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Title: Evaluating impacts of fish stock enhancement and biodiversity conservation actions on the livelihoods of small-scale fishers on the Beijiang River, China.

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Abstract

Inappropriate development and overexploitation have seriously degraded aquatic resources in China. Stakeholders identified three fish stock enhancement and biodiversity conservation scenarios for the Beijiang River: S1, increased fish restocking; S2, no fishing season and habitat conservation; S3, strict pollution control. Potential impacts of these actions on the livelihoods of fishers were evaluated using applied economic modeling. Baseline costs and benefits came from logbooks from 30 fishers and a survey of 90 households in three villages. The financial net benefit for a household was US$1583 (￥11,160) annually, representing a 142% and 387% return on capital and operating costs, respectively. Larger catches associated with S1 and S2 generated a net benefit of US$1651 and US$1822, respectively. Strict pollution control resulting in higher catches (+20%) and lower operating costs (-20%) would increase the net benefit by 15.9% to US$1835 annually. Pollution control would benefit other resource users and is a pre-requisite for ecological restoration.

Recommendations for Resource Managers

- Stringent pollution control measures are essential to conserve aquatic biodiversity and enhance the livelihoods of fishers but will require considerable public and private sector investment.
- Enhanced fish stocks in the Beijiang River could benefit poor livelihoods but may not be sufficient to lift households out of poverty, aged fishers require government assistance to diversify their livelihoods, access alternative urban employment and survive with dignity.
- Adopting the economic modeling approach presented here could enable responsible authorities to simultaneously evaluate fish stock enhancement and biodiversity conservation options.
- Broader application of the approach presented here could help ensure small-scale inland fisheries are managed sustainably and aquatic ecosystems are restored and protected by 2020, in line with Target 6 of the United Nations' Convention on Biological Diversity Strategic Plan for Biodiversity.

Keywords: applied economic modeling; cost-benefit analysis; culture-based fisheries; natural resources management; Shaoguan City, Guangdong Province, China

1. Introduction

Population growth and economic development throughout China have been powerful driving forces that have exerted immense pressure on aquatic resources. Major problems include land-use change for agriculture and forestry expansion, agrarian reform and agricultural intensification, residential and industrial development and large-scale interventions in hydrological regimes to impound and divert water for irrigation and hydroelectric power generation (Orderud et al., 2015). Resulting impacts include diffuse and point source pollution throughout river catchments, flow regime disruption, destruction of aquatic habitats and loss of habitat connectivity. Highland aquatic resources are especially vulnerable as they often harbour endemic or endangered species of global conservation concern, but are sensitive to change (Santasombat, 2011; Sterling et al., 2006).

Overexploitation of aquatic resources has been widespread in inland waters in China and has caused dramatic fish stock declines and endangered several species (Darwall and Freyhof, 2016). River sand mining to supply the construction industry has contributed further to aquatic resources degradation (Lund et al., 2014). Inappropriate development and overexploitation of aquatic resources has had serious negative impacts on biodiversity, ecosystem services and livelihoods, particularly those of poor and vulnerable groups (MEA, 2005; Chi et al., 2013; Galipeau et al., 2013; Russi et al., 2013). Given the parlous state of freshwater fish populations globally (Sala et al., 2000; Vorosmarty et al., 2010), Aichi Target 6 adopted in 2010 by parties to the United Nations' Convention on Biological Diversity under the Strategic Plan for Biodiversity is focused on sustainable management and harvest of stocks (CBD, 2016). The target specifies that: 'By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits'.

Policies, institutions and processes have been instigated to conserve aquatic ecosystems and restore freshwater fish stocks in China, notably: no fishing seasons, stock enhancement, establishing conservation zones for aquatic species, government regulations to control overfishing and pollution and reallocation of fishers to non-fishing work (Li et al., 2013). Such measures often focus on addressing biological and ecological impacts resulting from non-compliance with regulations (Peterson and Stead, 2011). Impacts of these policies and conservation measures for aquatic resources on the livelihoods of local people, particularly the costs and benefits to fishing households in highland areas have not been evaluated.

The aim of this paper is to use applied economic modeling to evaluate the probable impacts of fish stock enhancement and pollution control on fish catches and livelihoods and highlight opportunities to enhance fish stock recovery plans and actions. Economic modeling has been applied widely in fisheries management science to: estimate the result of changes in fishing effort (Chae and Pascoe, 2005; Thogersen et al., 2012); assess the performance of fishing regulation and its effects on fisheries (Johnston et al., 2010; Edwards et al., 2011; Marchal et al., 2011; Holland and Herrera, 2012); analyse the economic effects of marine protected areas (Merino et al., 2009); evaluate the potential performance of stock enhancement programmes (Ye et al., 2005). Application of economic modeling to evaluate impacts of restocking and conservation measures on small-scale fishers on inland waters constitutes a notable innovation, with potential to contribute to achieving Aichi Target 6 by 2020.

2. Materials and methods

Interactive stakeholder participation in joint assessment and decision-making is regarded as a prerequisite for the sustainable management of natural resources (Pretty, 2003). The needs of diverse groups of people, disaggregated by wealth, gender and age must be accounted for to ensure outcomes are comprehensive and equitable (Punch and Sugden, 2011). All stakeholder groups should be engaged in planning conservation and fisheries management activities to demonstrate the process is transparent and accountable and ensure that actions are compatible and feasible (Fabinyi, 2010; Peterson and Stead, 2011). Consequently, the HighARCS project was implemented at five sites in Asia to assess whether an integrated action planning approach could facilitate full and equitable participation and reconcile biodiversity conservation with the wise use of highland aquatic resources (Bunting et al., 2016). The project formulated an eight phase multi-stakeholder planning process founded on full and equitable stakeholder representation in an extended process of joint problem identification, analysis and integrated action planning. Details of the planning process and outcomes are presented in the online WRAP toolkit (Bunting et al., 2013). The Integrated Action Plan (IAP) formulated for the Beijiang River, China through interaction with stakeholders involving focus group discussions and key informant interviews (Luo et al., 2012), included five conservation and livelihoods-oriented actions to enhance fish stocks and protect locally threatened species. Preliminary assessment showed that three scenarios (S1, S2 and S3) could potentially enhance the livelihoods of poor fishers (Table 1). To evaluate the significance of these an applied economic modeling approach was used and the following sections outline the scenarios tested, approach to sampling within fishing communities, data collection and economic model formulation.

2.1. Modeling scenarios

Proposed conservation measures and performance assumptions for the three scenarios are summarised in Table 1. Scenario S1 ‘Increased fish restocking’ is focused on boosting the existing fisheries enhancement programme. Fish restocking in Shaoguan City began in 1995, with the number of fry released increasing from 4 million to 8 million in 2012 (SCAU, 2009). Species stocked include bighead carp (*Aristichthys nobillis*), black amur bream (*Megalobrama terminalis*), common carp (*Cyprinus carpio*), crucian carp (*Carassius carassius*), grass carp (*Ctenopharyngodon idellus*), silver carp

(*Hypophthalmichthys molitrix*) and *Spinibarbus denticulatus*. Owing to limited financial support and hatchery capacity, the magnitude of restocking has been restricted in the Beijiang River. Despite this, analysis of catch records for 12 fishing boats over 4 years showed that fish restocking may have increased catches by 12-38%, equating to 120-380 kg of fish per boat in a 50 km stretch of river downstream of the release point (Luo et al., 2013). It was assumed that the scale of fish restocking and number of release points would be increased, whilst maintaining the current species combination.

Scenario S2 'No fishing season and habitat conservation' assumed that a two-month long cessation of fishing would continue and that the recovery of fish stocks would be aided by protecting and improving important fish habitats. The closed fishing season on the Beijiang River (April and May) had been operational for three years; closed seasons in China were implemented for offshore fishing grounds in 1995 and for inland fisheries on the Yangtze River in 2002. Scenario S3 'Strict pollution control' assumed that improving water quality in the river would result in higher fish stocks and catches and that fishers would save money owing to a reduction in damage and lower costs in reaching suitable fishing areas. Pollution can corrode fishing equipment (i.e. boats, nets and creels) and it was assumed that stricter pollution control would reduce operating costs by 20%, whilst catch levels would increase by 20% owing to enhanced fish stocks and growth rates. A range of performance assumptions was tested from 5% to 100%; 20% was selected as an appropriate level to illustrate the potential impact of different scenarios. A difference in fish catches of 23.8-42.7% up- and down-stream of Shaoguan City had been recorded previously and attributed to poor water quality below the city (Luo et al., 2013), hence, 20% was deemed reasonable. For both S1 and S2 it was assumed that the same fishing effort would be involved using the same equipment so that the variable costs would remain constant.

2.2. Study area and village selection

HighARCS study sites were selected using the following criteria: 'they were moderately elevated, ranging from 300-2,000 m above sea level, shared characteristics of highland environments (sloping topography, disruption prone communications, rivers affected by dam construction, deforestation and mining) and had resident communities dependent on the exploitation of aquatic resources' (Bunting et al., 2016). Consequently, the assessment in China was centred on Shaoguan City, an industrial city with 3.1 million residents, lying to the south of Nanling Mountain. The city is located on a confluence of the Beijiang River (North River), the second largest branch of the Pearl River in south China (Figure 1).

The Beijiang River is 573 km long, drains a watershed of 52,068 km^2 and has an average flow rate of 45,700 billion m^3 annually. The watershed is vegetated with subtropical evergreen forest and the region is characterised by typical highland features (SCAU, 2009). The river has been extensively dammed for hydroelectric power generation. There are nine fishing communities in Shaoguan City along the Beijiang River. Historically, aquatic resources on which the livelihoods of fishers depended were plentiful in the Beijiang River (Liu et al., 2011). With industrial and economic development, however, the stock of aquatic resources has declined owing to overfishing, pollution, hydropower station construction and sand mining (SCAU, 2009).

Three fishing communities located on different branches of the Beijiang River were selected for the study to enable comparison regarding the location of the restocking point, dams and urban centre (Figure 1). Lishi village is 15 km from Shaoguan City on the Wujiang River (depth 5-7m) flowing from the north-west. Zhoutian village is 35 km from the city on the Zhenjiang River (depth 1-2 m owing to the hydroelectric power station upstream) flowing from the north-east. Kengkou village is 31 km from the city on the main Beijiang River, formed after the Wujiang and Zhenjiang merge in Shaoguan City. Kengkou, Lishi and Zhoutian villages consisted of 50, 70 and 60 households,

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respectively, of which around 30 in each depended largely on fishing (Luo et al., 2012).

2.3. Data collection

Primary data for economic modeling were collected with logbooks kept by fishers in the three fishing communities. In each village, ten households deemed most dependent on fishing were selected to keep a daily record for one year from June 2010 to June 2011. Logbooks included daily fishing time, total harvest weight by species, quantities consumed and sold, and prices achieved, operating costs and other food items purchased. Data for capital costs for durable equipment and tools and the opportunity cost for labour were collected during household surveys conducted in April 2010 (Liu et al., 2011). Thirty fishing households selected at random were interviewed in each community, giving a total sample of 90 households. The interviews focused on livelihood activities, assets, income, household inputs and expenses, constraints to fishing, risks and socioeconomic status. Labour opportunity costs were calculated according to the average salary of former fishers who had secured work in the city.

Focus group discussions were conducted in the three fishing communities with separate groups of men, women, boys and girls to obtain an overview of qualitative information on: local fishing and marketing systems; constraints facing fishers; knowledge of conservation measures implemented locally and associated effects (Liu et al., 2011). A total of 10 focus groups involving 8-10 participants were conducted (Punch and Sugden, 2013). Key informant interviews were conducted with the leader and elderly fishers in each village and meetings convened with local fisheries officers and other selected stakeholders (e.g. policy-makers, fishery experts, government staff, representatives from sand mining companies, industrial firms, restaurants and farmers) to review local fisheries management and conflicts among different stakeholders. A total of 40 key informant interviews were completed (Luo et al., 2012). Records from 12 fishing boats that were collected by the Shaoguan Fishing Monitoring Team from

2009-2012 along the major branches of the Beijiang River were used as a further point of reference.

2.4. Applied economic modeling approach

Considering the impact of seasonality on fishing activities, it was deemed necessary to deal with catches and cash-flows on a monthly, as opposed to annual basis, to achieve a higher resolution. Costs and benefits were compiled for typical fishing households and the annual net benefit was calculated. A discounted cash-flow assessment over 10 years was used to derive two standard financial indicators, the Net Present Value (NPV) and Internal Rate of Return (IRR). At the household scale, the annual net benefit from fishing for a household was calculated using Formula 1.

[Formula 1]

$$\pi = \sum_{i,j}[((1+\alpha_{ij})H_{ij} \times p_{ij} - (1-\beta_i)VC_i - FC_i - DC_i) + DS_i]$$

where *i* and *j* represent the month of harvest and species harvested, respectively; π is the annual net benefit of a fishing household (￥ y^{-1}); H_{ij} is the harvest of species *j* in month *i* (kg m^{-1}); p_{ij} is the price of species *j* in month *i* (￥ kg^{-1}); VC_i, FC_i and DC_i represent the variable operating costs, fixed operating costs (i.e. fishing license fee), and depreciation of capital costs in month *i*, respectively (￥ m^{-1}); DS_i is the diesel subsidy from the government to fishers in month *i* (￥ m^{-1}); α_{ij} is the percentage change (expressed as a decimal) in the catch level of species *j* in month *i* based on assumptions made for a particular scenario; β_i is the percentage change (expressed as a decimal) in variable operating costs in month *i* associated with a particular scenario.

Depreciation for capital costs was calculated according to the estimated economic life of equipment and tools and the anticipated salvage value. Standard financial indicators, net benefit (￥ y^{-1}) including and excluding depreciation, rates of return (%) on capital and operating costs and payback periods (years) were calculated for annual cash-flows. An exchange rate of ￥7.05 to US$1 for 2010 was used for currency conversions (Internal Revenue Service, 2015). To evaluate medium-term financial returns the NPV of cash-flows was calculated over 10 years at discount rates of 5%, 10% and 20% as shown in Formula 2. A ten-year time horizon was used as although the full benefits of conservation action for aquatic resources will be apparent in the medium- to long-term (10-20 years), fishers would place greater emphasis on more immediate financial returns (2-5 years). A range of discount rates were used as when an intervention is likely to yield non-cash benefits to society and the economy a lower rate of return on capital employed may be acceptable (i.e. 5%) whilst investors in a purely commercial venture would expect a positive return on their investment at higher discount rates (i.e. 20%).

[Formula 2]

$$\mathrm{NPV} = \sum_{t=1}^{t=n} \frac{\pi_t}{(1+rate)^t}$$

where *t* and *n* represent the time period for assessment (one year) and number of assessment periods, respectively; π represents the annual net benefit; *rate* is the assumed discount rate (expressed as a decimal). The IRR (%) over a ten-year period was estimated using the iterative function supported by Microsoft Excel. Sensitivity analysis was conducted by testing the influence of changing input costs and market values of fish and removal of the government diesel subsidy on the ten-year IRR, as compared with the baseline.

3. Results

3.1. Financial parameters for household

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Monthly average household fish catches were highest in Kengkou and ranged from 80-120 kg per household (Figure 2). Catchers in Zhoutian and Lishi were generally lower and ranged from 50-100 kg and 40-60 kg, respectively. The highest catches in Kengkou and Zhoutian were recorded in June following the closed season for fishing. Typical catches were comprised of several species (Figure 3). Common carp accounted for 28.6% of the overall catch and this was matched by the contribution of miscellaneous species that accounted for less than 3% of the catch or were not identified individually.

On the basis of the information from logbooks and interviews, financial parameters were calculated for fishing households in each village (Table 2). The highest net benefit (excluding depreciation and the opportunity cost of labour) was ￥11,990 y^{-1} in Kengkou village. The average monthly fish catch of households was 77.5 kg in Kengkou and this was 81% and 22% higher than in Lishi and Zhoutian, respectively. Capital expenditure on diesel engines in Kengkou was significantly less than the other two villages and the associated expenditure on diesel was less than a quarter of that in Lishi and Zhoutian. The average net income (excluding depreciation and the opportunity cost of labour) was ￥11,160 y^{-1} across all three villages but this was reduced to ￥2199 y^{-1} when the opportunity cost of labour was included.

3.2. Baseline scenario

Results of the baseline assessments are presented in Table 2. Including the opportunity cost of labour, average capital costs were ￥7858 per household and variable operating costs (excluding depreciation) were ￥11,743 y^{-1}. The average fish catch was 719 kg y^{-1} and net benefit was ￥2199 y^{-1}, excluding depreciation. Rates of return on capital and operating costs were 28% and 19%, respectively; the estimated payback period was 3.6 years. The ten-year NPV at discount rates of 5% and 20% was -￥8432 and -￥10,793, respectively. The IRR was negative over ten years. Omitting the opportunity cost of labour, variable operating costs were reduced to ￥2783 y^{-1}, the net benefit excluding depreciation increased to ￥11,160 y^{-1} and rates of return on capital and operating costs were higher at 142% and 387%, respectively. The estimated payback period was 0.7 years, the ten-year NPV at discount rates of 5% and 20% was ￥60,755 and ￥26,772, respectively, and the IRR was 102% over ten years. As the purpose of this paper was to analyse the impact of conservation of aquatic resources on the livelihoods of existing fishers, it was decided to exclude the opportunity cost of labour from the assessment of prospective conservation scenarios. Financial indicators for the baseline (B) are summarised in Table 2.

3.3. Scenario outcomes

Scenarios S3 and S2 would result in the greatest benefits for fishers with a 10-year IRR of 120% and 118%, respectively (Table 3). Increased fish catches from 719 kg for the baseline to 863 kg under both scenarios account for virtually all the improvement witnessed. Scenario S1 resulted in a modest improvement in the 10-year IRR to 107%, as compared with 102% for the baseline.

3.3.1. Scenario S1: Increased fish restocking

Assuming a 20% increase in landings of stocked species, the average annual catch for a household would be 776 kg, an increase of 7.9% above the baseline (Table 3). The net benefit (excluding depreciation) would be ￥11,641 y^{-1} an increase of 4.3% above the baseline. Rates of return on capital and operating costs increased slightly and the payback period was marginally shorter. Despite the apparent contribution of stocked fish to catch returns in the Beijiang River, logbooks kept by fishers revealed that catch rates for species released were different in the three villages. The proportion of annual catches accounted for by stocked species was 18.9%, 44.5% and 56.1% in Zhoutian, Kengkou and Lishi, respectively. This implies that Kengkou and Lishi would gain most from both increased caches and net benefit (excluding depreciation) under this scenario. Anticipated percentage changes in catches and net benefit with increased fish stock enhancement activity for each village are shown in Table 4.

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3.3.2. Scenario S2: No fishing season and habitat conservation

Predicted outcomes for fishing households under this scenario are presented in Table 3. With a 20% increase in annual landings, households would expect to catch 863 kg and the annual net benefit (excluding depreciation) would be ￥12,846, an increase of 15.1% above the baseline. The enhancement of both catches and net financial benefits is much higher than under scenario S1, even though the costs and risks associated with implementation appear significantly lower. Rates of return on capital and operating costs increased significantly and the IRR was 118% over ten-years. This implies that the closed fishing season would improve the livelihoods of fishers in the long run. Concerns expressed over limited options for livelihoods diversification when fishing is prohibited could be addressed through compensation payments or support to generate an alternative income.

According to logbooks from the three communities, catches appeared higher in June 2011 following the closed season (Figure 4). This could be considered to represent a short-term benefit, but assessing the net benefit obtained by typical households in June demonstrated that it did not compensate for the loss of income during the closed season. During interviews with fishers after the closed season, all expressed hope that the government would subsidize them during future closed seasons as they had no alternative means of sustaining their livelihoods. It transpired that the government was planning to subsidize the fishers which should enhance the performance of this policy.

3.3.3. Scenario S3: Strict pollution control

Assuming pollution control measures were effective the net benefit (excluding depreciation) would be ￥12,938, an increase of 15.9% above the baseline (Table 3). Rates of return on capital and operating costs increased and the payback period was reduced to 0.61 years and the IRR increased to 120% over ten years. Outcomes show that fishers stand to benefit more from stricter pollution controls than from the other scenarios. Other groups, including farmers and citizens would benefit from enhanced pollution control.

3.4. Sensitivity analysis

Modeling outcomes demonstrated that a 20% decline or increase in the value of fish would result in a corresponding 15.1% fall or rise in the net benefit to fishers. Underlying reasons for these changes, for example, recovering stocks increase the supply of fish to the market, or inflation pushes up costs for fishers, could act to mitigate any anticipated change in benefits to households. Should the government decide to abolish the diesel subsidy it would severely impact fishers as it accounts for about 40% of the gross income associated with fishing. Without the subsidy, the average annual net benefit accruing to a household would be ￥5526, which would only be sufficient to cover food costs. A decrease in the diesel subsidy by 20% would result in an annual net benefit of ￥9134 which is 18.2% lower than the baseline.

4. Discussion

4.1. Reasoning concerning a declining fishery

Baseline assessment results showed that fishers would have no capacity to invest in future fishing activity and explain why most young people have left to find employment in urban areas, particularly those with skills (Punch and Sugden, 2013). For middle-aged and older fishers, it is difficult for them to access alternative employment. Fishers that are unable to exit a declining fishery may increase their fishing effort thus amplifying the decline (Cinner et al., 2011; Daw et al., 2012). Remaining fishers should be encouraged to adopt sustainable practices and avoid catching threatened species.

Baseline analysis outcomes show that when labour opportunity costs are low, owing to barriers to taking up alternative employment, modest financial returns still make fishing a viable activity. This assumes, however, that fishers possess boats and equipment, enabling them to fish, and that capital costs have been depreciated against previous returns. Elsewhere household members have continued to fish when it appears unsustainable as it is part of their tradition, provides enjoyment, entails minimal costs and offers a reputable channel for underutilised labour, while other livelihoods activities and strategies effectively subsidise fishing (Martin et al., 2013).

Perceived risks associated with alternative livelihoods options may deter fishers from opting to pursue new opportunities (Tucker et al., 2013). Logbooks showed that the average annual cost of food purchased by households was ￥5794, representing more than half the average annual net benefit from fishing. Fishers on the Beijiang River are heavily dependent on the 'equilibrium of survival' elaborated by Sen (2000: 164) when income from livelihoods activities must be sufficient to purchase adequate staple foods. Fishers reportedly only consume fish they are unable to sell (SCAU, 2009). Even modest fish intake could benefit adolescent girls, pregnant women and young children disproportionally in terms of their nutrition and long-term health outcomes (1,000 Days, 2017).

4.2. Fisheries management implications

Fry release has been demonstrated to enhance inland fisheries stocks (Cooke et al., 2016). The effectiveness of the release policy depends, however, on the location and scale of releases and behaviour of fishers, so as not to target juvenile fish following stocking. Such assurances were given by fishers, but other stakeholders interviewed said fishers might be tempted to catch juvenile fish to support their livelihoods (Liu et al., 2011). Effective monitoring and education are needed to ensure the policy is effective. The success of fry release programmes can depend on public participation. Concerned citizens and fishers participate in fry release activities in Shaoguan City and contribute to aquatic resources conservation. Precautions must be taken, however, to prevent introducing invasive species and diseases, pathogens and pests during stocking and 'avoid deleterious genetic effects on wild stocks' (Lorenzen et al., 2010, 190). Established good practices should be followed (Blankenship and Leber, 1995; De Silva et al., 1996; Lorenzen et al., 2010).

Ongoing stock enhancement involves releasing non-native species and the associated ecological risks should be reviewed regularly by the responsible authorities. Supplementary economic modeling scenarios could identify the most promising options for stock enhancement using only native species. Preliminary assessment showed that restocking endangered fish species would have minimal impact on the livelihoods of fishers, but this could contribute to ecological restoration. Technically it is possible to control fishing activity, establish protected areas and develop hatcheries for endangered species to promote conservation. Greater awareness that endangered species contribute little to their income could persuade fishers that they would not forego much in complying with and supporting conservation measures.

Analysis of data collected from 12 fishing boats from 2009 to 2012 showed that the no fishing season may have been effective in increasing fish stocks in the river and hence bolstering fish catches (Luo et al., 2013). Comparing catches in the same calendar month for June to December from 2009 to 2012, normalised against the mean average for monthly catches during a specific year, these authors showed an increasing trend following the implementation of the closed season for fishing on the Pearl River. Further assessment is required, however, prior to attributing these increased catches solely to the effects of the closed season.

During interviews with fishers, most were very worried about the impact of pollution, both on aquatic resources and the fishing equipment they use, particularly in Kengkou and Zhoutian. Records from 12 fishing boats on the Beijiang River from 2009-2012 showed that when the river passed through big industrial cities including Lechang and Shaoguan where pollution is worst, fish catches at the downstream location were 23.8-42.7% lower as compared with the upstream location (Luo et al., 2013). Although stakeholders from the government, industrial companies and restaurants said they had taken measures to control pollution, the situation is far from ideal. The effectiveness of environmental protection measures depends on compliance with, and when necessary enforcement of, government regulations.

Although the diesel subsidy is linked to the fuel price and horsepower of the engine used by individual fishers, it is apparent that the subsidy received is considerably higher than the cost of fuel used (Table 1). It may be regarded as a general subsidy to fishers in the absence of other social support payments. Transforming the diesel subsidy to a payment to use selective fishing gear, target invasive, introduced species and return threatened species and juveniles could contribute to positive conservation outcomes.

4.3. Policy and research requirements

Improvements to aquatic resources and ecosystems will not be immediate. Effects of conservation measures assessed here would be apparent in the medium- to long-term. Imposition of a closed season has an immediate impact on the livelihoods of fishers, but they would stand to gain more in the long-term if the policy was effective. Prospects for the livelihoods of fishers are intrinsically linked to regional economic development and the status of highland aquatic resources within the watershed. An ecosystem-based approach to fisheries management must be adopted that addresses higher level driving forces and counters negative pressures being experienced locally (Ahmed et al., 2013; Bunting et al., 2016). Were the opportunity cost of labour to increase it would appear to make fishing less attractive. Should households steer their livelihood strategies away from fishing, it may reduce fishing pressure, permitting fish stocks to increase. Removal of such connections to nature may, however, make communities and ecosystems more vulnerable in the future (Jodha, 1998).

To comprehensively evaluate the feasibility of the conservation measures considered here, further research is needed concerning the technical requirements, socioeconomic implications and possible ecological impacts. Applied economic modeling outcomes presented here could be used to facilitate such appraisals. Realistically it is doubtful that the fortunes of existing fishing communities can be improved quickly enough to avoid further impoverishment and hardship. Fishers require assistance from the government to enable them to engage in alternative livelihoods activities. The local government has provided some training to fishers to help secure urban employment and this may be useful for the younger generation, but additional measures are needed for older fishers who have no other means of support.

5. Conclusions

Aquatic resources in the Beijiang River have been degraded dramatically over the past 20 years, with both stocks of aquatic resources and biodiversity diminished. This has impacted significantly on socioeconomic development locally and the health and well-being of poor and vulnerable groups. Selected fish stock enhancement and pollution control measures were tested to assess the impacts of plausible scenarios on the livelihoods of fishers using an economic modeling approach. Financial returns associated with different scenarios concerning the anticipated performance of the different actions were compared. Results showed that strict pollution control would yield the largest benefits for fishing communities, improve living conditions for other groups and contribute to the regeneration of degraded aquatic ecosystems that would benefit biodiversity. The second most promising scenario for fishers was the introduction of a no fishing season and habitat conservation. The third best scenario was associated with increased fish restocking to bolster stocks. The success of the conservation measures described here depends on the policies and regulations framed by the government and effective monitoring and enforcement. Prior to implementation, potential environmental and ecological impacts require assessment and poorly defined risks demand further analysis. Appropriate best practice guidelines for fish restocking (Lorenzen et al., 2010) and principles for integrated action planning (Bunting et al., 2016) should be adopted to ensure that fish stock enhancement and conservation initiatives are planned jointly with stakeholders and implemented in a responsible manner.

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Table 1. Scenarios for highland aquatic resources conservation and performance assumptions

Scenario	Conservation measures	Performance assumptions
Baseline (B)	Restocking the same number and species of fish and no fishing season.	Catches remain constant in terms of species, amount and distribution.
S1	Increased fish restocking (based on current species composition stocked).	Catch of fish species released increased 20%.
S2	No fishing season (April 1 to May 31) and habitat conservation (setting up fish protection zone, restoring aquatic plants in the river and stabilizing fish habitats by control of sand mining and public education).	Catch of all fish species increased by 20% in the long run.
S3	Strict pollution control (increased sewage treatment capacity in urban area and biogas tanks in rural area).	Fishing costs decreased by 20% and catch of all species increased by 20%.

Table 2. Financial parameters for baseline scenarios for households in communities indicated

Financial parameter	Lishi	Zhoutian	Kengkou	Average
Capital costs (￥ y^{-1})				
Boat	3817	3654	3574	3641
Diesel engine	1917	2238	1167	1650
Nets	1068	790	855	930
Creels (traps)	973	87	2313	1244
Boat awning	350	350	400	367
Fish hooks	14	0	53	26
Total	8139	7119	8362	7858
Variable operating costs (￥ $month^{-1}$)				
Net repairs	13.7	3	6.4	8.1
Boat repairs	34.7	33.6	20.2	29.8
Fuel	288.1	222.8	50.1	194
Own labour opportunity costs [7]	664.5	837.8	741.7	746.7
Total [6]	1001	1097.2	818.4	978.6
Fixed operating costs (excluding depreciation) (￥ y^{-1})				
Fishing licence	105	105	105	105
Fishing income (￥ $month^{-1}$)				
Average fish catch weight (kg) [3]	42.8	63.3	77.5	59.9
Average fish price (￥ kg^{-1}) [4]	14.6	12.5	7.9	11.7
Other income (￥ $month^{-1}$)				
Diesel subsidy [5]	519.9	418.5	472.4	469.8
Net income excluding depreciation and including labour opportunity costs (￥ y^{-1}) [1]	1620	1246	3090	2199
Net income excluding depreciation and labour opportunity costs (￥ y^{-1}) [2]	9594	11,299	11,990	11,160

Note: Annual net income excluding depreciation and including labour opportunity costs [1] = (average fish catch weight per month [3] * average fish price [4] + diesel subsidy per month [5] – variable operating costs per month [6]) * 12 months; Annual net income excluding depreciation and labour opportunity costs [2] = (average fish catch weight per month [3] * average fish price [4] + diesel subsidy per month [5] – variable operating costs per month [6] (excluding own labour opportunity costs [7]) * 12 months.

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Table 3. Financial indicators for the baseline and scenarios for households on an annual basis (where *αj* is the percentage change in the catch of selected species *j* and *βi* is the percentage change in operating costs in month *i*)

Parameters		Baseline B	Scenario S1 (*αj* +20%)	Scenario S2 (*αj* +20%)	Scenario S3 (*βi* -20%; *αj* +20%)
Capital costs (￥)		7858	7858	7858	7858
Variable operational costs (￥)		2783	2783	2783	2692
Fishing license (￥)		105	105	105	105
Fish caught (kg)		719	776	863	863
Net benefit excluding depreciation (￥)		11,160	11,641	12,846	12,938
Rate of return on initial capital cost (%)		142	148	163	165
Rate of return on operating costs (%)		387	403	445	463
Payback period		0.7	0.67	0.61	0.61
NPV (￥) at:	5%	60,755	63,990	72,147	72,851
	10%	45,414	47,916	54,225	54,785
	20%	26,772	28,377	32,425	32,807
10-year IRR (%)		102	107	118	120

Table 4. Estimated catch (kg y^{-1}), net income (￥ y^{-1}) and percentage change against the baseline under Scenario 1 for households in communities indicated

Community	Baseline catch (kg y^{-1})	Baseline net income (￥y^{-1})	Estimated catch under S1		Estimated net income under S1	
			kg y^{-1}	%	￥y^{-1}	%
Kengkou	930	11,990	1013	8.9	12,504	4.3
Zhoutian	760	11,299	789	3.8	11,610	2.8
Lishi	513	9594	571	11.3	10,070	5.0
Average	719	11,160	776	7.9	11,641	4.3

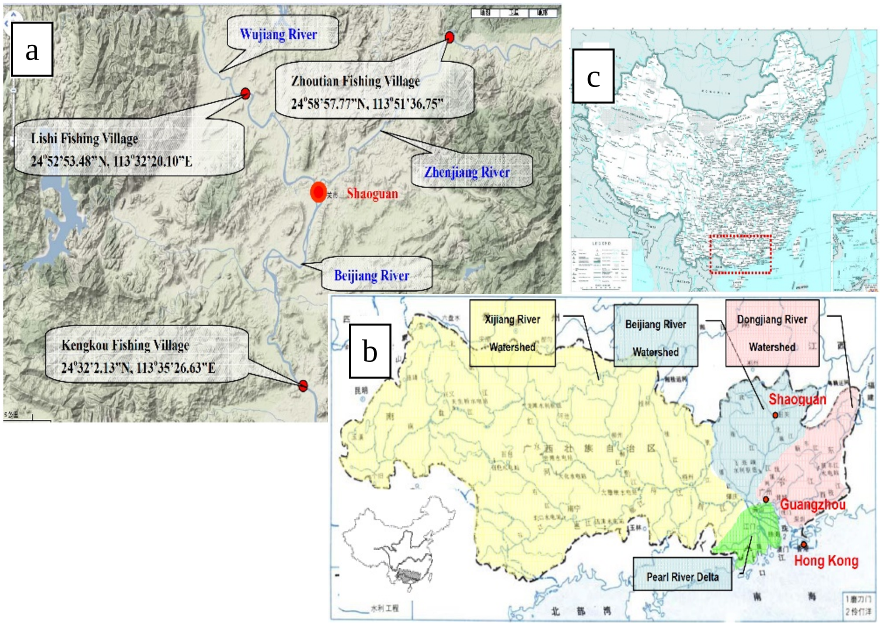

Figure 1. Location of the fishing villages in the Beijiang River catchment (a.), location of the Beijiang River within the Pearl River catchment (b.) and location of the Pearl River within China (c.) (adapted from Luo et al., 2012).

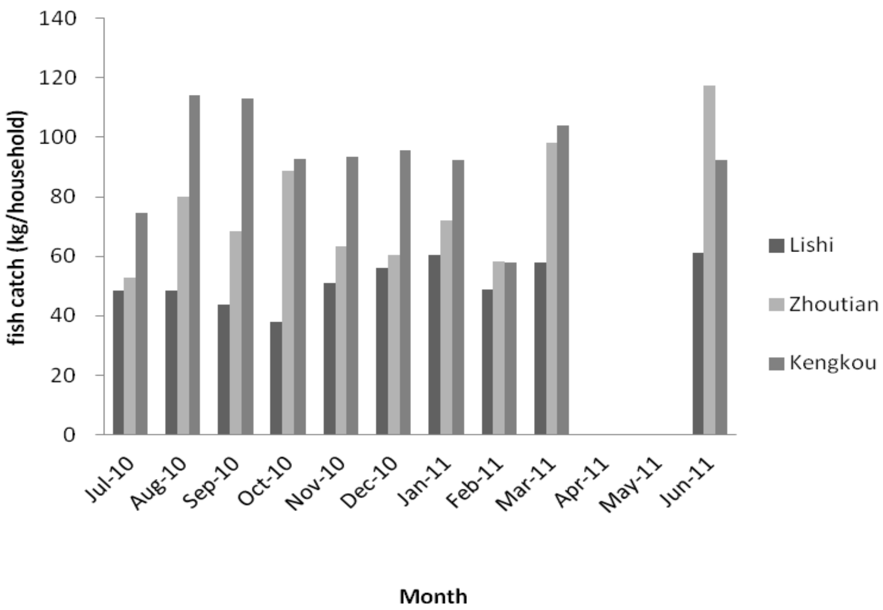

Figure 2. Mean monthly fish harvest (kg per household) in fishing communities indicated from July 2010 to June 2011 (note April and May are the closed fishing season).

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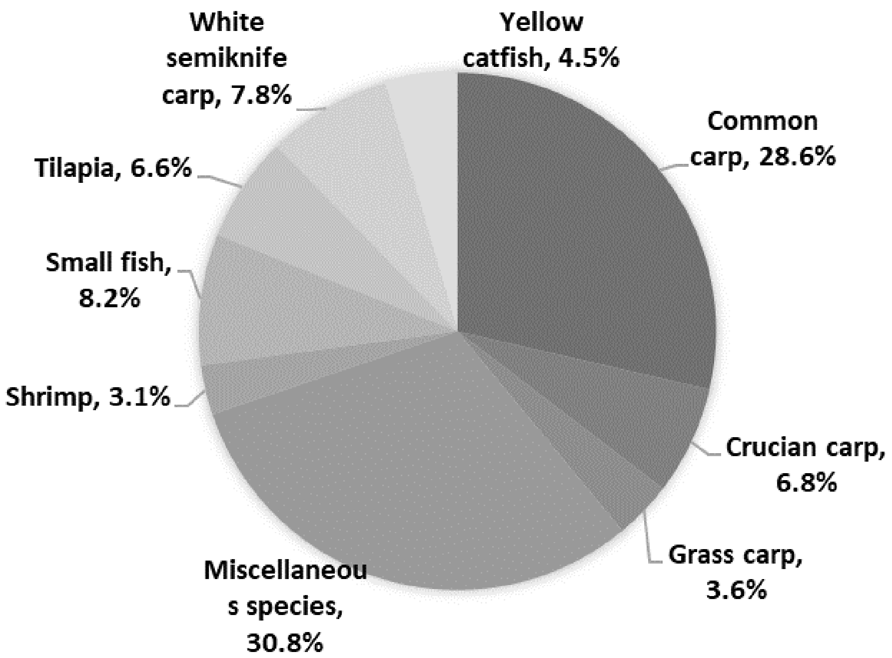

Figure 3. Species harvested in three fishing communities.

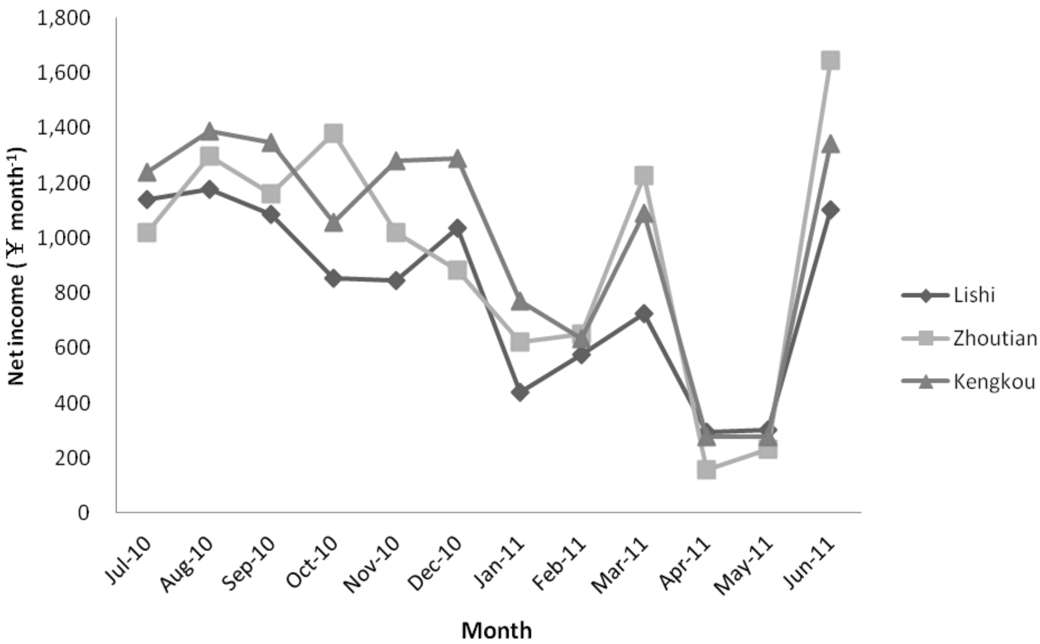

Figure 4. Monthly net income (￥) from fishing for households in communities indicated (April and May are the closed season for fishing).