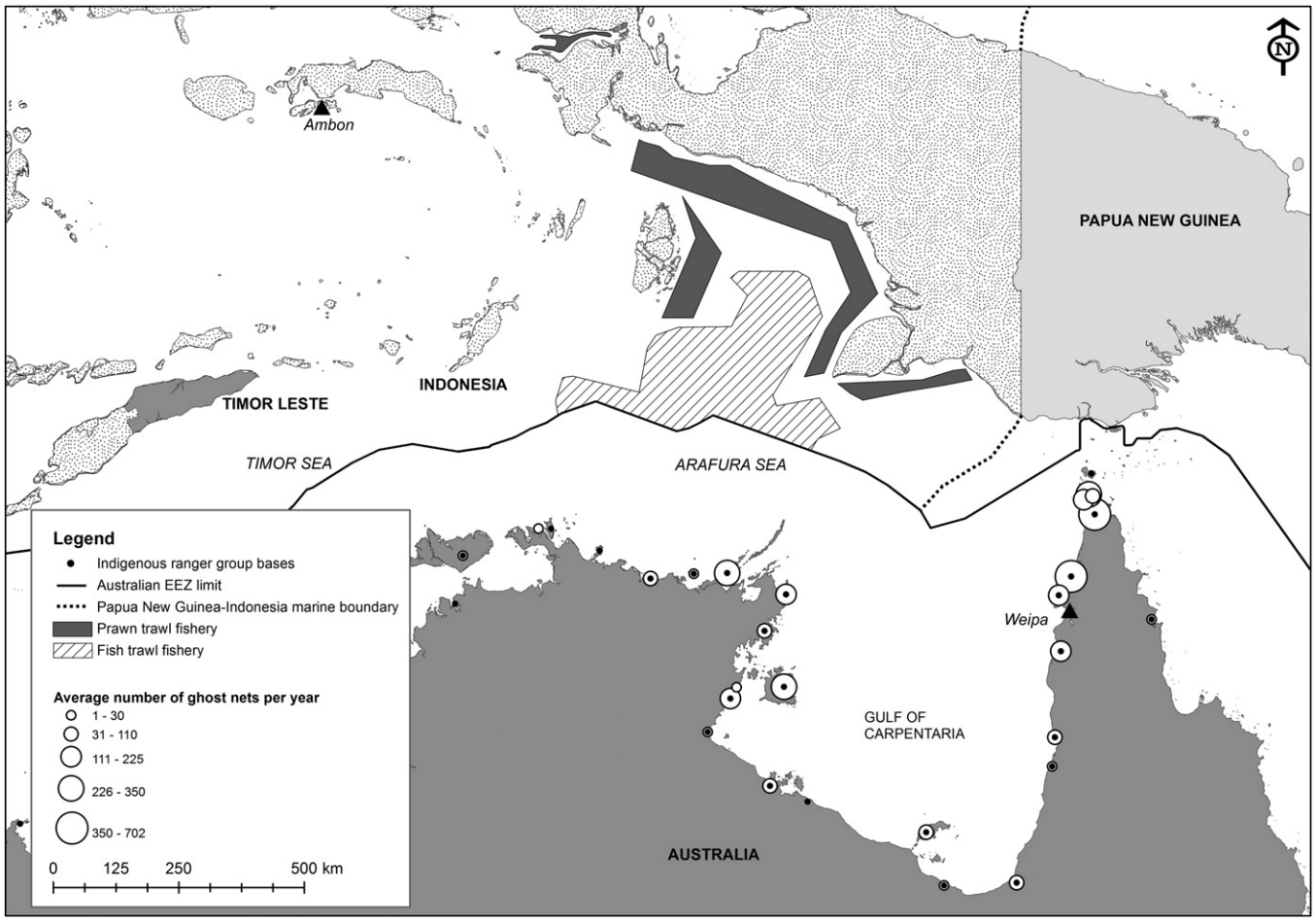

Fig. 1. The Arafura Sea and Gulf of Carpentaria, showing the littoral nations, and locations of Indonesian prawn and fish trawl fisheries, annual average ghost net retrievals in 2004–2011, and the 23 Indigenous ranger groups' communities and bases.

(White, 2004; Griffin, 2008). The majority are washed up on the north east coastline (Fig. 1). Those that do not wash up continue to drift with the Gulf's clockwise gyre until they become stranded on shorelines to the south and west.

Since 2004 over 10,000 ghost nets have been retrieved from the Gulf coastline by a network of approximately 220 Indigenous Land and Sea Rangers operating from 23 communities (Fig. 1), coordinated by GhostNets Australia. Rangers use a 'Net Kit' identification guide developed by the World Wide Fund for Nature (WWF), which enables the source fishery to be determined (Hamilton et al., 2002). Once retrieved, ghost nets are usually burned in situ or transported to local council landfill sites for disposal. In 2009 GhostNets Australia sought a more environmentally-friendly solution to this problem by introducing a net re-cycling project that encourages Aboriginal artists from rangers' communities to make artworks from the debris, and linking art agents and buyers to the artists. Pieces created by the 'GhostNet Art' program have been bought and exhibited by Australian and international collectors for prices of up to AUS$5000 each. In 2011 there were nine GhostNet Art groups involving approximately 60 artists.

2.2. Value Chain Analysis (VCA)

Akenji and Bengtsson (2010) modified VCA to analyse stakeholders and the benefits and costs that they derive from the use and disposal of plastic packaging in Asia. Based on these, they identified intervention points and strategies required to mitigate the environmental impacts of plastic waste. They developed the 'Triple I' framework (Interests, Influence and Instruments), which combines consumption theory (the Need–Opportunities–Abilities model; Gatersleben and Vlek, 1998), stakeholder theory (Freeman, 1984; Mitchell et al., 1997) and theory of change (the Awareness–Agency–Association model; Ballard, 2005) with VCA.

The Triple I framework involves three qualitative stages of analysis:

1. Interests: key stakeholders in the product, their needs and expectations of the product, and the drivers and patterns of usage;
2. Influence: the role of each stakeholder in the value chain, the extent of their influence in the use and recovery of the product, and their influence over other stakeholders;
3. Instruments: the mechanisms that stakeholders apply to wield influence through policies and institutions.

Stakeholders in the study area and their interests, influence and instruments were identified from reviews of social and economic issues undertaken for the ATSEA TDA by Stacey et al. (2011), details of GhostNets Australia (Gunn et al., 2010; Heathcote et al., 2011) and other relevant literature. Stakeholders were categorised according to Brown et al.'s (2001) definitions on a continuum of local to global scale: 'local on-site', 'local off-site', 'regional/national' and 'international'. Local on-site actors were considered to be 'primary'

stakeholders, defined by De Groot (2006) as those who stand to gain or lose the most from a management decision.

This review was augmented in April 2012 by a 1-day ATSEA workshop held in Ambon, Maluku Province, the primary commercial fishing port in the Arafura Sea (Fig. 1). The workshop was attended by 22 people, including representatives of the Indonesian Central and Provincial Ministry of Marine Affairs and Fisheries, GhostNets Australia, seven skippers of commercial gill net, purse seine and shrimp trawl vessels, and representatives of a shrimp trawl fishing company and two Trawl Associations. Participants discussed the features of fisheries in the Arafura Sea, key stakeholders and their roles (Table 1), and the supply chain for fishing nets. A questionnaire was also distributed to the skippers to elicit their perceptions of the frequency and causes of net loss, plus their disposal practices for damaged nets.

Following Akenji and Bengtsson (2010) we completed the Triple I analysis by identifying the 'nexus of influence' between the most influential stakeholders, and hence potential points of intervention in the value chain. We subjectively assessed the relative influence of stakeholders by representing their relationships as either one-way or mutual. However, unlike Akenji and Bengtsson (2010), due to a lack of detailed information we did not weight these relationships. We also applied principles of social network theory by summing the total number of outgoing linkages for each stakeholder to evaluate their relative importance in the nexus of influence. In social network analysis terms, these 'ties' quantify the degree of centralisation of the network (i.e. the relative influence of particular actors), and also the degree of heterogeneity (i.e. the relative diversity and cross-scale linkages between actors) (Reagans and Zuckerman, 2001; Sandstrom and Carlsson, 2008; Sandstrom and Rova, 2010).

2.3. Life Cycle Assessment (LCA)

LCA is a structured process developed in four stages (ISO, 2006a, b):

1. Goal and scope definition, in which the intended application as well as the extent of the study is clearly exposed;
2. Inventory analysis, where information about the product system and sub-systems is gathered and relevant inputs and outputs are quantified;
3. Impact assessment, which converts the flows from the inventory into simpler indicators related to the potential impacts associated;
4. Interpretation of the results, where the findings of the two previous steps are combined and evaluated to meet the previously defined goals of the study.

We applied stages 1 and 2 to qualitatively assess the relative economic, environmental and social impacts of nets on the stakeholders identified by the Triple I analysis, collated into sub-systems.

Table 1
Indonesian fishery management institutions and their roles in the Arafura Sea commercial shrimp and fish trawl fisheries.

Institution	Role
Central Ministry for Marine Affairs and Fisheries	Licensing commercial fishery vessels operating beyond 12 nautical miles or vessels > 30 tonnes; imposing spatial, temporal (e.g. seasonal closures) or gear (e.g. Turtle Exclusion Devices) restrictions; monitoring commercial catches and sales through log books; managing fishing ports
Provincial Ministry for Marine Affairs and Fisheries	Licensing commercial fishery vessels operating between 4 and 12 nautical miles or vessels of 5–30 tonnes; monitoring commercial catches and sales through log books
Indonesian Navy	Enforcement of fishing regulations and standards
Indonesian Police	Enforcement of fishing regulations and standards
Trawl Associations	Representing the 14 shrimp or trawl companies operating in the Arafura Sea; negotiating licensing with Central or Provincial Ministry for Marine Affairs and Fisheries, including renewal; implementing regulations and standards amongst member companies

3. Results

3.1. Goal and scope definition

Our goal and scope was to examine the value chain of a trawl net (either semi-demersal or shrimp) used by a commercial Indonesian registered and owned vessel in the Arafura Sea, and made in Indonesia from polyethylene 'webbing' manufactured in South Korea. The fishing vessel is 200 tonnes in weight and operated by an Indonesian crew of 15–20 from Ambon. The vessel's owner company is a member of a Trawl Association. Due to its size the vessel is licensed by the Central Ministry of Marine Affairs and Fisheries (CMMAF; Table 1).

Results of the questionnaire survey showed that all skippers had lost nets, but at a low frequency, with the majority (70%) losing them less than once every five years (Table 2). All losses were caused by snagging on the sea bed, and none reported other causes. All skippers stated that they returned damaged nets to port rather than discard them at sea. From these results we assumed that the trawl net was lost through snagging, and then drifted into the Gulf.

We focussed on a trawl net because they accounted for 67% of the 2132 ghost nets retrieved from the Gulf in 2011, and only 6% of these originated from Australian trawl fisheries (GNA, 2011). Ghost net material examined at the workshop by the skippers confirmed that the remainder is from shrimp and fish trawl vessels operating in the eastern Arafura Sea (Fig. 1). Workshop participants also confirmed that these nets are constructed from webbing manufactured in South Korea and imported by Indonesian net-makers in Maluku Province.

We identified four sub-systems in the value chain:

1. Webbing manufacture: construction of polyethylene raw material by a South Korean factory, and distribution to an Indonesian net-maker;
2. Net for fishing: construction of the trawl net by net-makers in Maluku Province, and its use by the Indonesian vessel in the Arafura Sea trawl fisheries;
3. Net as debris: the impact of the ghost net after it is lost and washed up as debris in the Gulf of Carpentaria, Australia, and subsequent retrieval by Indigenous rangers;
4. Net disposal: the use of net material by Indigenous Australians to make GhostNet Art, and the burning or disposal of surplus net in landfills.

3.2. Triple I analysis

3.2.1. Interests

The analysis identified 24 stakeholder groups or institutions in the four sub-systems (Fig. 2).

Table 2
The frequency of net losses reported by seven Indonesian skippers at the Ambon workshop in April 2012. Note that three skippers operated in more than one fishery.

Fishery	Loss frequency			
	Never	>5 years	1–5 years	Annually
Shrimp trawl ($n = 3$)		2		1
Purse seine ($n = 4$)	2	2		
Gill net ($n = 3$)		3		
Total	2	7		1

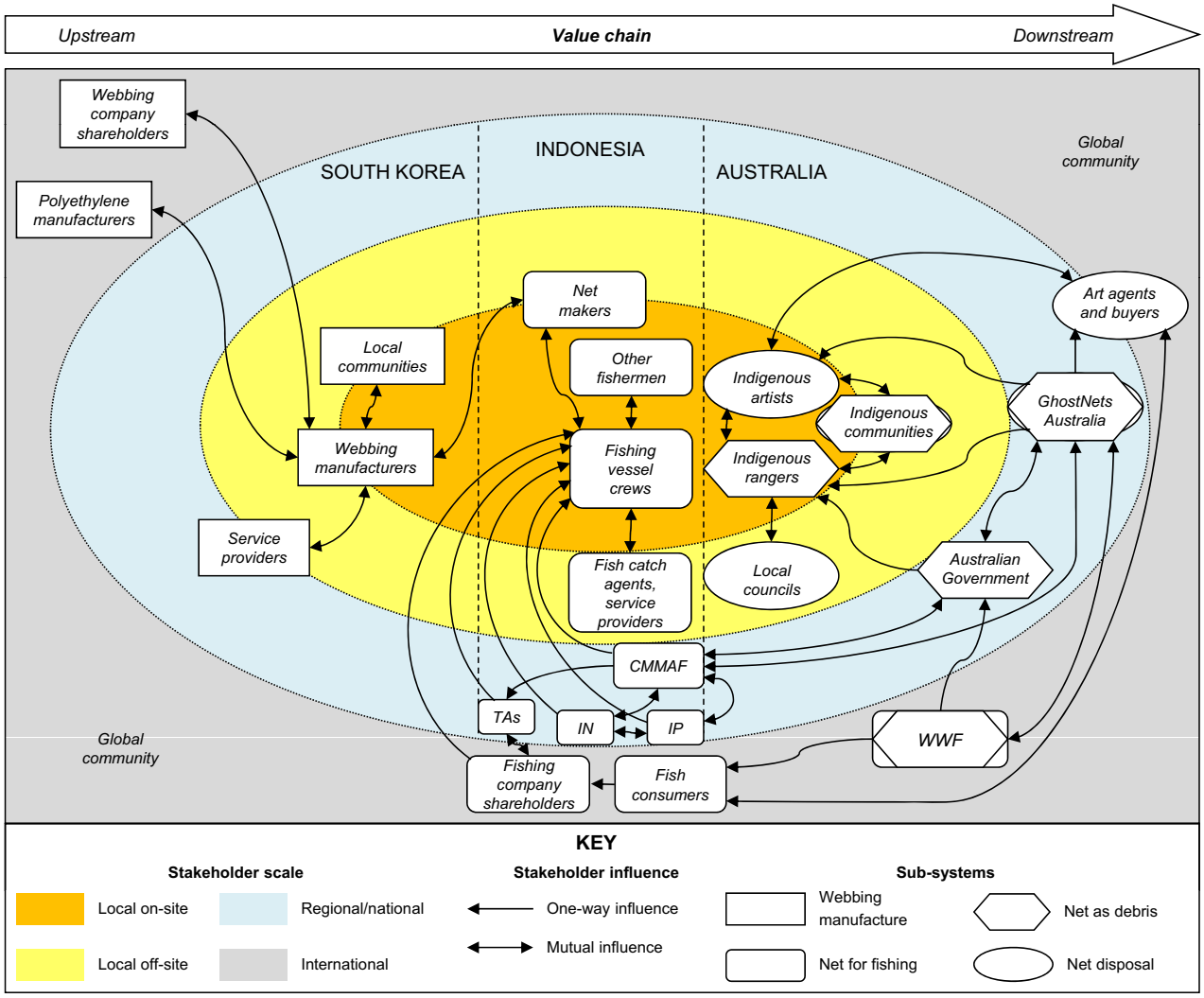

Fig. 2. Analysis of principal stakeholders identified as bearing the benefits and costs of a trawl net in Tables 3 and 4, their sub-systems and influence on one another. Abbreviations are: CMMAF (Central Ministry for Marine Affairs and Fisheries), IN (Indonesian Navy), IP (Indonesian Police), WWF (World Wide Fund for Nature) and TAs (Trawl Associations). 'Global community' has an interest in all sub-systems but negligible influence.

3.2.1.1. Webbing manufacture (South Korea). Manufacturing fishing net involves the processing of raw polyethylene pellets to create webbing (Korean Trading and Industries, 2012). The factory imports raw materials from international polyethylene manufacturers, and consumes power, water and other services provided by both national/regional and local off-site stakeholders. It provides direct employment for the company workers and managers on-site and off-site (Table 3). For example, at a webbing manufacturer in India, 160 factory workers are employed on-site, and 15 off-site at its head office, generating an annual turnover of US$1.9 million (Garware Marine Industries, 2011). This provides dividends to international shareholders in the company.

The greatest negative impact of webbing manufacture is to local (including webbing manufacturers) and global communities through pollution from factory processes (Table 4). An LCA of the European plastics industry has shown that green house gas emissions per unit of production are particularly high due to the energy required to operate machinery (Pilz et al., 2010).

3.2.1.2. Net for fishing (Indonesia). This sub-system begins with the fashioning of webbing into a trawl net by a net-maker. The net-maker is a small independent local on-site or off-site business in Maluku Province who buys webbing from South Korean manufacturers and supplies nets to fishing vessels. The net-maker benefits economically from employment and income (Table 3). Use of a trawl net by a fishing vessel benefits the crew, fishing company employees and international shareholders, who derive income from the sale of the catch, plus fish sale agents and providers of services for fishing vessels. International fish consumers are also beneficiaries since Indonesia was the world's third largest exporter of wild-caught shrimp in 2005 (Gillett, 2008) and fish in 2009 (FAO, 2010). This is predominantly supplied by the commercial vessels in the Arafura Sea because trawl fishing was banned in western Indonesia in 1980 (Gillett, 2008; Af-idati and Lee, 2009).

The primary cost of trawling is its environmental impacts, with knock-on effects on other stakeholders. These are summarised by the FAO (2005) as overfishing, changes in species composition and biodiversity, and modification of benthic habitat and structure. Competition with artisanal fishers for shared fish stocks is also a common economic impact caused by commercial fleets in Indonesia (Af-idati and Lee, 2009). These effects will negatively affect other local on-site subsistence, artisanal and commercial fishers in the Arafura Sea (Table 4).

Table 3
Stakeholder interests and the benefits they receive from a trawl net through its value chain. Abbreviations are: CMMAF (Central Ministry for Marine Affairs and Fisheries), IN (Indonesian Navy), IN (Indonesian Police), WWF (World Wide Fund for Nature) and TAs (Trawl Associations).

Sub-systems	Benefits	Stakeholders and scale			
		Local on-site	Local off-site	Regional/national	International
1. Webbing manufacture (South Korea)	Manufacturers' and distributors' employment, dividends to shareholders	Webbing manufacturers	Service providers, local communities	Polyethylene importers	Company shareholders
2. Net for fishing (Indonesia)	Net makers' and fishing vessel crews' employment, dividends to fishing company shareholders	Net makers, fishing vessel crews	Net makers, fish catch agents, service providers	CMMAF, IN, IP, TAs	Fish consumers, fishing company shareholders WWF
3. Net as debris (Australia)	Indigenous ranger employment, health benefits of 'working on country', training	Indigenous rangers	Indigenous communities	GhostNets Australia, Australian Government	Global community
4. Net disposal (Australia)	GhostNet Art artists' employment, health benefits	Indigenous artists	Indigenous communities	Art agents and buyers, GhostNets Australia	Art agents and buyers

Other key interests in this sub-system are Indonesian fishery management institutions at the regional/national scale which regulate the impacts described above (Table 1). At the international scale WWF promotes sustainable fisheries management in the region (WWF, 2011). Consequently these stakeholders have interests in both the benefits (Table 3) and costs (Table 4) of a trawl net.

3.2.1.3. Net as debris (Australia). Having been snagged and lost the net breaks free and floats to the surface, drifting across the Indonesian–Australia border into the Gulf. The primary local on-site beneficiaries are Indigenous rangers, who gain employment from the retrieval of ghost nets (Table 3). Their marine debris retrieval activities are funded by the Australian Government and coordinated by GhostNets Australia, and rangers receive social benefits such as training in project management, the use of computers and global positioning systems (Gunn et al., 2010). This is part of a novel national program which creates employment opportunities for disadvantaged Aboriginal Australians to develop livelihoods as stewards of their traditional lands, resulting in synergistic benefits for their health, cultural renewal and natural resource management. Rangers taking part in customary and contemporary land and sea management practices show reduced rates of diabetes and lower risks of cardiovascular disease (Burgess et al., 2009; Garnett et al., 2009). These activities create co-benefits for Aboriginal health (Burgess et al., 2005), effective natural resource management through the integration of traditional ecological knowledge and western science (e.g. Gratani et al., 2011; Butler et al., 2012), and also build capacity for adaptation to climate change (Berry et al., 2010).

Although the net may provide temporary micro-habitat to juvenile fish (Macfadyen et al., 2009) and pelagic insects (Goldstein et al., 2012), its main environmental impact is negative, because it entangles large marine fauna. In Australia, injury and fatality to vertebrate marine life caused by marine debris has been listed as a key threatening process under the national Environment Protection and Biodiversity Conservation Act 1999 (Kiessling, 2003; Limpus, 2008, 2009; White, 2004; Heathcote et al., 2011). In the Gulf, nesting marine turtles are the most common by-catch because they congregate in in-shore waters and beaches during the monsoon. Of the 130 marine animals found in retrieved ghost nets in 2011, 95 (73%) were turtles. The majority were found dead, although a minority were released by rangers (GNA, 2011).

These environmental impacts incur costs for coastal Indigenous communities both on-site and off-site, because turtles and dugong underpin their traditional identity, and provide an important food source (Butler et al., 2012). WWF is an international stakeholder because it has invested in identifying and mitigating the ghost net problem through development of the Net Kit (Hamilton et al., 2002), and global communities are also impacted by the loss of large marine animals of biodiversity value (Table 4).

3.2.1.4. Net disposal (Australia). Once located, the ghost net is burned by rangers or transported to be buried in the local council's landfill. Following the introduction of GhostNet Art, some of the net material is stored for use by local Indigenous artists.

The benefits of arts projects in remote Aboriginal communities are widely recognised. The sale of artworks generates employment and income for the artists and their families (Table 3). Engagement in arts can also mitigate mental disorders (Berry, 2009; Dyer and Hunter, 2009; Rigby et al., 2011), which are a symptom of the history of disenfranchisement that has eroded Aboriginal well-being since European colonisation (Hunter, 2007). Although the impacts of GhostNet Art have not been studied specifically, the social benefits outlined above are likely to emerge within involved communities. Other beneficiaries at the regional/national and international scale are the art agents and buyers who purchase the art (Table 3).

The nets that are taken to landfills contribute to the financial costs of local councils who operate them. Although the

Table 4
Stakeholder interests and the costs they incur from a trawl net through its value chain. Abbreviations are: CMMAF (Central Ministry for Marine Affairs and Fisheries), IN (Indonesian Navy), IP (Indonesian Police), WWF (World Wide Fund for Nature) and TAs (Trawl Associations).

Sub-systems	Costs	Stakeholders and scale			
		Local on-site	Local off-site	Regional/national	International
1. Webbing manufacture (South Korea)	Pollution	Webbing manufacturers, local communities	Local communities	Other communities	Global community
2. Net for fishing (Indonesia)	Exploitation of shared stocks, by-catch of non-target species	Other fishermen	Fish catch agents, service providers	CMMAF, IN, IP, TAs	WWF, global community
3. Net as debris (Australia)	By-catch of cultural keystone species	Indigenous rangers and communities	Indigenous communities	GhostNets Australia, Australian Government	WWF, global community
4. Net disposal (Australia)	Pollution, costs of disposal	Indigenous communities	Local councils	Other communities	Global community

polyethylene is inert if buried, when burned pollutants such as heavy metals, polychlorinated biphenyls and dioxins are emitted, contributing to atmospheric pollution, acidification and eco-toxicity (Tan and Khoo, 2006; EPA, 2003, Table 4).

3.2.2. Influences and instruments

Fig. 2 illustrates the relationships amongst the stakeholders identified above relative to their position in the value chain and its sub-systems.

3.2.2.1. Webbing manufacture (South Korea). Within this sub-system there are moderate and mutual influences between the stakeholders, driven largely by market supply and demand for polyethylene, services and webbing. Between this sub-system and the net for fishing sub-system there is a similar mutual influence amongst the webbing makers in South Korea and the net makers in Indonesia.

3.2.2.2. Net for fishing (Indonesia). The dynamics between the stakeholders in this sub-system are more complex. Fishing vessels purchase nets from the net-makers. However, their fishing practices with the nets are governed by the influence of four key institutions: CMMAF, the Indonesian Navy (IN), Indonesian Police (IP) and Trawl Associations (TAs; Table 1). TAs also influence fishing company shareholders through advice on fishing profitability and practices, which in turn drive the companies' decisions about the operations of their fishing vessels. Also, company shareholders can influence the TAs' policies.

Mutual relationships exist between the fishing vessels and other local on-site fishermen, plus off-site fish catch agents and other service providers. At the international scale, fish consumers may have a one-way influence on fishing company shareholders through demand and attitudes towards the sustainability of commercial fisheries. For example, the dolphin-safe tuna labelling scheme initiated by consumer groups in the early 1990s had a significant influence on the modification of drift netting practices, reducing dolphin by-catch in the eastern Pacific (Baird and Quastel, 2011). WWF may also influence fish consumers by raising awareness of unsustainable fishing practices. In its Indonesian Seafood Guide WWF recommends that consumers should reduce their consumption of shrimp due to the impact of trawling on the sea bed (WWF, 2011).

3.2.2.3. Net as debris (Australia). There are no direct relationships between primary stakeholders in the net for fishing (Indonesian fishing crews and other fishermen) and net as debris sub-systems (Indigenous rangers and communities in Australia). GhostNets Australia has influence on rangers through its coordination role and the Australian Government has an influence through its funding program. The government also has a mutual relationship with GhostNets Australia; the government provides its funding, while GhostNets Australia provides information on marine debris which informs government policy, and delivers local outcomes by retrieving ghost nets and protecting marine biodiversity. WWF also has influence over the Australian Government by lobbying for the protection of endangered species, and its specific interest in the impacts of ghost nets on marine biodiversity.

This sub-system is linked upstream to the net for fishing sub-system by three relationships. First, at the regional/national scale the Australian Government has a mutual relationship with the CMMAF through ATSEA. None of the parties have strong influence over each other or instruments other than a shared commitment to improve the management of the North Australian Large Marine Ecosystem. Second, GhostNets Australia is now mutually engaged with CMMAF following the Ambon workshop. Third, WWF has influence on fish consumers by raising awareness of the sustainability of fisheries and their impacts on marine biodiversity, including by-catch and marine debris (WWF, 2011). Previously it may have had a more direct influence on Indonesian fishers through an observer program in 2005–2006 which monitored the by-catch of turtles in various fishing gears in Indonesia (Zainudin et al., 2007).

3.2.2.4. Net disposal (Australia). While the net as debris and net disposal sub-systems are linked by relationships between the primary on-site stakeholders (Indigenous rangers, artists and communities) there is no linkage upstream between the Indigenous artists in Australia and primary stakeholders in Indonesia. GhostNets Australia has influence on Indigenous artists through its coordination role, and similarly with the art agents and buyers at the regional/national and international scale. At the international scale there is a mutual relationship between art agents and buyers and fish consumers. Agents and buyers are likely to be fish consumers, and GhostNet Art may raise the awareness of other consumers about ghost nets.

3.2.3. Nexus of influence

The Triple I analysis reveals an anomaly in the value chain between primary stakeholders in the net for fishing (Indonesian fishing vessel crews) and net as debris sub-systems (Indigenous rangers, communities and artists). In order to address this anomaly a nexus of influence must be identified which can reduce the generation of potential ghost nets through lost fishing gear.

The analysis reveals two linked routes involving 15 stakeholders (Table 5). The first and most direct involves the linkages between Indigenous rangers, communities and GhostNets Australia, who have a mutual relationship with the Australian Government. GhostNets Australia and the government also have mutual relationships with the CMMAF through ATSEA. In turn, the CMMAF,

Table 5
Characteristics of the 15 stakeholders in the two linked nexus of influence to Indonesian fishing vessel crews, ranked in descending order of total outgoing ties, and the number of sub-systems in which each stakeholder occurs.

Stakeholders	Scale (country)	Out-going ties (%)	Sub-system
GhostNets Australia	Regional/national (Australia)	6 (15)	2
Central Ministry for Marine Affairs and Fisheries	Regional/national (Indonesia)	5 (13)	1
Indonesian Navy	Regional/national (Indonesia)	3 (8)	1
Indonesian Police	Regional/national (Indonesia)	3 (8)	1
World Wide Fund for Nature	International	3 (8)	2
Indigenous rangers	Local on-site (Australia)	3 (8)	1
Indigenous communities	Local on-site/off-site (Australia)	2 (5)	2
Indigenous artists	Local on-site (Australia)	2 (5)	1
Trawl Associations	Regional/national (Indonesia)	2 (5)	1
Fishing company shareholders	International	2 (5)	1
Australian Government	Regional/national (Australia)	2 (5)	1
Art buyers and agents	Regional/national (Australia)/ International	2 (5)	1
Fishing company shareholders	International	2 (5)	1
Fish consumers	International	1 (3)	1
Local councils	Local off-site (Australia)	1 (3)	1

IN and IP can influence fishing vessel crews through licensing and other regulatory mechanisms. Also within this nexus is the influence of the CMMAF on the TAs, fishing company shareholders and hence fishing crews (Fig. 2).

The second, less direct route also involves Ghost Nets Australia which links GhostNet Art artists, agents and buyers, who can raise awareness of the ghost net problem amongst fish consumers. This may be augmented by the mutual influence between GhostNets Australia and WWF, who also influence fish consumers. Fish consumers influence Indonesian fishing company shareholders and TAs, and hence fishing vessel crews.

As quantified by their outgoing ties, the most influential stakeholder in these two routes is GhostNets Australia, with 15% of ties, followed by the CMMAF (13%; Table 5). This indicates that there is a degree of centralisation focussed around GhostNets Australia. Of the 15 stakeholders, 11 were regional/national or international scale, and only four were local on-site or off-site. Of these, only GhostNets Australia, WWF and Indigenous communities have direct interests and influence in more than one sub-system, although the global community has an indirect stake in all subsystems but negligible influence (Fig. 2, Tables 3 and 4). This suggests that the degree of heterogeneity within the stakeholder network was limited.

4. Discussion

Our analysis reveals the complexity of the ghost net issue in the Arafura Sea, a characteristic which typically impedes efforts to tackle marine debris (Lee et al., 2006; McIlgorm et al., 2008; Macfadyen et al., 2009). We identified 24 stakeholder entities within four sub-systems across three nations and internationally. These ranged from individuals at the local on-site scale (e.g. Indonesian fishing vessel crews, Indigenous rangers and artists) to the global community. Furthermore, in reality the value chain of a trawl net was far more complex. Had sub-systems upstream from webbing manufacture (e.g. oil refining, machinery manufacture) and downstream from net for fishing (e.g. fish processing, transport) been included, the number of stakeholders would have been considerably larger.

Our combined VCA and LCA approach highlighted the anomaly in the value-adding process between the net for fishing and net as debris sub-systems. A conventional VCA would curtail the analysis at the net for fishing sub-system, but including elements of LCA allows the full value chain to emerge, and the market failure between primary stakeholders in the net for fishing (Indonesian fishing vessel crews) and net as debris (Indigenous rangers and communities) sub-systems. Hence our approach augments recent efforts to improve VCA by including social, economic and environmental externalities generated by value chains (Clift and Wright, 2000; Riisgaard et al., 2010), and LCA by including social costs (Pelletier et al., 2007; Benoît and Mazijn, 2009).

Our study also exemplifies the complexity of the costs and benefits inherent in marine debris issues. A qualitative representation of the trade-offs for primary stakeholders (Fig. 3) shows that trawl nets provide economic benefits in all sub-systems by generating employment. As ghost nets, they also provide employment plus social benefits for Indigenous rangers and artists. These are offset by the environmental costs from pollution, impacts on target and non-target species by trawl nets, and by-catch from ghost nets on large marine fauna (Fig. 3a). Were ghost nets from trawl fisheries to be prevented, there would be no distinct alteration to the benefits and costs in the webbing manufacture sub-system, because Arafura Sea trawl nets probably represent a small fraction of the factory's market for webbing. However, if fishing crews operating in the Arafura Sea lost fewer nets, their demand for replacements could decline, potentially having a detrimental effect on net makers' employment (Fig. 3b). Downstream, the decline in ghost nets would reduce the environmental costs of by-catch and pollution from burning. This would be countered by potential reductions in the need for rangers to clear ghost nets, and the supply of material for artists, which would curtail economic and social benefits. For rangers the extent of this outcome would be moderated by the ongoing presence of marine debris (including ghost nets) from other sources, plus their roles in other forms of 'caring for country'. For artists, the supply of net material would not decline significantly due to the continuing supply from other forms of ghost net (Fig. 3b). Such complex trade-offs are typical in assessments of marine debris, and are largely caused by the challenge of quantifying a mix of social and environmental values in comparable terms (McIlgorm et al., 2008; Macfadyen et al., 2009; Butler et al., 2011a).

In spite of the benefits of ghost nets for Indigenous rangers and artists, the environmental costs should be mitigated in order to achieve environmentally sustainable trawl fisheries. The identification of the nexus of influence relative to the anomaly in the value chain enables the prioritization of intervention points and stakeholders (Akenji and Bengtsson, 2010). In our case, there were two linked routes of influence which lead to Indonesian fishing vessel crews in the net for fishing sub-system, involving a complex network of 15 stakeholders. It is notable that for plastic packaging in Asia and its role as a marine pollutant, the key nexus through which changes in consumer behaviour could be achieved was between packaging brand owners and large food retailers further upstream in the manufacturing and supply sections of the value chain (Akenji and Bengtsson, 2010). Our results therefore re-affirm the differing interventions required to tackle the value chain of lost or abandoned fishing gear relative to land-derived marine debris (McIlgorm et al., 2008).

Having identified the nexus of influence it is necessary to design appropriate intervention strategies which can be tailored to the characteristics of the stakeholders concerned. Also, preventative strategies are more cost-effective than curative or mitigating strategies (McIlgorm et al., 2008; Macfadyen et al., 2009), but designing and implementing them requires an understanding of the causes of net loss, which may be specific to individual fisheries (Brown et al., 2005). In the case of the Arafura shrimp or fish trawl fisheries, the only reported cause was accidental snagging on the seabed. Discarding of damaged nets was not practiced. However, only seven skippers were surveyed, and there were 140 vessels in the Arafura Shrimp TA in 2005 (FAO, 2005). Also, no fish trawl skippers were surveyed.

Assuming that our results are representative of trawl vessels, one preventative strategy would be education and awareness-raising amongst fishing vessel skippers and crew of the downstream impacts of ghost nets. Such schemes are relatively low cost (Macfadyen et al., 2009), and easily implemented through stakeholders such as WWF who have experience of environmental education related to sustainable fisheries in the region. However, the scheme's efficacy would be enhanced by a deeper understanding of fishing skipper and crews' motivations in order to change behaviour, as acknowledged for other marine debris interventions (Wurpel et al., 2011; Slavin et al., 2012). A second strategy relates to fishery management. Brown et al. (2005) suggest that a key cause of trawl net loss is spatial fishery pressure, which results in trawling over sub-optimal rough sea bed, and gear conflict. This is a possible cause of net loss since fishing pressure is high in the Arafura Sea due to the large number of Illegal, Unreported and Unregulated (IUU) vessels (Wagey et al., 2009). Brown et al.'s (2005) recommended intervention is improved zoning and more effective fisheries enforcement.

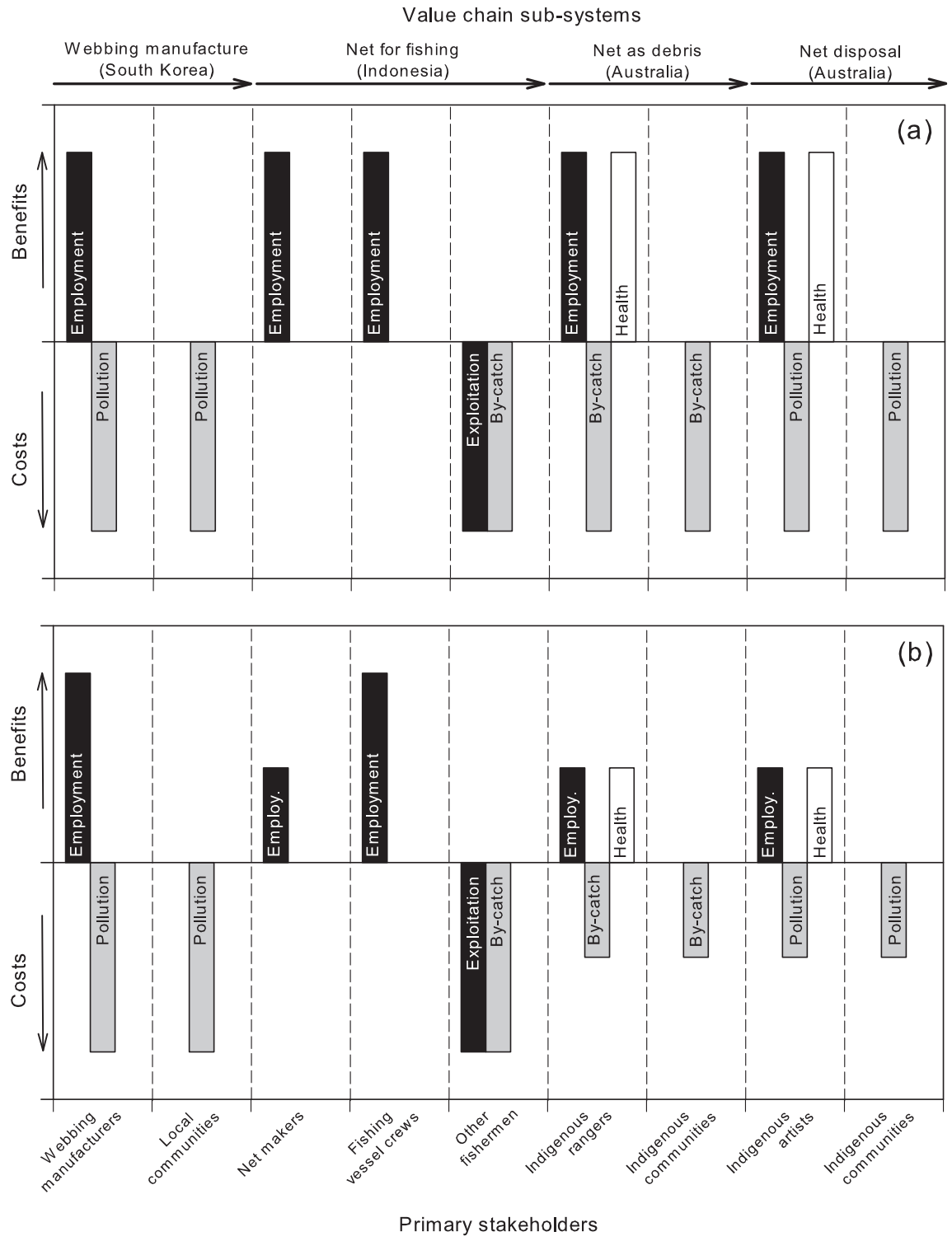

Fig. 3. Trade-off analysis of the economic (black bars), environmental (grey bars) and social (white bars) costs and benefits incurred by primary stakeholders in the value chain sub-systems for (a) the current situation and (b) prevention of ghost nets derived from trawl nets.

However, considering the limited efficacy of fisheries governance in the Arafura Sea (Af-idati and Lee, 2009; Wagey et al., 2009), voluntary or informal strategies are likely to be more feasible. Examples of successful non-government organisation or consumer-driven schemes in developing countries are the campaigns for dolphin-friendly tuna (Baird and Quastel, 2011) and turtle exclusion devices for trawlers (Margavio et al., 1993; Tucker et al., 1997). Considering the existence of fish consumers in both nexus of influence, and their linkages to WWF, GhostNet Art agents and buyers and fishing company shareholders, this approach may hold the greatest potential. The feasibility of other more complex preventative measures such as gear marking (e.g. Kiessling, 2003) and market-based instruments (e.g. McIlgorm et al., 2008) will be constrained by the limited capacity of Indonesian government

institutions which would be required to assist implementation. Economic instruments are also confounded by the problems of monetizing social and environmental costs and benefits, and hence evaluating their efficiency (McIlgorm et al., 2008; Macfadyen et al., 2009). Our results suggest that such trade-offs are particularly complex in the Arafura Sea context, potentially preventing economic valuation.

Two organisations are particularly influential in the stakeholder network. GhostNets Australia contributed 15% of the out-going ties, and has interests in two sub-systems. They provided linkages between Indigenous rangers and artists to the Australian Government and also between these Australian stakeholders and the Indonesian CMMAF in the net for fishing sub-system. WWF has a less influential role, but is also involved in two sub-systems and links the Australian Government to international fish consumers. Therefore the mutual tie between GhostNets Australia and WWF is potentially a key relationship, since it is the bridge between Australian and Indonesian interests in three sub-systems, linking stakeholders from local on-site to international scales. This provides an example of the important role of 'bridging' or 'boundary' institutions in complex adaptive systems, which by linking across multiple social and ecological scales generate information flow, innovation and adaptive capacity (Olsson et al., 2004; Berkes, 2009). Often such organisations are characterised by individuals who act as 'institutional entrepreneurs', using their skills as knowledge and resource brokers to generate new ties and hence social capital (Moore and Westley, 2011). Their role is particularly important in facilitating the management of common pool resources where formal government capacity is limited (Berkes, 2007).

The evolving management of fisheries, ghost nets and livelihoods in the Arafura Sea is indicative of adaptive co-management. This is an emergent, self-organising process whereby multi-scale partnerships, social networks and institutions are formed between stakeholders, combining iterative social learning and innovation with conflict resolution and power-sharing in response to natural resource management crises (Olsson et al., 2004; Armitage, 2005a; Folke et al., 2005; Plummer and Armitage, 2007; Armitage et al., 2009; Plummer, 2009). However, this process is at an early stage, as evidenced by the centralisation of the social network around one stakeholder, GhostNets Australia, and the corresponding limited level of heterogeneity, both of which are indicators of limited co-management (Sandstrom and Rova, 2010).

Due to its trans-boundary and complex nature, marine debris necessitates co-management between multiple actors (Lee et al., 2006; McIlgorm et al., 2008; Macfadyen et al., 2009; Sheavly, 2011), and the ATSEA program potentially provides a platform for the further generation of cross-scale partnerships and innovation in the Arafura Sea. Consequently, more extensive ties may emerge in the network, and thus more direct linkages between primary stakeholders. For example, exchange visits are planned between Indigenous rangers and Indonesian fishermen to foster mutual awareness of the ghost net issue (Gunn et al., 2010). Furthermore, as in other marine contexts (e.g. narwhal in Arctic Canada: Armitage, 2005b; Armitage, 2007; common seals in Scotland: Butler et al., 2006; Thompson et al., 2007; Butler et al., 2008, 2011b; Butler, 2011; Young et al., 2012), this process has been triggered by threats to iconic marine fauna (i.e. turtles and dugong), which due to their extensive ranges provide ecosystem services to local, national and international beneficiaries (Butler et al., 2012).

5. Conclusions

We have demonstrated the utility of combining the principles of VCA and LCA to illuminate the complex value chain, stakeholders and the costs and benefits inherent in the ghost net issue. Applying Akenji and Bengtsson's (2010) Triple I framework we have shown how the nexus of influence between stakeholders can be used to develop feasible interventions, and with the addition of rudimentary social network analysis, key stakeholders identified. However, we acknowledge that the method has several limitations and caveats. First, as for most VCAs (Akenji and Bengtsson, 2010; Riisgaard et al., 2010), it is necessarily qualitative. Second, the method only identifies the current nexus of influence, and not potential alternatives. Third, in the context of marine debris it cannot identify the behavioural causes of littering or net loss, which are fundamental to designing interventions. This requires additional analysis, exemplified by the Ambon workshop with Indonesian fishery stakeholders. However, adaptive co-management processes that may emerge through the nexus of influence could provide opportunities for subsequent more detailed research.

Nonetheless, the method can provide a more sensitive and high-resolution analysis of marine debris in TDAs, which currently lack detailed assessments of livelihood trade-offs inherent in interventions (Pernetta and Bewers, 2012). For ghost nets in the Arafura Sea our results can contribute to the ATSEA TDA. However, our case study only considered trawl fisheries, and the sample size of surveyed skippers was small. To refine the recommendations for these fisheries, more extensive research of the causes of net loss is necessary. The fact that the rate of losses reported by the skippers was low, and they all disposed of damaged nets at port implicates additional sources of trawl ghost nets. Furthermore, an analysis of the other fisheries operating in the Arafura Sea (i.e. purse seine and gill nets) is required, including IUU fisheries which have differing drivers and stakeholders (Wagey et al., 2009). The ATSEA program provides an ideal platform for the further application of our approach, and to foster the adaptive co-management of ghost nets and other marine debris in the region.

Acknowledgements

This study was co-funded by the Australian Government's Caring for Country support to GhostNets Australia and the CSIRO Wealth from Oceans National Flagship. The Ambon workshop was also funded by ATSEA. The authors gratefully acknowledge the contribution of the workshop participants. Jen Goldberg (GhostNets Australia) kindly provided cartographic skills.

References

Af-idati, N., Lee, S.-G., 2009. Management measures of shrimp trawling fishery in Arafura Sea, Indonesia: a challenge. J. Coastal Dev. 12 (2), 56–63.
Akenji, L., Bengtsson, M., 2010. Is the customer really king? Stakeholder analysis for sustainable consumption and production using the example of the packaging value chain. In: Sustainable Consumption and Production in the Asia-Pacific Region: Effective Responses in a Resource Constrained World. IGES, Hayama, Japan, pp. 23–46.
Alongi, D.M., Edyvane, K., Guterres, M.O., Pranowo, W.S., Wiransantosa, S., Wasson, R., 2011. Biophysical Profile of the Arafura and Timor Seas. Report Prepared for the Arafura and Timor Seas Ecosystem Action Program, Jakarta.
Armitage, D., 2005a. Adaptive capacity and community-based natural resource management. Environ. Manage. 35, 703–715.
Armitage, D., 2005b. Community-based narwhal management in Nunavut, Canada: uncertainty, change and adaptation. Soc. Nat. Resour. 18, 715–731.
Armitage, D., 2007. Building resilient livelihoods through adaptive co-management: the role of adaptive capacity. In: Armitage, D., Berkes, F., Doubleday, N. (Eds.), Adaptive Co-management: Collaboration, Learning, and Multi-level Governance. UBC Press, Vancouver, pp. 62–82.
Armitage, D., Plummer, R., Berkes, F., Arthur, R., Charles, A.T., Davidson-Hunt, I., Diduck, A.P., Doubleday, N.C., Johnson, D.S., Marschke, M., McCooney, P., Pinkerton, E.W., Wollenberg, E.K., 2009. Adaptive co-management for social-ecological complexity. Front. Ecol. Environ. 7, 95–102.
ATSEA, 2010. Arafura Timor Seas Ecosystem Action Program. www.atsea-program.org/ (accessed 01.10.12.).
ATSEA, 2011. Stakeholders Report of the Arafura and Timor Seas; Technical Paper for the Transboundary Diagnostic Analysis Component of the Arafura and Timor Seas Ecosystem Action Program. ATSEA, Jakarta, Indonesia.

Baird, I.G., Quastel, N., 2011. Dolphin safe tuna from California to Thailand: localisms in environmental certification of global commodity networks. Ann. Assoc. Am. Geogr. 101 (2), 337–355.
Ballard, D., 2005. Using learning processes to promote change for sustainable development. Action Res. London 3 (2), 135–156.
Benoît, C., Mazijn, B., 2009. Guidelines for Social Life Cycle Assessment of Products. United Nations Environment Programme, New York.
Berkes, F., 2007. Community-based conservation in a globalized world. Proc. Natl. Acad. Sci. U. S. A. 104, 15188–15193.
Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manage. 90, 1692–1702.
Berry, H.L., 2009. Social capital and mental health among Indigenous Australians, New Australians and Other Australians living in a coastal region. Aust. e-Journal Adv. Ment. Health 8 (2), 142–154.
Berry, H.L., Butler, J.R.A., Burgess, C.P., King, U.G., Tsey, K., Cadet-James, Rigby C.W., Raphael, B., 2010. Mind, body, spirit: co-benefits for mental health from climate change adaptation and caring for country in remote Aboriginal Australian communities. NSW Public Health Bull. 21, 139–145.
Blaber, S.J.M., Dichmont, C.M., Buckworth, R.C., Badrudin, Sumiano, B., Nurhakim, S., Iskandar, B., Fegan, B., Ramm, D.C., Salini, J.P., 2005. Shared stocks of snappers (Lutjanidae) in Australia and Indonesia: integrating biology, population dynamics and socio-economics to examine management scenarios. Rev. Fish Biol. Fish. 15, 111–127.
Brown, J., Macfadyen, G., Huntington, T., Magnus, J., Tumilty, J., 2005. Ghost Fishing by Lost Fishing Gear. Final Report to DG Fisheries and Maritime Affairs of the European Commission. Fish/2004/20. Institute for European Environmental Policy and Poseidon Aquatic Resource Management Ltd.
Brown, K., Tompkins, E., Adger, W.N., 2001. Trade-off Analysis for Participatory Coastal Zone Decision-making. Overseas Development Group, University of East Anglia, Norwich, UK.
Burgess, C.P., Johnston, F.H., Bowman, D.M.J.S., Whitehead, P.J., 2005. Healthy country: healthy people? Exploring the health benefits of Indigenous natural resource management. Aust. N. Z. J. Public Health 29, 117–122.
Burgess, C.P., Johnston, F.H., Berry, H.L., McDonnell, J., Yibarbuk, D., Gunabarra, C., Mileran, A., Bailie, R.S., 2009. Healthy country, healthy people: the relationship between Indigenous health status and "caring for country". Med. J. Aust. 190, 567–572.
Butler, J.R.A., 2011. The challenge of knowledge integration in the adaptive co-management of conflicting ecosystem services provided by seals and salmon. Anim. Conserv. 14, 599–601.
Butler, J.R.A., Middlemas, S.J., Graham, I.M., Thompson, P.M., Armstrong, J.D., 2006. Modelling the impacts of removing seal predation from Atlantic salmon, *Salmo salar* L., rivers in Scotland: a tool for targeting conflict resolution. Fish. Manage. Ecol. 13, 285–291.
Butler, J.R.A., Middlemas, S.J., McKelvey, S.A., McMyn, I., Leyshon, B., Walker, I., Thompson, P.M., Boyd, I.L., Duck, C., Armstrong, J.D., Graham, I.M., Baxter, J.M., 2008. The Moray Firth Seal Management Plan: an adaptive framework for balancing the conservation of seals, salmon, fisheries and wildlife tourism in the UK. Aquat. Conserv. Mar. Freshw. Ecosyst. 18, 1025–1038.
Butler, J.R.A., Wong, G., Metcalfe, D., Honzak, M., Pert, P.L., Bruce, C., Kroon, F.J., Brodie, J., 2011a. An analysis of trade-offs between multiple ecosystem services and stakeholders linked to land use and water quality management in the Great Barrier Reef, Australia. Agric. Ecosyst. Environ.. http://dx.doi.org/10.1016/j.agee.2011.08.017. Online: http://dx.doi.org/10.1016/j.agee.2011.08.017.
Butler, J.R.A., Middlemas, S.J., Graham, I.M., Harris, R.N., 2011b. Perceptions and costs of seal impacts on salmon and sea trout fisheries in the Moray Firth, Scotland: implications for the adaptive co-management of special areas of conservation. Mar. Policy 35, 317–323.
Butler, J.R.A., Tawake, L., Tawake, A., Skewes, T., McGrath, V., 2012. Integration of traditional ecological knowledge and fisheries management in the Torres Strait, Australia: the catalytic role of turtles and dugong as cultural keystone species. Ecol. Soc. 17 (4), 34. http://dx.doi.org/10.5751/ES-05165-170434.
Clift, R., Wright, L., 2000. Relationships between environmental impacts and added value along a supply chain. Technol. Forecast Soc. 65 (3), 281–295.
Coles, C., Mitchell, J., 2011. Gender and Agricultural Value Chains: a Review of Current Knowledge and Practice and their Policy Implications. In: ESA Working Paper No. 11–05. Agricultural Development Economics Division, The Food and Agriculture Organisation of the United Nations.
De Groot, R.S., 2006. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landscape Urban Plan. 75, 175–186.
Dyer, G., Hunter, E., 2009. Creative recovery: art for mental health's sake. Australas. Psychiatry 17 (Suppl. 1), 146–150.
EPA, 2003. Hazards of Burning in Backyards Fact Sheet. US Environmental Protection Agency, Washington DC. http://www.epa.gov/osw/nonhaz/municipal/backyard/pubs/residents.pdf (accessed 15.09.12.).
FAO, 2005. World Inventory of Fisheries: Impacts of Fishery Activities. FAO Fisheries and Aquaculture Department, The Food and Aquaculture Organization of the United Nations, Rome. http://www.fao.org/fishery/topipc/12273/en (accessed 15.09.12.).
FAO, 2010. The State of World Fisheries and Aquaculture. FAO Fisheries and Aquaculture Department, The Food and Aquaculture Organization of the United Nations, Rome.
Finnveden, G., Hauschild, M.Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., Suh, S., 2009. Recent developments in life cycle assessment. J. Environ. Manage. 91, 1–21.
Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Res. 30, 441–473.
Freeman, R.E., 1984. Strategic Management: a Stakeholder Approach. Pitman, Boston.
Gatersleben, B., Vlek, C., 1998. Household consumption, quality of life and environmental impacts: a psychological perspective and empirical study. In: Noorman, K.J., Uiterkamp, T.S. (Eds.), Green Households? Domestic Consumers, Environment and Sustainability. Earthscan Publications Ltd., UK, pp. 141–183.
Garnett, S.T., Sithole, B., Whitehead, P.J., Burgess, C.P., Johnston, F.H., Lea, T., 2009. Healthy country, healthy people: policy implications of links between indigenous human health and environmental condition in tropical Australia. Aust. J. Policy Rev. 68, 53–66.
Garware Marine Industries, 2011. http://www.garwaremarine.com/ (accessed 14.09.12.).
Gillett, R., 2008. Global Study of Shrimp Fisheries. FAO Technical Paper 475. The Food and Aquaculture Organization of the United Nations, Rome.
GNA, 2011. GhostNets Australia Annual Report. www.ghostnets.au/news (accessed 14.09.12.).
Goldstein, M.A., Rosenberg, M., Cheng, L., 2012. Increased oceanic microplastic debris enhances oviposition in an endemic pelagic insect. Biol. Lett.. Online: http://dx.doi.org/10.1098/rsbl.2012.0298.
Gratani, M., Butler, J.R.A., Royee, F., Burrows, D., Valentine, P., Canendo, W., Anderson, A., 2011. Is validation of indigenous ecological knowledge a disrespectful process? A case study of traditional fishing poisons and invasive fish management from the Wet Tropics, Australia. Ecol. Soc. 16 (3), 25. http://dx.doi.org/10.5751/ES-04249-160325.
Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings: entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Phil. Trans. R. Soc. London B 364 (1526), 2013–2025.
Griffin, D., 2008. Pilot Investigation of the Origins and Pathways of Marine Debris Found in the Northern Australian Marine Environment. Report to the Department of the Environment, Water, Heritage and the Arts, Canberra, Australia.
Gunn, R., Hardesty, B.D., Butler, J.R.A., 2010. Tackling 'ghost nets': local solutions to a global issue in northern Australia. Ecol. Manage. Restor. 11, 88–98.
Hamilton, C., Cook, K., White, D., 2002. The Net Kit: A Net Identification Guide to Northern Australia. WWF, Australia, Sydney.
Heathcote, G., Gunn, R., Goldberg, J., Hamblin, L., Morrison, S., 2011. Summary Report 2004–2009. GhostNets Australia, Darwin.
Horne, R., Grant, T., Verghese, K., 2009. Life Cycle Assessment: Principles, Practice and Prospects. CSIRO Publishing, Collingwood, Australia.
Hunter, E., 2007. Disadvantage and discontent: a review of issues relevant to the mental health of rural and remote Indigenous Australians. Aust. J. Rural Health 15, 88–93.
ISO, 2006a. ISO 14040 international standard. In: Environmental Management – Life Cycle Assessment – Principles and Framework. International Organisation for Standardization, Geneva, Switzerland.
ISO, 2006b. ISO 14044 international standard. In: Environmental Management – Life Cycle Assessment – Requirements and Guidelines. International Organisation for Standardisation, Geneva, Switzerland.
Kaiser, J., 2010. The dirt on ocean garbage patches. Science 328 (5985), 1506.
Kiessling, I., 2003. Finding Solutions: Derelict Fishing Gear and Other Marine Debris in Northern Australia. Report to the National Oceans Office for the Key Centre for Tropical Wildlife Management. Charles Darwin University, Darwin.
Korean Trading and Industries, 2012. http://koreakti.co.kr/english/e-kti-company01.html (accessed 15.09.12.).
Lee, D.,-I., Cho, H.-S., Jeong, S.-B., 2006. Distribution characteristics of marine litter on the seabed of the East China Sea and the South Sea of Korea. Estuar. Coast. Shelf Sci. 70, 187–194.
Limpus, C., 2008. A Biological Review of Australian Marine Turtle Species 2: Green Turtle *Chelonia mydas* (Linnaeus). Queensland Environment Protection Agency, Brisbane, Australia.
Limpus, C., 2009. A Biological Review of Australian Marine Turtle Species 3: Hawksbill Turtle *Eretmochelys imbricata* (Linnaeus). Queensland Environment Protection Agency, Brisbane, Australia.
Macfadyen, G., Huntington, T., Cappell, R., 2009. Abandoned, Lost and Otherwise Discarded Fishing Gear. UNEP Regional Seas Reports and Studies, No. 185; FAO Fisheries and Aquaculture Technical Paper, No. 523. UNEP/FAO, Rome.
Margavio, A., Laska, S., Mason, J., Forsyth, C., 1993. Captives of conflict: the TEDs case. Soc. Nat. Resour. 6, 273–290.
McIlgorm, A., Campbell, H.F., Rule, M.J., 2008. Understanding the Economic Benefits and Costs of Controlling Marine Debris in the APEC Region (MRC 02/2007). Report to the Asia-Pacific Economic Cooperation Marine Resource Conservation Working Group by the National Marine Science Centre (University of New England and Southern Cross University), Coffs Harbour, Australia.
Mitchell, R., Agle, B., Wood, D., 1997. Towards a theory of stakeholder identification and salience: defining the principle of who and what really counts. Acad. Manage. Rev. 22 (4), 853–886.
Moore, M.-L., Westley, F., 2011. Surmountable chasms: networks and social innovation for resilient systems. Ecol. Soc. 16 (1), 5. http://www.ecologyandsociety.org/vol16/iss1/art5/.
Nurhakim, S., Adrianto, L., Wagey, G.A., August 21, 2008. Socio-Ecological Dynamics of the Arafura and Timor Seas. In: Presentation to the Coast-to-Coast Conference, Darwin, Australia.
Olsson, P., Folke, C., Berkes, F., 2004. Adaptive co-management for building resilience in social-ecological systems. Environ. Manage. 34, 75–90.

Pelletier, N.L., Ayer, N.W., Tyedmers, P.H., Kruse, S.A., Flysjo, A., Robillard, G., Ziegler, F., Scholz, A.J., Sonesson, U., 2007. Impact categories for Life Cycle Assessment research of seafood production systems: review and prospectus. Int. J. LCA 12 (6), 414–421.

Pernetta, J.C., Bewers, J.M., 2012. Transboundary diagnostic analysis in international waters interventions funded by the Global Environment Facility. Ocean Coast. Manage. 55, 1–12.

Pilz, H., Brandt, B., Fehringer, R., 2010. The Impact of Plastics on Life Cycle Energy Consumption and Greenhouse Gas Emissions in Europe. Summary Report to Denstatt GmbH, Vienna, Austria.

Plummer, R., 2009. The adaptive co-management process: an initial synthesis of representative models and influential variables. Ecol. Soc. 14 (2), 24. http://www.ecologyandsociety.org/vol14/iss2/art24/.

Plummer, R., Armitage, D.R., 2007. Charting the new territory of adaptive co-management: a Delphi study. Ecol. Soc. 12 (2), 10. http://www.ecologyandsociety.org/vol12/iss2/art10/.

Reagans, R., Zuckerman, E.W., 2001. Networks, diversity and productivity. The social capital of corporate R and D teams. Organ. Sci. 12, 502–517.

Resosudarmo, B.P., Napitupulu, L., Campbell, D., 2009. Illegal fishing in the Arafura Sea. In: Resosudarmo, B.P., Jotzo, F. (Eds.), Working with Nature against Poverty: Development, Resources and the Environment in Eastern Indonesia. Institute of Southeast Asian Studies, Singapore, pp. 178–200.

Rigby, C.W., Rosen, A., Berry, H.L., Hart, C.R., 2011. 'If the land's sick, we're sick': prolonged drought and Aboriginal social and emotional health in NSW. Aust. J. Rural Health 19, 249–254.

Riisgaard, L., Bolwig, S., Ponte, S., du Toit, A., Halberg, N., Matose, F., 2010. Integrating poverty and environmental concerns into Value-Chain Analysis: a strategic framework and practical guide. Dev. Policy Rev. 28 (2), 195–216.

Ryan, P.G., Maloney, C.L., 1993. Marine litter keeps increasing. Nature 361, 23.

Ryan, P.G., Moore, C.J., van Franeker, J.A., Maloney, C.L., 2009. Monitoring the abundance of plastic debris in the marine environment. Phil. Trans. R. Soc. London B 364 (1526), 1999–2012.

Sandstrom, A., Carlsson, L., 2008. The performance of policy networks: the relation between network structure and network performance. Policy Stud. J. 36 (4), 497–525.

Sandstrom, A., Rova, C., 2010. Adaptive co-management networks: a comparative analysis of two fishery conservation areas in Sweden. Ecol. Soc. 15 (3), 14. http://www.ecologyandsociety.org/vol15/iss3/art14/.

Sheavly, S., 2011. The Honolulu Strategy: a Global Framework for the Prevention and Management of Marine Debris. Report for the 5th International Marine Debris Conference 2011, Hawaii.

Slavin, C., Grage, A., Campbell, M.L., 2012. Linking social drivers of marine debris with actual marine debris on beaches. Mar. Pollut. Bull.. http://dx.doi.org/10.1016/j.marpolbul.2012.05.018.

Stacey, N., Nurhakim, S., Nugroho, D., Soselisa, H., Resosudarmo, B., Kalis, O., Monteiro, J., Prescott, J., Martin, J., Karim, J., 2011. Socio-economic Profile of the Arafura and Timor Seas. Report for the Transboundary Diagnostic Component of the Arafura Timor Seas Ecosystem Action Program, Jakarta.

Tan, R.B.H., Khoo, H.H., 2006. Impact assessment of waste management options in Singapore. J. Air Waste Manage. Assoc. 56 (3), 244–254.

Thompson, P.M., Mackey, B., Barton, T.M., Duck, C., Butler, J.R.A., 2007. Assessing the potential impact of salmon fisheries management on the conservation status of harbour seals (*Phoca vitulina*) in north-east Scotland. Anim. Conserv. 10, 48–56.

Thompson, R.C., La Belle, B.E., Bouwman, H., Neretin, L., 2011. Marine Debris: Defining a Global Environmental Challenge. In: Global Environment Fund Scientific and Technical Advisory Panel GEF/C.40/Inf 14. United Nations Environment Programme.

Tucker, A.D., Robins, J.B., Mcphee, D.P., 1997. Adopting turtle excluder devices in Australia and the United States: what are the differences in technology transfer, promotion, and acceptance? Ocean Coast. Manage. 25 (4), 405–421.

Tull, M., 2009. The History of Shark Fishing in Indonesia: A HMAP Asia Project Paper. Working Paper No. 158. Murdoch Business School and Asia Research Centre, Murdoch University.

UNEP, 2012. Progress in the Implementation of UNEP's Marine Litter Activities 2007–2011 and the Way Forward from 2012–2016. In: Intergovernmental Review meeting on the Implementation of the Global Action for the Protection of the Marine Environment from Land-based Activities, Third Session, Manila, 25–27 January 2012.

Wagey, G.A.., Nurhakim, S., Nikijuluw, V.P.H., Badrudin, Pitcher, T.J., 2009. A Study of Illegal, Unreported and Unregulated Fishing in the Arafura Sea, Indonesia. Research Centre for Capture Fisheries, Agency for Marine and Fisheries Research, Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia.

White, D., 2004. Marine Debris in Northern Territory Waters 2002. The World Wide Fund for Nature Report. WWF, Australia.

Wilkinson, J., 2006. Fish: a global value chain driven onto the rocks. Sociol. Ruralis 46 (2), 139–153.

Wurpel, G., Van den Akker, J., Pors, J., Ten Wolde, A., 2011. Plastics Do Not Belong in the Ocean: Towards a Roadmap for a Clean North Sea. IMSA, Amsterdam.

WWF, 2011. Healthy Seas, Healthy Seafood: Consumer Guide to Sustainable Seafood. WWF-Indonesia, Jakarta. http://wwf.panda.org/what_we_do/how_we_work/conservation/marine/sustainable_fishing/sustainable_seafood/seafood_guides/ (accessed 12.09.12.).

Young, J.C., Butler, J.R.A., Jordan, A., Watt, A.D., 2012. Less government intervention in biodiversity management: risks and opportunities. Biodivers. Conserv. 21, 1095–1100.

Zainudin, I.M., Pet-Soede, L., Hitipeuw, C., Adnyana, W., July 2007. Interaction of Sea Turtles with Indonesian Fisheries: Preliminary Findings. Indian Ocean Turtle Association Newsletter No. 6.