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Exploring mangrove social-ecological system dynamics in South-East Asia: linking livelihoods, vulnerability and ecosystem services in Vietnam

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Contents

Abstract
Globally, human activities have led to rapid mangrove degradation. In Vietnam, as across much of coastal South-east Asia, mangroves play a vital role in the livelihoods of coastal rural communities with relatively low levels of development. However, little is known about the precise impact of human activity on the ecosystem services underpinning these livelihoods. This paper analyses the livelihoods of mangrove dependent communities to gain insights into how social-ecological systems are responding to human activities by identifying: 1) key aspects of change; 2) current household livelihood strategies; 3) characteristics of households most dependent on mangrove system provisioning goods; and 4) livelihood trajectories of illustrative mangrove dependent households. Guided by the sustainable livelihoods framework and resilience theory, employing a comparative case study of three communes on Vietnam's northern coast, this research takes a mixed methods approach. Findings demonstrate that a rapidly growing aquaculture industry, facilitated by far-reaching land and market reforms, and local misappropriation of the benefits of these reforms, has undermined mangrove goods and services. A strong aquaculture industry has led to increased livelihood diversification at the community level, but growing specialisation at the household level. Female headed households were significantly more dependent on mangrove resources in all communes, and limited land use rights increased dependence on mangrove resources in communes with a growing aquaculture industry. Access to land, finance and social networks have increased the resilience of livelihoods, while a lack of these in combination with an absence of rights, environmental degradation, sickness and discrimination increased vulnerability. The paper concludes by identifying the key challenges facing mangrove social-ecological systems as: ensuring the maintenance of ecosystem functions and processes underpinning local livelihoods; fostering equitable distribution of ecosystem goods and services to encourage their sustainable use; and increasing the diversification of income opportunities to reduce pressure on mangrove resources.

Keywords: ecosystem services; resilience; vulnerability; coastal zone management; sustainable development; natural resource management

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1. Introduction

Goods and services provided by mangroves are important components of coastal rural livelihood strategies (Van Hue and Scott 2008). However, rapid economic development has significantly altered coastal wetlands contributing to widespread degradation and mangrove loss (Seto and Fragkias 2007). Such degradation occurs through deliberate and inadvertent actions resulting from undervaluation of wetland functions and processes (Vilardy et al. 2011). Political, socio-economic and environmental shocks and stresses on ecosystems negatively impact the structure, function, and flow of services provided to society, causing significant impacts on human welfare (Martin-Lopez et al. 2009; MEA 2005). This particularly threatens natural resource dependent communities due to their reliance on these services for their survival (Dasgupta 2007).

This paper studies the links between mangrove and livelihood systems, providing an empirical contribution to address the gap identified by Carpenter et al. (2009) in understanding the consequences of changes in ecosystem services for natural resource dependent communities. Dynamics and feedbacks between wetland resources and coastal livelihoods in three social-ecological contexts in northern Vietnam are investigated in order to: (1) identify the drivers that have impacted the

dynamics of each social-ecological system; (2) establish the range of contemporary household livelihood strategies; (3) identify the characteristics of households most dependent on mangrove systems and the services they obtain; and (4) establish how social-ecological dynamics have temporally altered household livelihood options.

The next sections outline the concepts related to livelihoods, resilience and ecosystem services, and the research process. Narratives of social-ecological system dynamics within each context are provided, exploring the political, socio-economic and environmental aspects contributing to contemporary livelihood strategies. Quantitative analysis then offers insights into the contribution of mangrove systems to local households' livelihood portfolios. Livelihood trajectories of individual households are then examined, providing an essential temporal dimension. Lessons from such insights are then discussed.

2. Literature review

A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living (Chambers and Conway, 1992). Assets are the tangible and intangible resources, categorised by Scoones (1998) as natural, social, financial, physical and human capitals, which households draw upon to make a living. The mix of assets and activities a household selects denotes the "livelihood strategy" (Scoones 1998), and also encapsulates cultural and social elements (Ellis 2000). Livelihoods are shaped by the changing natural environment and form within complex social, economic and political contexts; the "shocks", "trends" and "seasonality" of which combine to determine the livelihood vulnerability context (Chambers & Conway, 1992; Scoones, 1998). Limitations of the livelihood approach include its neglect of power relations and social and environmental dynamics, and a narrow focus on the short-term and local scale (Scoones 2009; de Haan and Zoomers 2005).

Scoones (1998: p2) states that "a livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base." Consideration of sustainability within a livelihoods approach resonates clearly with the concepts of social-ecological systems and resilience theory (Marschke and Berkes 2006). Berkes and Folke (1998) use the term "social-ecological" system to illustrate the integrated nature of human-environment relations, arguing that the separation of social and ecological systems is artificial and arbitrary. Social-ecological systems display strong reciprocal feedbacks and act as complex adaptive systems (Costanza et al. 1993; Berkes et al. 2003; Folke et al. 2004). Resilience refers to "the capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity" (Walker et al. 2004: p2). This helps address the limitations of the livelihoods approach by examining the shocks and stresses of livelihood dynamics, while also providing a useful perspective for analysing ecosystem service use (Marschke and Berkes 2006; Andersson et al. 2007). Nevertheless, the application of concepts relating to ecological resilience in relation to social systems has been questioned because of inattention to power issues relating to political-economy and cultural theory (Armitage and Johnson 2006;

Nadasdy 2007; Duit et al. 2010). Furthermore, the need remains to fully address the role of values and normative dimensions of resilience (Armitage et al. 2012).

The Millennium Ecosystem Assessment (MEA, 2005) provides a framework for analysing social-ecological systems that considers feedbacks at multiple scales among direct and indirect drivers, ecosystem services, and human well-being, organising ecosystem services under provisioning, regulating, cultural and supporting service categories. The MEA framework nevertheless fails to consider the full ensemble of process and feedbacks required to fully understand complex and dynamic human–ecosystem relations (Carpenter et al. 2009). In addition, both livelihood and resilience approaches have lacked integration with social-ecological history (Vilardy et al. 2011). With this in mind, we combine livelihood and resilience frameworks, using the MA framework to categorise ecosystem services, with particular attention given to livelihood trajectories. A livelihood trajectory is defined as "the consequences of the changing way in which individuals construct a livelihood over time" (Bagchi et al. 1998: p457). This approach is applied to explore life histories of individual households and their strategic behaviour and changing livelihoods in relation to specific needs, aspirations and limitations, and contextualised in relation to local power dynamics (Sallu et al. 2010). This enables close examination of the interrelated and dynamic links within social-ecological systems, and fosters greater understanding of the political, socio-economic and environmental aspects underpinning ecosystem service provision and the ways people use and manage these services over time (Vilardy et al., 2011). This feeds into the important and growing application of the livelihood trajectory approach (Murray 2001; de Haan and Zoomers 2005).

Using a sustainable livelihood framework (SLF) and trajectory analysis allows us to identify key aspects of mangrove change within each community. Comparing how these changes have influenced current livelihood strategies and activities across the communities, the ecosystem services framework allows categorisation of the goods and services that households receive from mangrove systems. Charting changes onto specific household livelihoods over time provides the opportunity to explore how processes of change have influenced livelihood trajectories. This provides important insights for future mangrove system planning, allowing us to identify key livelihood vulnerabilities and the factors that cause them. We argue that, in the context of rapid environmental change across Southeast Asia, intensive large scale commercial aquaculture is undermining mangrove systems and creating livelihood dependency on aquaculture related activities. This is increasing livelihood vulnerability of marginalised households by removing a source of livelihood and coping, and altering the structure of the local economy.

3. Material and methods

Data were collected during February - August 2012 within mangrove systems of three coastal communities in northern Vietnam: Giao Xuan (Nam Dinh province); Da Loc (Thanh Hoa province); and Dong Rui (Quang Ninh province). Communes were selected due to their geographic location, while being representative of distinct social-ecological systems with differing environmental contexts, social compositions, and household histories. For the purpose of this study, a community is considered a

sub-set of the commune and is defined as those households who use mangroves in three geographically defined territories. Residents in all study communities had some degree of access to surrounding communal wetlands.

A mixed method approach was taken. Household surveys (n=248) were conducted to identify current livelihood strategies and resource use patterns (Giao Xuan, n=79; Da Loc, n=70; Dong Rui, n=99). Semi-structured interviews provided in-depth historical and current perspectives on livelihood strategies and related trajectories (n=10 in each commune; total n=30). These sought to elucidate how: a) households use mangrove systems, b) changes in the wetlands (degradation, storm damage etc.) affect livelihood decisions, and c) these interact with broader political, socio-economic and environmental aspects to determine use outcomes and subsequent livelihood impacts.

To achieve objectives 1-3, survey data were collected on general household information (age, gender, education, etc.) and all subsistence and income generating activities using snowball sampling (cf. Luttrell 2006; Pereira et al. 2005). Key informants identified by local partners and research participants during pilot studies provided a starting point for surveys in each commune. To enable rigorous assessment of the relative importance of mangrove resources to household livelihoods, specific information was collected on seasonality, effort, yield and income from mangrove goods. To achieve objective four, livelihood trajectory data were collected through semi-structured interviews, which covered key events that altered mangrove systems and the subsequent changes in livelihood activities (cf. Sallu et al. 2010; Turner 2009). Interview respondents were selected from survey respondents, maintaining a balance between broad categories of household based on wealth, occupation, gender, age, location of residence and ethnicity (Luttrell, 2006). The time span covered by the interviews was limited to the period 1975-2012. This covers Vietnam's reunification to the present day, encapsulating the collectivised farming era and subsequent changes in economic policy, land allocation, and decentralisation of the forestry sector: significant events in setting the boundaries of the livelihood context.

Data analysis was iterative and initially involved descriptive analysis to log trends and patterns in preliminary data collected during pilot studies in each commune. More detailed analysis was conducted as quantitative and qualitative data accumulated. Quantitative data analysis first explored frequencies of livelihood subsistence and income using SPSS (IBM SPSS 19). Data were then analysed using Kruskal-Wallis and Mann-Whitney tests (Ahenkan and Boon 2011; Cox et al. 2010), with independent livelihood variables categorised using cluster analysis and tested against the dependent variable of percentage of household income derived from mangroves in public areas (Brouwer et al. 2007). Qualitative data were coded under emerging themes (Kaplowitz and Hoehn 2001; Kaplowitz 2001). During livelihood trajectory analysis, tendencies towards resilience or vulnerability were determined by an increase or decrease in access to financial, human, physical, social or natural capitals. This facilitated identification of aspects of change that had played a major role in the formation of livelihood strategies. Emerging contradictions and similarities were exposed through repetitive triangulation. Continual iterative reflections were carried out as further data and results emerged to determine how and why any conflicts in information may have occurred. This resulted in a cyclical process

culminating in inductive interpretation and explanation of results as livelihood system data was positioned within the developing socio-economic and political context.

4. Results

The results section is broken down into subsections relating to research objectives. Section 4.1 refers to objective one (key aspects of mangrove change); section 4.2 relates to objective three (current household livelihood strategies); sections 4.3 and 4.4 relate to objective 3 (characteristics of households most dependent on mangrove system provisioning goods and the types of goods they receive); and section 4.5 relates to objective 4 (livelihood trajectories of illustrative mangrove dependent households.

4.1 Social-ecological dynamics

Mangroves perform a vital role in the productivity of highly dynamic wetland ecosystems, the provision of which is largely determined by a complex set of political, socio-economic and environmental aspects. Key factors relating to mangrove change were identified. Aquaculture, property rights regimes, and the role of local authorities were important in all three communities, along with market liberalisation, participation and pollution in Giao Xuan, Da Loc and Dong Rui respectively. The unique interaction of factors has defined the contours of the local livelihood context, creating both opportunities and threats to the portfolio of livelihood activities available to households over historical time. Although these factors relate to political, socio-economic and environmental aspects, they are intricately linked and frequently overlap.

4.1.1 Political aspects

Following the First Indochina War and independence from French colonialism in 1954, local authorities in Giao Xuan and Da Loc converted mangrove areas into sea-grass plantations in order to manufacture products such as mats for export to the Soviet Union.

> *"The Commune Committee are responsible for cutting down the mangroves, they cut them*
> *down so that they could grow sea-grass and make money from selling mats. The mats were bad quality so it wasn't very successful."* (Male interviewee, Giao Xuan, June 2012)

During the Second Indochina War (1955 – 1975), particularly in the area surrounding Giao Xuan, American air forces destroyed dike networks, destabilising the local environment and economy, and damaging the mangroves. Subsequent to Vietnam's reunification (1975) and with the market for sea-grass products diminishing, small sections of wetland were replaced with aquaculture farms, which the government deemed integral to the nation's economic recovery following decades of war:

> *"…when sea-grass didn't bring them* [local government] *much money, they converted the area to aquaculture farming instead."* (Male interviewee, Da

Loc, August 2012)

Nevertheless, throughout the era of collectivised farming from independence (1954) to ‘Doi Moi’ economic reforms (1986), wetlands were formally considered as wild areas open to all, although community rules and traditions determined what people could do.

Introduction of market incentives following ‘Doi Moi’, led increasing numbers of people to claim sections of wetland in order to establish aquaculture farms. Young, healthy and strong male headed households were best positioned to claim land, marginalising the old, weak, or female headed households. This resulted in conflicts within Giao Xuan and Da Loc, which often turned violent:

> *“…that’s when all the conflicts started, people trying to get rich quickly by claiming land for themselves…two people have even been killed and people have gone to jail.”* (Female interviewee, Da Loc, August 2012)

With no formal legislation for wetlands, emerging regulatory frameworks struggled to keep pace with changing social, political, economic and environmental conditions being driven by economic reforms, changes in land allocation, and decentralisation in the forestry sector. Confusion emanating from a lack of coordination and coherence of regulations allowed exploitation of ambiguities and loopholes for personal gain, with scant regard for the negative consequences for wetlands:

> *“…there was no guard in the past, it wasn’t necessary. But now people are destroying the mangroves for aquaculture and the state just lets it happen…there’s no regulation.”*
> (Male interviewee, Giao Xuan, June 2012)

In light of these changes, local authorities in both Giao Xuan and Da Loc intervened and redistributed the wetland area through a formal bidding process. In some cases land was allocated to influential and powerful individuals (or those closely connected to them):

> *“….people would go to the sea and claim bits for themselves and this caused many conflicts, so in the end the district came and allocated the land to the highest bidder, or their family and friends.”* (Female interviewee, Giao Xuan, June 2012)

In doing so, local authorities benefitted financially from both the bidding process, and from imposing taxes on aquaculture production. However, land was only allocated to households from the local area.

The political aspects of mangrove change in Dong Rui differ to those of Giao Xuan and Da Loc. Due to its close proximity to China Dong Rui had been settled by a largely ethnic Chinese population. As a consequence of the Sino-Vietnamese war (1979), the ethnic Chinese settlers were evicted by the Vietnamese government and the area was resettled by ethnic ‘Kinh’ Vietnamese from nearby Hai Phong city. At that time, respondents indicated that Dong Rui was surrounded by extensive mangroves which provided rich natural resources for the whole community to enjoy a

good, stable standard of living. Mangroves had been cultivated by the previous Chinese settlers who had great knowledge and awareness of the functions that the mangroves performed:

> *"…when we first arrived* [in 1979] *and the Chinese left, there was one Vietnamese man who had been living in the commune all his life and he was allowed to stay* [by the authorities]*. He told us about the importance of the mangroves and how the Chinese would plant trees because they knew how important they were for protecting the community and providing food."* (Male interviewee, Dong Rui, July 2012)

However, subsequent to economic reforms, the newly established local authorities sold huge swathes of wetland to aquaculture investors from outside provinces. In some cases, to circumvent strict national legislation on land ownership, local authorities used the names of their family and friends on contracts in order to sell land. Many people in the community disapproved, but had no voice or platform to raise their concerns:

> *"They* [the local government] *sold the land to businessmen from other provinces, and would even use names of people in their family to sign contracts….they did not inform the local people, or even the district authorities…everyone was unhappy, but we are just farmers, there's no-one that will listen to us."* (Female interviewee, Dong Rui, July 2012)

Although political aspects differ somewhat in each commune, the underlying issues in all three relate to wetland privatisation and local authorities' actions. However, outcomes are quite different in terms of tenure rights, with rights given to locals in Giao Xuan and Da Loc, while external aquaculture investors acquired land in Dong Rui.

Recently, all three communes have hosted INGO and state run mangrove afforestation projects, largely on land previously used for large scale intensive aquaculture. This was facilitated by increasingly open international relations following economic reforms, allowing international development agencies, both governmental and non-governmental, to provide the necessary finance and capacity to undertake substantial replanting. Additionally, in 1989, 12,000 ha near Giao Xuan were recognised as Southeast Asia's first Ramsar site, becoming a Natural Reserve in 1995, and Xuan Thuy National Park in 2003. Subsequently, a conservation approach to wetland management has been implemented whereby the government have *"….worked to preserve the value of this area through…new laws, policies and investment…so that the core zone is a strictly protected area without any human activity allowed.*" (CORIN-Asia 2010: p19). Local communities have therefore been prohibited from performing previously undertaken livelihood activities, because it is believed that biodiversity *"….is under threat from unsustainable levels of fishing and overgrazing…and reckless cutting of mangrove trees…of thousands of local people."* (CORIN-Asia, 2010: p29). Aquaculture farming, which constitutes a significant area of the core zone, is not considered to impact upon wetland resources and is not prohibited. Afforestation efforts by governmental and non-governmental bodies enlist the services of forest guards in order to enforce policies prohibiting human activities in the mangroves. However, in all three communes, concerns were raised regarding

forest guards' incompetence, ineffectiveness, or in some cases, corruption (taking bribes and ignoring illegal resource extraction).

> *"…the forest guard does not do the job well, and he only got the job because he is connected to important people. People give him money and they can do what they want in the forest."* (Male interviewee, Giao Xuan, June 2012)

4.1.2 Socio-economic aspects

During the collective farming period (1954–1986) agricultural land was allocated relatively equally, while wetlands were considered common property. There were no markets for mangrove goods, but households in Giao Xuan and Da Loc still used the wetlands as a core component of their livelihood activities. Groups or families would forage in specific areas where they had accumulated intricate local ecological knowledge through experience and learning:

> *"…there was lots* [of food] *to collect back then. The wetland was open to everyone but people had their own area that they would go to collect."* (Female interviewee, Da Loc, August 2012)

> *"…we* [her family] *foraged the same area for years…nobody knew the area as well as me, and nobody could forage like me. I knew the best places and times to catch many different types of animal."* (Female interviewee, Da Loc, July 2012)

With little incentive to overexploit, this system was deemed largely sustainable, as it dispersed collectors over a larger area and facilitated species switching to prevent over-exploitation in one place.

Economic reforms (1986) fostered lucrative domestic and international markets for aquaculture goods, particularly in China, Europe and the US. Subsequent conversion of huge wetland areas into aquaculture farms exposed communities to unprecedented and highly uncertain economic and environmental dynamics, particularly in Giao Xuan, where clam and shrimp farming were established relatively early (1989) due to strong trade links with China. Subsequently, Giao Xuan experienced two major ecological collapses: in 1991 over-exploitation led to near collapse of local clam varieties; in 1997 imported clam species began to dominate local varieties. However, motivated by strong market incentives, the aquaculture sector has been sustained through increased financial risk taking and investment. Higher income households have also consolidated and expanded their wetland ownership by buying land from poorer households in times of stress(e.g. when fields and watchtowers have been destroyed by severe storms), or from households with poorer skills and abilities to make profits:

> *"…the district authorities came and sold the wetlands to the highest bidders. Some people weren't good at aquaculture and the rich people bought their land off them for a cheap price when they got into trouble. Some people got land and sold it straight away and got rich quickly."* (Female interviewee, Giao Xuan, June 2012)

Local authorities and several higher income households believe a growing

aquaculture sector has had a positive environmental impact, providing employment to households who would otherwise overexploit wetland resources, e.g. through livestock grazing, cutting for fuel wood and foraging for food:

> *"…the poor can now get work on clam farms, and because they have a wage they rely less on the mangroves. The clam farms provide stable work every month, so it depends on the people whether they want to work or not….The people employed usually have experience and are hard working."* (Male interviewee, Giao Xuan, June 2012).

In Da Loc the aquaculture industry took longer to establish due to a lack of trade links and relatively little knowledge of aquaculture farming and techniques. Local authorities in Da Loc initiated a shrimp farming enterprise in 2002, but this was abandoned (for reasons unknown to respondents) and the land was auctioned to local households who were encouraged, largely through bank loans, to invest. Additionally, in the late 2000s locals in Da Loc observed the financial benefits gained through clam farming in neighbouring provinces and started to claim sections of wetland. In Dong Rui, subsequent to economic reforms, and recognising the huge potential of the rich wetland resources in the newly settled area, local authorities invited pioneering aquaculture investors from neighbouring provinces to assess the suitability of the area for aquaculture farming. The ensuing enterprises often brought their own workforce so locals received few benefits. Additionally, more pressure was placed on the remaining, greatly reduced, public wetland area:

> *"When I first arrived* [in 1979]*…there was no money to be made from selling animals from the sea because there were so many, everyone had plenty to eat. Since the land was sold and destroyed, people have to travel very far to collect fewer animals that are harder to catch."* (Male interviewee, Dong Rui, July 2012)

In all three communes, poorer households complained of having a smaller area in which to forage, and that the quality of produce had significantly reduced due to the impact of aquaculture on the environment.

In all three communes, local authorities consider a lack of awareness on the part of locals regarding the important role of mangroves a significant cause of degradation. However, the more marginalised feel that overexploitation of wetlands is due to corrupt and profit-seeking activities of local authorities. Moreover, lower income households in all communes, are compelled to forage in significantly reduced areas due to the rapid privatisation of previously public land, placing more pressure on the land still available to them. In Giao Xuan, this has been intensified by the creation of the National Park core zone, which prohibits access for foraging. Compounding these issues is the rapid development experienced in all three communes, with infrastructure projects such as roads, dams, and harbours being developed. Mangrove plantation projects are also prohibiting communities from foraging in plantation zones. In Giao Xuan and Da Loc, households also feel there is growing pressure on wetlands from a growing population who, motivated by lucrative price incentives, have acquired greater skills and techniques to exploit wetland resources and are catching animals before they are mature enough to reproduce. In Dong Rui, population pressure was not identified as an issue. However, concerns

were raised by a number of ethnic ‘Kinh’ Vietnamese that the ethnic ‘Dao’ minority group, who arrived in 2002 as part of a resettlement programme, have little awareness of the importance of mangroves. Respondents indicated that the Dao were using aggressive, damaging foraging techniques (e.g. using large axes to cut the roots of trees to access the animals sheltering inside). However, many put this down to marginalisation of the Dao who have not been involved in commune meetings due to cultural and language issues:

> *“Dao people have very damaging ways of catching animals. They cause a lot of damage but they don’t know because they are uneducated, and because they don’t speak Vietnamese they don’t go to local meetings or understand the radio announcements. They are left out of everything.”* (Male interviewee, Dong Rui, July 2012)

4.1.3 Environmental aspects

Since the 1986 economic reforms, rapid development and a fast expanding aquaculture sector have compounded prevailing environmental changes. In Giao Xuan, pollution flowing downstream from cities along the Red River, combined with additional debris from aquaculture watch towers, is a major concern. Debris becomes trapped in nets and on boundaries used to demarcate aquaculture fields with a negative impact on freshwater flows that mangroves require for survival. Although respondents acknowledged that mangroves naturally perish over time and can be destroyed by severe weather events, they also stated that degradation from aquaculture conversion had made mangroves more susceptible to storm damage. Furthermore, the existing damage caused to the wetland from agricultural waste is exacerbated when heavy rain forces sluice pipes to open to drain agricultural land:

> *“…we get all the rubbish from the cities coming down the river, and all the chemicals from the rice fields, and it all gets dumped into the sea and makes it so dirty that the sea and land can’t breathe.”* (Male interviewee, Giao Xuan, June 2012)

In Da Loc there is growing concern regarding disease outbreaks from intensive aquaculture (i.e. infectious diseases caused by viral, bacterial and parasitic agents), and the threat this poses to the wetland. There is significant concern about the vast amounts of imported sand required to prepare wetlands for aquaculture farming, and its negative local ecological impact. Severe weather events also have an indirect impact, as salinization of agricultural land from flooding increases household reliance on wetlands as a food source.

The impact of pollution from the growing aquaculture industry is the chief concern in Dong Rui. Following settlement in 1979, local authorities set land aside for the community to construct boundary fields to make the capture of aquatic food more effective. However, this interfered with natural water flows and the animals trapped within the boundaries started to die at an increased rate, the decomposition of which also caused neighbouring mangroves to perish. When the boundary gates were opened, accumulated effluent was released and contaminated the nearby area. Despite this, and subsequent to economic reforms, vast swathes of wetland were sold to outside aquaculture investors, and the same processes that had occurred

during the construction of boundary fields were again observed. The sheer scale of wetlands being converted, and the additional impact of chemical waste from commercial aquaculture, meant the whole area was damaged, and nearly all the surrounding mangroves were destroyed. Investors were quick to abandon the now unproductive aquaculture fields, leaving the community with a heavily degraded area that they depend on for their livelihoods.

4.2 Contemporary livelihood strategies

In the context of the above dynamics and livelihood challenges, and considering divergent historical and cultural perspectives, each community exhibits a distinct set of livelihood strategies and corresponding activities. The current success of the aquaculture industry in Giao Xuan has resulted in rapidly increasing incomes, represented by significantly higher average annual income per capita than Da Loc and Dong Rui (see supplementary material Table S1). In Giao Xuan, although aquaculture has significantly contributed to higher incomes, especially for aquaculture farm owners, high inequality is reflected in the range of average total household incomes. Despite comparable levels of average total household income between Da Loc and Dong Rui, the almost three times greater income range in Da Loc, suggests the growing aquaculture industry is increasingly impacting upon income inequality. Households with higher income are aquaculture farm owners and employees. In Giao Xuan, lower average numbers of livelihood activities per household than both Da Loc and Dong Rui indicates greater reliance on the aquaculture sector as an income source. In Giao Xuan and Da Loc where the aquaculture industry is prevalent, households are engaged in a lower percentage of the total available livelihood activities compared to Dong Rui.

In all three communes wetland livelihood activities contribute a significant proportion of total income (Figure 1). Conversely, even though 100% of households in each community are engaged in on-farm activities, these tend to be for household consumption and contribute only a small proportion of total income. Although a smaller proportion of households are engaged in off-farm livelihood activities in all communities, income from these activities contribute a larger proportion compared to on-farm activities. Households with more income from on-farm and off-farm activities tend to have less income from wetlands.

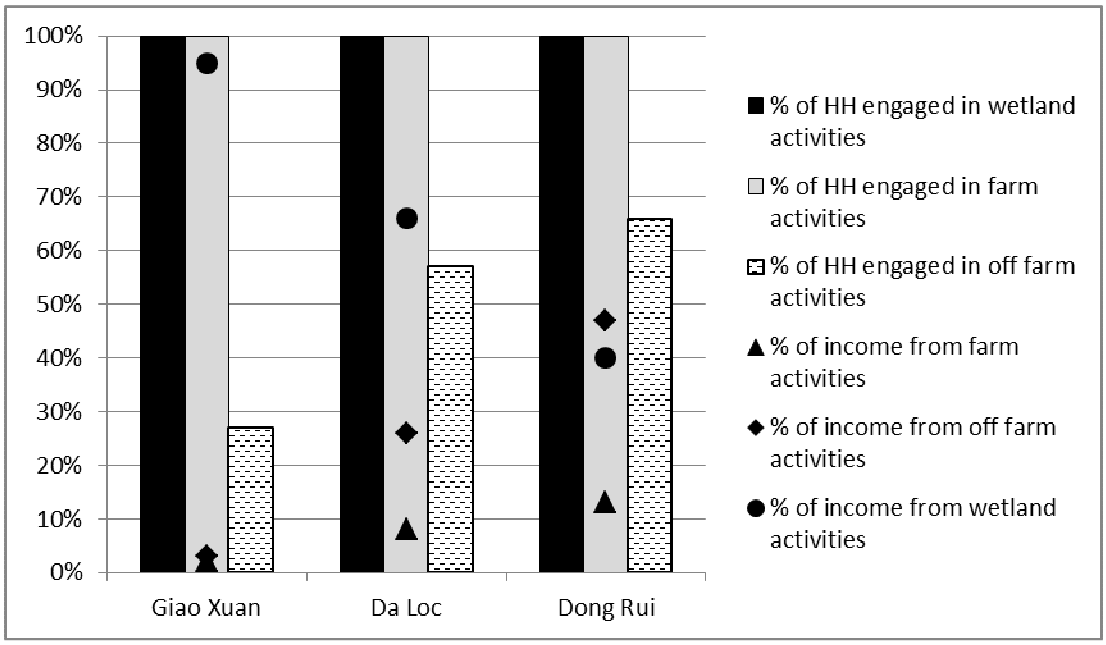

Figure 1: Community livelihood categories (wetland, on-farm, and off-farm) and percentage contribution to total income. Wetland activities comprise aquaculture farming, aquaculture employment and wild foraging. On-farm activities comprise crop cultivation (sweet potato, peanut, maize, bean, chilli, sugar cane and fruit) and livestock tending (buffalo, pig, chicken and duck). Off-farm activities include fishing, industry, service, migration and other. Sample sizes: Giao Xuan, n=79; Da Loc, n=70; Dong Rui, n=99.

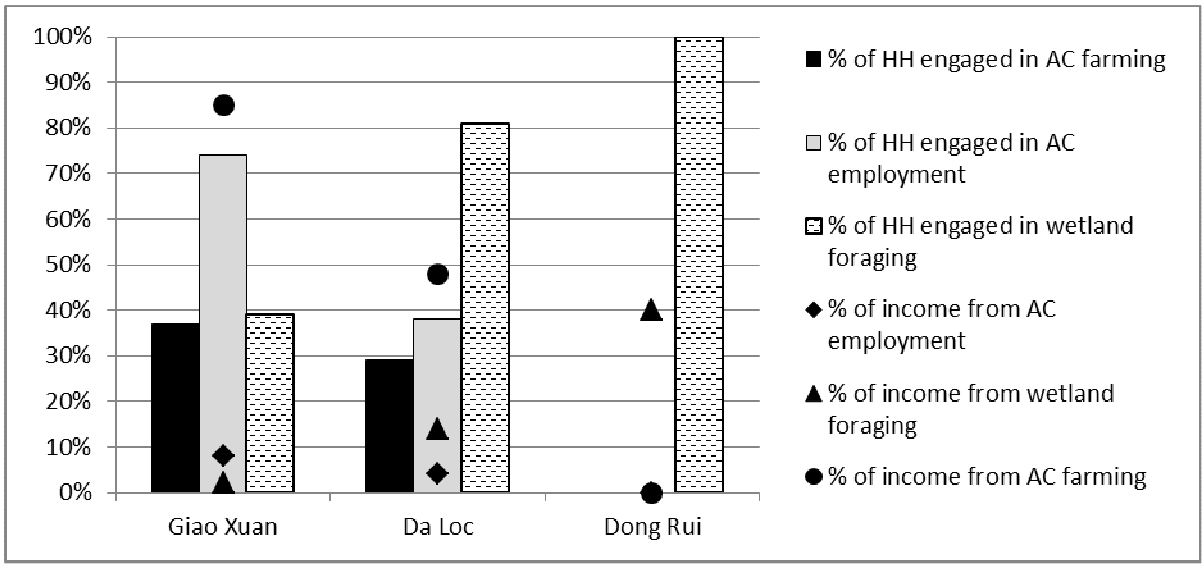

Figure 2: Breakdown of wetland livelihood activities (aquaculture farming, aquaculture employment and wild foraging) and per cent of total income. Sample sizes: Giao Xuan, n=79; Da Loc, n=70; Dong Rui, n=99. *NB: AC= aquaculture*.

Specific livelihood activities relating to wetlands in all three communities are aquaculture farming, aquaculture employment and foraging for food (Figure 2). In Giao Xuan, the percentage of households engaged in aquaculture farming (37%) represents a substantial proportion of total income for that community (85%). Although a higher percentage of households are engaged in aquaculture employment (74%), the proportion of income gained through this activity is low (8%). Even though 39% of households are engaged in wetland foraging, it constitutes only 2% of total income. The unequal distribution of income in Giao Xuan is further apparent because of the 95% of total income generated through wetland activities only 7% comes from aquaculture employment and foraging.

In Da Loc, even though aquaculture farming is in its infancy, a notable portion of households are engaged in it (29%) and it represents a large portion of income (48%). As in Giao Xuan, a high proportion of households engaged in aquaculture employment (38%) represent a low proportion of total income (4%). Furthermore, over twice as many households are engaged in wetland foraging (81%), but represent over three times the proportion of income (14%) as generated through aquaculture employment. The growing inequity of incomes described by respondents in Da Loc is apparent when considering that of the 66% of total income generated through wetland activities, only 18% comes from aquaculture employment and foraging. However, a larger number of households are engaged in non-wetland related livelihood activities than is observed in Giao Xuan (Figure 2). In Dong Rui, which experienced aquaculture industry collapse, no households engage in aquaculture farming or employment, and 100% engage in wetland foraging, representing 40% of total income.

These results indicate that when the aquaculture industry is strong: income tends to be unequally distributed and concentrated among the aquaculture farmers; average household livelihood diversification is lower; and marginalised households with less power remain dependent on wetland foraging as a livelihood activity.

A significantly lower number of households were engaged in foraging in Giao Xuan, where aquaculture is well established, compared to Da Loc and Dong Rui ($\chi2=89.4$, $p=0.000$, $phi=0.6$). However, within Giao Xuan, households with lower income ($\chi2=14.1$, $p=0.001$, $phi=0.42$), female heads ($\chi2=7.4$, $p=0.007$, $phi=0.3$), and fewer land rights ($\chi2=21.4$, $p=0.000$, $phi=0.52$) were significantly more likely to forage. Households with high livelihood diversity were also significantly more likely to forage in wetland areas ($\chi2=24.9$, $p=0.000$, $phi=0.56$). There was no significant association between wetland foraging and income, gender, land rights or livelihood diversity in Da Loc, and all households in Dong Rui are engaged in wetland foraging.

4.3 Characteristics of households most dependent on wetland foraging

In each commune, a set of characteristics have been identified for those households most dependent on mangroves for their livelihoods (Tables 1a, 1b and 1c; Table S2 shows the breakdown of variable groups). Female headed households were more dependent on mangrove resources in all three communes. In Giao Xuan and Da Loc, where commercial aquaculture prevails, households with few land rights were more dependent on mangroves than those with stronger rights. Where commercial aquaculture is in its infancy or collapsed, as in Da Loc and Dong Rui respectively, households with low education levels were more dependent on mangroves than those with higher education levels. In Giao Xuan, there was more dependence on mangroves among households with high livelihood diversity, while in Dong Rui, higher dependency was found among households with low livelihood diversity. As low income households were found to be more dependent in both these communes, this indicates that low income households in Giao Xuan are using mangroves to diversify their livelihoods, while low income households in Dong Rui are not. This could be because Dong Rui does not have an aquaculture industry, and hence aquaculture employment, as a livelihood option.

4.4 Ecosystem services provided by mangroves

All three communities benefit from ecosystem services, distinguished here using the MA (2005) categorisations (Table S3). Cultural services were consistently ranked lowest across all three communities, although Dong Rui respondents identified aesthetic qualities and heightened sense of well-being as important benefits. Supporting services were the next most identified service across all communities, particularly soil retention, nutrient cycling, oxygen production and habitat provision. Provisioning and regulating services were the most identified services among all communities, representing more direct benefits. However, perceptions differed between communes regarding these. In Giao Xuan provisioning services were identified more frequently by the highest number of households, with regulating services largely corresponding to the storm protection benefits of mangroves. In Da Loc, regulating services were identified more frequently and by more households. This could be due to recent experiences of extensive storm damage and saline intrusion, with the resulting damage to arable farm land still fresh in respondents' memories. In Dong Rui a higher percentage of statements were made regarding regulating services, although several households identified provisioning services. In Dong Rui, because there has been no protective community dike, respondents highlighted that moderately intense storms can have severe negative impacts on their crops, and mangroves are seen as crucial for storm protection. With soil quality already poor, saline intrusion resulting from storms is a significant community concern.

Table 1(a): Characteristics of households in Giao Xuan most dependent on mangroves for income.

	Giao Xuan				
	Test statistic	**Degrees of freedom**	**Sig.**	**z score**	**Post-hoc r score**
Age	10.961 Ω	4	0.027**	-3.219	0.001
Gender	352 β	-	0.006***	-3.00	0.3
Education	-	-	-	-	-
Years lived in commune	-	-	-	-	-
HH members	-	-	-	-	-
Livelihood diversity	13.344 Ω	2	0.001***	-3.454	0.001
Income	5.935 Ω	2	0.05**	-2.426	0.015
Land user rights	15.416 Ω	2	0.000***	-3.603	0.000

Table 1(b): Characteristics of households in Da Loc most dependent on mangroves for their income

	Da Loc				
	Test statistic	**Degrees of freedom**	**Sig.**	**z score**	**Post-hoc r score**
Age	-	-	-	-	-
Gender	442.5 β	-	0.087*	-1.710	-0.2
Education	375 β	-	0.026**	-2.221	-0.3
Years lived in commune	5.489 Ω	2	0.064*	-2.228	0.026
HH members	-	-	-	-	-
Livelihood diversity	-	-	-	-	-
Income	-	-	-	-	-
Land user rights	10.459 Ω	2	0.005***	-3.122	0.002

Table 1(c): Characteristics of households in Dong Rui most dependent on mangroves for their income

	Dong Rui				
	Test statistic	Degrees of freedom	Sig.	z score	Post-hoc r score
Age	-	-	-	-	-
Gender	685 β	-	0.005***	-2.786	0.3
Education	18.642 Ω	4	0.001***	-2.656	0.008
Years lived in commune	13.409 Ω	2	0.001***	-3.430	0.001
HH members	7.698 Ω	2	0.021**	-2.101	0.036
Livelihood diversity	24.459 Ω	2	0.000***	-2.656	0.008
Income	11.649 Ω	2	0.003***	-3.475	0.001
Land user rights	-	-	-	-	-

* p = 0.05 to 0.1, **p = 0.049 to 0.011, ***p = 0.01 to 0

β = Mann-Whitney test

Ω = Kruskal-Wallis test

The ecosystem services obtained from mangrove systems differ in each community due to specific biophysical and geographic characteristics (Table 2). Focus groups revealed that households use diverse strategies to respond to income shocks, such as increasing foraging for goods to sell, drawing on savings, bank loans, social and kinship networks, and selling assets and labour. Foraging for mangrove goods to sell was the most important insurance against economic shocks because it meant less reliance on others, as the extended family are usually poor so cannot offer support, and no repayments are incurred. Interviews indicated that in all three communes, households with higher dependence on mangroves rely on

mangrove provisioning goods to sell in order to cope with shocks and stresses such as crop failures, celebrations, the start of the new school year, and seasonal fluctuations in the weather. Interviews and focus groups in Giao Xuan also revealed that during August and September when mangrove provisioning goods are at their lowest, mangrove dependent households find it most difficult to meet their subsistence needs. In addition, interviews indicated that although prices offered to foragers for mangrove goods were relatively stable, this was due to wholesalers giving consistently low prices in order maximise their profits.

Table 2. Species, and estimated effort, weight and price of provisional services from mangroves

Giao Xuan				
Catch	**Season (height)**	**Est. effort (hrs)**	**Est. weight (kg)**	**Est. $/kg**
Fish	All year (March - July)	5 – 6	5 – 10	1 – 1.5
Crab	All year (March – July)	5 – 6	3 - 4	1.5
Clam	All year	5 – 6	2 - 10	1 – 3.5
Shrimp	All year (March – July)	5 – 6	5 – 30	3 – 5
Da Loc				
Fish	All year (February – April)	5 – 6	3	5
Crab	All year (January – August)	5 – 6	4 – 5	1
Clam	All year (February – May)	4 – 6	6 – 7	0.5
Dong Rui				
Fish	All year (April – June)	8	10	1 – 5
Crab	All year (March - August)	3	6 – 8	1 – 1.5
Clam	All year (May – September)	6	5 – 7	3 – 4
Worm	All year (September – February)	8	2 – 4	2 – 3
Octopus	All year (June – August)	6	0.5 – 1	20 – 50
Shrimp	All year (September – December)	6	4 – 6	5
Jellyfish	All year (February – March)	6	-	5 – 10.5

4.5 Livelihood trajectory analysis

Five trajectories were selected as representative of the wider community's experiences, encompassing all wealth groups (Table 3), from which some generic trends were observed. Resilience was increased by access to mangrove system provisions during collectivised farming and/or chronic or transitory periods of low income; economic liberalisation facilitating access and diversity of employment, markets, knowledge, networks and capital; family and social support networks; the ability to exploit changes in wetland allocation; access to bank loans; and the young and healthy able to acquire land, gain employment or forage for ecosystem provisions. Vulnerability was increased by environmental degradation; loss of access to common resources, especially for female headed households; low incomes and susceptibility to poverty (through lack of social or state support, loss of labour from sickness or death, asset selling and/or debt accumulation); and discrimination.

Table 3. Livelihood trajectories of households most reflective of the impact of social-ecological dynamics.

Case study household	Factors leading to resilience (R) and vulnerability (V)
Case 1 – Male, age 54, Giao Xuan Before economic reform there was no market for wetland products, so he and others in the community collected a range of naturally occurring produce for household needs. Following economic reforms in 1989 he was employed on a trading boat, which took him to China where he first became aware of the lucrative clam market. He invited a specialist from China to Giao Xuan to teach him clam harvesting techniques and help him establish a clam farm for export to China. Subsequent to the success of this, other locals were attracted to the wetlands to capture clams as a commodity, and began to assert claims over sections of land. By 1991, overexploitation resulted in the complete collapse of the native clam population. In 1992, however, he was able to draw on accumulated capital and trading links with neighbouring provinces to import clam seed varieties to cultivate before selling on to China. This was highly successful and the market peaked in 1995. By 1997, however, the imported clams began to die due to incompatibility with local environmental conditions. Many clam fields were abandoned and became available for him to buy as a result. Undeterred, in 1999 he decided to search further afield, to provinces in the south of Vietnam, to find clam species more suited to local conditions. He combined the import of new clam species with new sand varieties to accommodate them. Although there was initial scepticism due to past failures, the enterprise was a success and markets developed both domestically and internationally. Furthermore, due to the stabilising effect on the environment from mangrove restoration efforts, he no longer needs to import clam seeds from the south. Clam farming is now the major industry in Giao Xuan, which is now one of the biggest producers in Vietnam. Although the industry is more stable now, he still has to make periodic alterations to his fields in order to maintain productivity. He is aware that importing clam and sand varieties is unsustainable, and is trying to reintroduce native species.	**R1. Access to natural resources** **R2. Salaried employment** **R3. Access to markets** **R4. Access to knowledge** **V1. Loss of natural capital** **R5. Draws on financial capital** **R6. Access to social networks** **V2. Loss of productive capacity** **R7. Accumulates land** **R8. Draws on financial capital** **R9. Rise in demand for aquaculture products** **R10. Regulating ecosystem service** **V3. Uncertainty due to suppression of ecosystem functions and processes**
Case 2 – Female, age 51, Giao Xuan She has lived in Giao Xuan all her life, where she lives with her 21 year old son. When she was young her family were poor and life was difficult, often there would not be enough food to eat and they would have to rely more heavily on the wetland for subsistence. There was no state support at the time, so when her family found themselves in hardship they would have to ask for loans from rich households which they had to pay back with interest. Following the birth of her son, she lost her husband and had to rely on her husband's family to support her and her new born baby. When the aquaculture sector began, she could not get access to any land for farming because she was not strong enough to claim land, and she was not rich enough to buy any. Even if she had the money, because she is a woman she cannot own land. When the aquaculture sector expanded she was young and healthy and able to find employment through family contacts. She established a reputation for being a good worker and was respected by her work colleagues, and so aquaculture owners began to ask her to manage work teams on their behalf. She has been able to develop such a wide network of contacts within the industry that she can even find employment in neighbouring districts. Her son is now old enough to contribute to household income, and he is also employed on aquaculture farms. However, aquaculture does not provide stable employment, particularly during the winter, so she still has	**V1. Lack of subsistence** **V2. Lack of financial capital** **V3. Lack of state support** **R1. Access to ecosystem provisions** **V4. Debt accumulation** **V5. Loss of labour** **R2. Family support network** **V6. Lack of access to land** **R3. Salaried employment** **R4. Applied human capital** **R5. Extended social networks** **R6. Gain in human capital** **V7. Unstable income**

to forage in the wetland to supplement her income. In recent years the rains have been less predictable and this has affected her rice crop, so she has to depend heavily on wetland foraging when this happens. She cannot make as much money from this as she did in the past, as there is less space to forage and fewer animals available to harvest, even though there are lots more animals in the aquaculture fields. She believes that aquaculture is eradicating the natural species, and is worried that eventually there will be no animals in the wetland to collect.	**R7. Provisional ecosystem service** **V8. Climatic impact on crops** **V9. Loss of access to ecosystem services** **V10. Altering ecosystem causes increased livelihood uncertainty**
Case 3 – Female, age 46, Giao Xuan When she was young she would collect products from the wetland area with her family for household consumption. When the wetland area her family had traditionally collected from was divided up and turned into aquaculture fields, her husband joined a collective that pooled all their savings together to buy a field. Combined with the income she received from labouring on aquaculture fields, they earned enough income for food and to send their son to school. When her husband became terminally ill he could no longer work, and she had to work fewer hours to tend to him. They received no state support, and with hospital bills mounting were forced to sell everything they owned and move into a smaller house next to the dike. The land near the dike is low quality and not suitable for growing crops, and household assets, such as livestock, are often stolen by groups of thieves that target vulnerable households. The community that lives near the dike, made up largely of elderly, disabled and (often illegal) migrant households, are supportive and pool their resources together in order to help each other. In addition, due to the growing aquaculture industry she has been able to receive loans from rich owners (usually with interest payable). Although she feels that the rich owners look down on the dike community, they will still employ them to work on their fields, but she still relies heavily on the public wetland space to forage for food for subsistence. This space, however, has vastly reduced and she must travel through the aquaculture fields to get there, and although she can make extra income from collecting the litter thrown from the watchtowers, she must be careful not to stray too close to the fields otherwise the owners will attack her. In addition, because people can make money from foraging now, they will commit more time and effort which means there are less animals to catch. Although she is aware of some livelihood opportunities available through various NGO projects, she is unable to get to the Women's Union meetings where opportunities are distributed, and she believes that she does not have the adequate level of skills and knowledge required to participate in the projects. Not only that, but these opportunities are usually shared among the families of Union leaders.	**R1. Access to ecosystem services** **V1. Loss of access to ecosystem services** **R2. Diversification of income** **V2. Loss of human capital** **V3. Loss of income** **V4. Accumulation of debt** **V5. Selling of assets** **V6. Low quality land for arable crops** **V7. Target of crime** **R3. Social support networks** **R4. Access to loans** **V8. Discrimination** **R5. Ecosystem service** **V9. Loss of access to land** **V10. Overexploitation of resources** **V11. Lack of access to village meetings** **V12. Lack of awareness** **V13. Elite capture**
Case 4 – Male, age 37, Dong Rui In 1979 he moved to Dog Rui from Hai Phong city as part of the resettlement programme. Life was difficult in the city with little work, and resettlement offered a house with land to cultivate, and 6 months' worth of rice from the state to help with the transition. The abundance of natural resources meant that food was easy to obtain and life was good. In 1986, encouraged by the local People's Committee, he took out a substantial loan to invest in a wetland boundary pond to allow more effective capture of marine creatures. This was very productive for the first 2-3 years, but then productivity sharply declined due to the impact the ponds had on the natural flow of water and the environment. Many residents raised this as an issue at village meetings at the time but their concerns were not acted upon by the authorities. As the bank loan repayments were mounting, he took out further loans in the hope that the pond would become productive again. This did not happen and eventually he gave up on the pond. For a while he could still make a living foraging in the vast wetland area, but when huge areas started to be sold to investors from other provinces this reduced the area open to the public. Furthermore, he	**R1. Access to ecosystem services** **R2. Access to loans** **V1. Loss of ecosystem function and process** **V2. Accumulating debt** **V3. Loss of income** **R3. Access to ecosystem service** **V4. Loss of access to ecosystem service** **V5. Onset of poverty** **V6. Vulnerable target of human trafficking syndicates** **V7. Negative climatic impact on crops**

claims that pollution from the aquaculture fields destroyed the whole surrounding area, which drove him to destitution. He was the victim of unscrupulous human traffickers to whom he paid money, provided to him by his wife's family in Hai Phong, on the understanding that he would gain well paid employment in China. On arrival the hours were long, conditions terrible and the pay was very low, so he fled back to Dong Rui, putting his life in danger and swimming across dangerous waters in order to cross the border from China to Vietnam. Additionally, his rice, peanut and sweet potato crops have been impacted by rapidly changing and unpredictable weather in recent years, with the winters becoming colder and the summer hotter. The irrigation system is inadequate and the quality of local soil is sandy, salty and of poor quality, and this restricts the options for changing crops, planting times, and varieties. If people do not get enough rice they go hungry, but he is lucky that he is still strong and can sell labour to a nearby paper factory and use his earnings to buy rice.	**V8. Poor infrastructure** **V9. Poor quality** **V10. Lack of diverse cropping options** **R4. Human capital**
Case 5 – Female, age 33, Dong Rui She is from the Dao ethnic minority, originally from the mountainous region of the province, and has lived in Dong Rui for 12 years since they were resettled here by the government. The Dao community were promised a better life at Dong Rui, but since arriving she has wanted to return to her home. The district authorities, however, have already converted the land they left for another purpose so she cannot return. She arrived with a small number of other Dao families, but as they did not speak Vietnamese, were not familiar with the environment and because they have different customs, beliefs and traditions to the ethnic 'kinh' Vietnamese, they struggled to integrate into the local community. They soon became isolated and were pushed into the area with lower quality land where it is difficult to grow crops. Almost all of her income comes from foraging in the wetland area, and this has been so since she and her family arrived, but she is given a lower price than the ethnic 'kinh'. Some Dao go to the wetlands in groups and have developed effective techniques for catching animals, but she is not involved in any of these groups. They have become rich but she remains poor. She has to pay community fees but she is unsure exactly what this is for as she is very poor but receives no state support.	**V1. Loss previous support mechanisms** **V2. Communication difficulties** **V3. Alienation from wider community** **V4. Lack of income diversity** **V5. Discrimination** **V6. Lack of skills** **V7. Lack of state support**

5. Discussion

5.1 Key aspects of social-ecological dynamics

Shocks and stresses emanating from the interaction of political, socio-economic and environmental aspects had significant and widespread impacts on the mangrove social-ecological systems studied here. Consistent with Gunderson and Holling (2002), feedbacks exacerbated negative impacts (e.g. biodiversity loss, water cycle disruption) leading to reduced provisioning services and impinging on rural coastal livelihoods. Changing tenure regimes towards privatisation further marginalised powerless groups, concurring with To et al. (2012) in Vietnam and Meinzen-Dick and Mwangi (2009) in Kenya, where formalisation of tenure rights led to elite capture. Furthermore, as reported in Nepal by Iversen et al. (2006), weak policy frameworks combined with increasing prices for wetlands and their resources created opportunities for elites to capture benefits through the lease of wetlands to external investors for commercial interest, consistent with results presented here. Formalisation of private tenure rights neglected the distinct multiple claims of poor, female, young headed households and the sick: groups least able to defend their

livelihoods or establish legal tenure rights (cf. Kelly and Adger 2000; Meinzen-Dick and Mwangi 2009). Formalising tenure arrangements will only bring livelihood benefits if careful consideration of the poor is made, which findings indicate rarely happens.

Inequality resulting from changing tenure regimes can be further exacerbated by economic reform. Results show that market incentives have prompted local governments to explicitly encourage aquaculture and the clearing of mangrove forests, placing greater pressure on wetlands (cf. Van Hue and Scott, 2008). Exploiting the opportunities generated through aquaculture requires market access, secure tenure over the resource base, sufficient labour and capital to invest, the capacity to wait for investments to mature, and sufficient entrepreneurial skills; abilities that the marginalised do not possess (cf. Sunderlin et al. 2005). Results are consistent with research which indicates that since far reaching economic reform, Vietnam has witnessed increasing socioeconomic disparities among regions and within localities (Luong 2003). Supporting findings from Indonesia (Dove 1993), the benefits of economic reform have been appropriated by wealthy, powerful and well-connected individuals. Additionally, market incentives have resulted in some households placing increasing pressure on reduced public wetland areas. The resulting intensification of competition and degradation of mangrove resources has disproportionately affected poorer households who have a greater dependence on mangroves for their livelihoods, as opposed to those interested in private commercial activity to supplement their incomes (cf. Van Hue and Scott 2008; Kelly and Adger 2000). As economic reforms have created markets for wetland goods, there remains a need to support the livelihoods of the poorest.

Together, changing land tenure, economic reform and elite capture can result in land use intensification and specialisation in production of wetland resources, severely undermining ecosystem functions and processes. Consistent with studies from Amazonia (Homma 1992), results show that sudden wetland commercialisation can contribute significantly to the collapse of the naturally regenerating resource base, and it is the least powerful households whose livelihoods depend highly on mangrove resources that suffer disproportionately (cf. Kelly and Adger 2000; Meinzen-Dick and Mwangi 2009). Results indicate that the quantity and quality of mangrove goods has declined as a result of rapid coastal development, particularly of the aquaculture industry. Recognising the full impact of tenure change, economic reform and elite capture on social-ecological dynamics is vital in order to support local livelihoods and to maintain social-ecological integrity.

5.2 Livelihood strategies

Economic reform, private tenure regimes and a rapidly growing aquaculture sector have led to divergent livelihood strategies being undertaken across all three communities. Consistent with Cinner and Bodin (2010) in east Africa, although aquaculture increases community livelihood opportunities through aquaculture farming and employment, aggregate household data indicates that households become more specialised. Households in all three communities were engaged in wetland related and on-farm livelihood activities to differing degrees. However, when the aquaculture sector is strong, it results in unequal income distributions, concentrated among successful farm owners, and off-farm strategies are less

prevalent, contributing less to total income. This leads to further pressure on mangrove resources by aquaculture and market incentives for public wetland goods, negatively impacting the livelihoods of those community members who remain highly dependent on the greatly reduced and more intensely exploited wetland area for foraging. Aquaculture's impact on household livelihood diversification should be recognised if livelihood benefits are to be realised.

5.3 Household characteristics

Communities are heterogeneous with households exhibiting a diverse range of needs. Female headed households are most dependent on mangroves, and are the poorest with the least land use rights. In Malawi, Kamanga et al. (2009) found that female headed households with little access to land derived a high proportion of their income from forest goods, in line with results presented here. Results also support findings from Vietnam (Van Hue 2006) and Ethiopia (Asfaw and Satterfield 2010) here entrenched customary norms and patriarchal cultures constrain women's access to land, resulting in female headed households depending more on foraged natural resources. Consistent with results from Kenya (Meinzen-Dick and Mwangi, 2009), younger headed households are also more dependent on mangrove resources: they are usually too young to have acquired wetland when it was reallocated, do not have the capital to buy or rent land and pay the necessary tax, and so resort to foraging in public areas. Support must be targeted towards these groups with the least power.

Non-farm livelihood opportunities and education significantly impact household dependency upon mangrove resources. In contrast to aggregate household livelihood diversification findings illustrated above, when individual households were analysed in communities where aquaculture is strong, households with greater dependence on mangroves have more diverse livelihoods. While households earning high incomes from aquaculture have less incentive to diversify, low income households diversify to reduce risk from external shocks and stresses (cf. Smucker and Wisner 2008). Conversely, when there is no aquaculture sector (e.g. Dong Rui), those households able to access a diverse range of livelihood activities, particularly off-farm activities, have less dependence on mangroves. Hence, less pressure is placed on mangroves when greater off-farm livelihood activities are available and utilised. Where the aquaculture sector has collapsed or is in its infancy (e.g. Dong Rui and Da Loc), less well educated households have greater dependence on mangroves due to limited access to alternative livelihood activities. Where aquaculture is successful, as observed in Giao Xuan, education is not significant, suggesting that power, wealth and social connections are more important for gaining a higher distribution of the benefits emanating from mangrove regulating and supporting services. Equitable access to education and off-farm livelihood activities should be encouraged to diversify livelihoods and support the mangrove social-ecological system.

5.4 Ecosystem services

Households use a small but diverse range of strategies to cope with shocks, stresses and seasonality (cf: Turner et al. 2003). Sale of mangrove products is the most important for marginalised households. Consistent with findings in Zambia (Kalaba et

al. 2013), the sale of forest products was more important than support from kinship ties due to a lack of economic prosperity among kinship networks. Foraging does not require any capital outlay. Results support others from Vietnam (Tran et al. 2010) where household perceptions of mangrove goods and services are influenced by factors including past experiences of extreme weather events and environmental conditions affecting their impact. It is crucial to integrate ecosystem services into mangrove management, and to consider the impact changes in mangroves have on household coping strategies and perceptions of mangroves (Trabucchi et al., 2012).

5.5 Livelihood trajectories

In all three communes, generic factors increased the likelihood of a livelihood trajectory increasing in resilience or vulnerability during 1975-2012. Uncovering how these factors have contributed to current livelihood strategies is crucial to understand how social-ecological dynamics have affected livelihood outcomes (Trabucchi et al. 2012; Sallu et al. 2010; Bandyopadhyay et al. 2011). Failure to do so will mean households face an increasing vulnerability context that will compromise the integrity of the social-ecological system upon which many households rely.

6. Conclusion

This paper has explored the impact of human activity on ecosystem services provided by mangrove systems in Vietnam, drawing on concepts of livelihood vulnerability and resilience. A mixed method approach examined the social-ecological dynamics in each commune and categorised households based on mangrove dependency and the emergence of vulnerability and/or resilience. This illustrated the high dependence on mangrove resources of the least powerful households, demonstrating the vulnerability of these households to mangrove system changes. Changes in land tenure, economic reform and elite capture were key issues, particularly in relation to a rapidly growing aquaculture industry, changing vulnerability context and overall direction of livelihood trajectories. The outcome of the combined impact of these key issues is that the least powerful become further marginalised and ecosystem functions and processes become undermined, further impacting livelihood options. In the context of increasing environmental change, key challenges in maintaining the social-ecological system include: ensuring the maintenance of ecosystem functions and processes underpinning local livelihoods; ensuring equitable distribution of ecosystem goods and services to encourage their sustainable use; and increasing diversification of income opportunities to reduce pressure on mangrove resources. It is imperative that local people are involved and ecosystem services are integrated into mangrove management, as conventional regimes exclude the least powerful, with negative impacts on local livelihoods and mangrove social-ecological system integrity.

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Supplementary information

Table S1. Community income and livelihood diversification

	Giao Xuan	Da Loc	Dong Rui
Average total household (HH) annual income ($)	18,618	4,116	3,442
Average total HH annual income range ($)	743-714,286	157-50,000	400-16,571
Average number of livelihood activities per HH	3.28	4.91	4.33
Total number of livelihood activities available	10	10	8
% of HH livelihood activities undertaken to those available	33	49	54

Table S2: Breakdown of groups in independent variables tested

	Giao Xuan	Da Loc	Dong Rui
Age (years)	20-29 (n=8) 30-39 (n=15) 40-49 (n=28) 50-59 (n=23) 60+ (n=5)	20-29 (n=8) 30-39 (n=15) 40-49 (n=28) 50-59 (n=23) 60+ (n=5)	20-29 (n=8) 30-39 (n=15) 40-49 (n=28) 50-59 (n=23) 60+ (n=5)
Gender	Male (n=61) Female (n=18)	Male (n=43) Female (n=27)	Male (n=68) Female (n=31)
Education		Low: secondary or lower (n=42) High: tertiary or higher (n=26)	None (n=8) Primary (n=23) Secondary (n=50) Tertiary (n=13 University (n=5)
Years in commune (years)		Low: <25 (n21) Middle: >25 - <39 (n=21) High: >39 (n=21)	Low: <14 (n=25) Middle: >14 - <31 (n=24) High: >31 (n=50)
HH members			Low: <4 (n=70) Medium: 5-6 (n=25) High: >6 (n=4)
Livelihood diversity	Low: <2 activities (n=15) Med: 3 activities (n=31) High: >3 activities (n=33)		Low: <3 activities (n=5) Med: 3-4 activities (n=47) High: >4 activities (n=47)
Income ($per capita)	Low: 0-730 (n=17) Middle: >730-<1,330 (n=28) High: >1,330		Low: 0-572 (n=32) Middle: 573-1,156 (n=34) High: >1,156 (n=33)
Land user rights	Low: forage only (n=50) Med: emp/CAC* (n=10) High: ACO (n=19)	Low: forage only (n=23) Med: emp/CAC* (n=38) High: ACO (n=6)	
Project awareness	None (n=27) Little: aware of one project (n=32)		Low: aware of one project or less (n=79)

	High: aware of more than one project (n=20)	High: aware of more than one project (n=20)

*emp/CAC = employed on aquaculture filed or communal ownership of aquaculture field

Table S3: Categories of ecosystem services from mangroves identified by households

	Giao Xuan	Da Loc	Dong Rui
Supporting	23 (5)	21 (4)	17 (6)
Provisioning	42 (9)	34 (8)	32 (9)
Regulating	30 (6)	45 (9)	37 (8)
Cultural	5 (1)	0 (0)	14 (5)

***NB**: numbers represent per cent of total statements made referring to that category, while numbers in brackets refer to number of households that identified that category*