Title: Evaluating sustainable intensification and diversification options for agriculture-based livelihoods within an aquatic biodiversity conservation context in Buxa, West Bengal, India

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Abstract

Potential impacts of sustainable intensification and diversification options for agriculture-based livelihoods in Buxa, West Bengal, India were evaluated using bioeconomic modelling. The baseline scenario involved multiple cropping seasons and a combination of crops on 0.9 ha landholdings, livestock husbandry, and exploitation of common property resources. With capital costs of Rs. 128,180 (US$ 2293) and annual operating costs of Rs. 37,290 (US$ 667), the net benefit generated (excluding depreciation) was Rs. 70,250 (US$ 1257) annually. The pay-back period was 1.8 years, and the Internal Rate of Return (IRR) was 53.7% over 10 years. Allocation of 20 days annually to fishing increased the net benefit to Rs. 75,030 (US$ 1,342) and IRR to 56.5% with minimal added costs and risks. Adopting the system of rice intensification (SRI) for paddy cultivation on 0.35 ha increased the IRR to 61.1%, while reducing agrochemical and inorganic fertiliser use. Including small-scale fish culture in a 0.1 ha pond integrated in the irrigation scheme for SRI cultivation resulted in an IRR of 77.3% and reduced the pay-back period to 1.3 years. Some risks to biodiversity are apparent with each scenario; however, with appropriate safeguards, sustainable agricultural intensification and livelihoods diversification could bolster agrobiodiversity and social-ecological resilience of highland communities, while alleviating pressure on biodiversity.

Keywords: Biodiversity conservation; Bioeconomic modelling; Highland aquatic resources; Livelihoods diversification; Sustainable agricultural intensification; Buxa, India

1. Introduction

Biodiversity, which underpins ecosystem processes and can be deemed to have economic or other values in its own right (Mace *et al*. 2012), is declining at an alarming rate in many areas due to anthropogenic activities (Hoffman *et al*. 2010). This loss of biodiversity, through impacts to ecosystem services, is having a significant detrimental effect upon human well-being and economies (Russi *et al*. 2013). In response to this crisis, the parties to the Convention on Biological Diversity (CBD) in 2010 adopted the Strategic Plan for Biodiversity which includes 20 targets (Aichi Targets) to be met by 2020.

As agricultural development and intensification is one of the greatest threats to biodiversity (BirdLife International 2008, Vie *et al*. 2009), one of the Aichi Targets (Target 7) aims to ensure 'By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity' (CBD 2013). Agricultural development must also contend with the perfect-storm forecast by Beddington (2010) whereby increased populations will demand higher crop production, despite increased competition for energy and water and adverse climate change impacts, with this production needing to be achieved in a sustainable manner, conducive to reducing greenhouse gas emissions and conserving biodiversity.

Challenges such as these are exemplified by the situation in the highlands of Asia. Deforestation and over-exploitation of natural resources, agricultural expansion and intensification, and disruption to hydrological regimes, owing to extensive water impoundment and transfer schemes for irrigation and hydroelectric power generation, have resulted in widespread environmental degradation and declines in aquatic biodiversity (Allen *et al*. 2010, 2012, Dudgeon 2003, 2006). Degraded ecosystems are more susceptible to anthropogenic pressures, environmental perturbations, and climate change impacts (Mason, 2001).

Highland areas in South Asia are vulnerable to climate change impacts as the effects are expected to be severe with increased rainfall over most of Asia, 'with up to [a] 50% increase along the Himalayan range' a 'very likely increase in the frequency of intense precipitation events in parts of South Asia' and an increase in 'extreme rainfall and winds associated with tropical cyclones' in south and southeast Asia (Conway and Waage 2010, p. 289-290). Stocks and flows of ecosystem services sustained by degraded ecosystems are diminished and consequently households and communities that depend upon them are dispossessed; impacts extend throughout catchments, threatening regional social and economic development.

With no scope for the physical expansion of agriculture in highland areas or consolidation of land-holdings owing to limited livelihoods options locally, attention must focus on the sustainable intensification of existing agricultural land and livelihoods diversification. This could enhance incomes and promote economic development and safeguard communities and social organisation while ensuring that biodiversity and ecosystem services are not further degraded, but are actively conserved and restored.

Highland aquatic resources are threatened by a range of pressures owing to poor socioeconomic conditions and weak governance, and it is broadly accepted that aquatic biodiversity conservation must be allied to sustainable development and wise-use of natural resources that engenders care and responsibility amongst user groups. This was the rationale for the HighARCS project. The project was implemented at five sites, one in China (Shaoguan City, Guangdong Province), two in India (Nainital District, Uttarakhand and Buxa, West Bengal) and two in Vietnam (Dakrong District, Quang Tri Province and Yen District, Son La Province). This paper focuses on the situation in Buxa located in the northeast of Jalpaiguri District, West Bengal, bordering Assam to the east and Bhutan to the north (Figure 1).

[Figure 1]

Situated in the foothills of the Himalayas, the 760 km^2 Buxa Tiger Reserve (BTR) forest was designated as a protected area for tiger (*Panthera tigris*) conservation in 1983. This area is rich in aquatic biodiversity and avian species (Sivakumar *et al*. 2006). A number of village clusters are located within the BTR, and communities practice predominantly rainfed agriculture to produce cash crops and food for household consumption. Wage-labour opportunities exist, working for the Department of Forestry, in towns in the adjacent plains, or for local stone collecting operations. Livestock are kept by most households in the forest-fringe and fodder may be gathered from accessible forest areas; some community members keep a number of goats and herd them large distances on a seasonal basis to find better grazing.

Highland aquatic resources are widely exploited through harvesting of aquatic plants and animals, notably fish, and Non-Timber Forest Products (NTFPs) are collected for cottage industries, domestic and decorative use, fodder, and medicinal purposes (Das 2005). Driving forces, largely beyond local control, have led to pressures in terms of behaviour and land-use change that have caused environmental degradation and prompted the migration of many younger people to seek employment in urban areas (Punch and Sugden 2013).

Policy-makers at a national level and authorities who are managing the situation locally impose restrictions on the nature and extent of activities permissible within the protected area. Communities striving to maintain their place in the BTR forest must attain food and nutritional security and pursue social and economic development given prevailing regulations and limitations, while contending with challenging environmental conditions and adverse demographic and economic trends that exert great pressure on traditional ways of living.

Households in Buxa rely upon a limited resource-base and must assess risks associated with investment in alternative agricultural systems. They must evaluate the potential opportunity costs of not using available human and financial resources for more lucrative purposes.

Consequently, appropriate methods are needed to test the feasibility and likely returns associated with proposed diversification and intensification options prior to attempts at implementation.

Amongst questions highlighted during horizon scanning with agriculture development specialists was ‘What systematic approaches can be used to identify and adapt technical options for increasing land and water productivity of rainfed crop and livestock systems so that they contribute to poverty reduction in different agroecological and socio-economic situations?’ (Pretty *et al*. 2010, p. 230). Within the HighARCS project an Integrated Action Planning approach was adopted to facilitate joint assessment and decision-making amongst stakeholder groups (Bunting *et al*. 2013b). Participatory approaches produced a comprehensive assessment of the prevailing situation, notably land-use and livestock husbandry practices and other livelihoods strategies including seasonal and permanent out-migration.

Integrated Action Plans (IAPs) were formulated through extended interaction with communities, highlighting areas for livelihoods enhancement and potential economic and social development (Mishra and Ray 2011). Subsequent application of the driving forces, pressures, state, impacts and responses (DPSIR) framework resulted in a more nuanced assessment of higher-level driving forces, contributing to pressures on highland aquatic resources, in terms of prevailing land-use practices and livelihoods.

Tools used to test the feasibility of IAPs included strengths, weaknesses, opportunities and threats (SWOT) analysis and assessment of social, technical, environmental, political/institutional and sustainability (STEPS) conditions needed for implementation. The compatibility of IAPs with biodiversity conservation was also tested; although it was not expected that the interventions would result in a net biodiversity gain. Considering financial returns, bioeconomic modelling was selected as a suitable approach to test the viability of proposed actions.

Bioeconomic modelling of agricultural systems has been conducted in a range of environments for arable, dairy, livestock, mixed, subsistence, and vegetable farming systems (Jansen and Van Ittersum 2007) and at different scales (Laborte *et al*. 2007). Application to the evaluation of small-scale agriculture-aquaculture and agriculture-fisheries systems is limited. Building on past applications of bioeconomic modelling to integrated aquaculture-wetland systems (Bunting and Shpigel 2009; Bunting *et al*. 2013a), the model formulated for this assessment was deterministic in nature, combining cropping and production data with expected costs and revenues to calculate cash-flows which would permit the estimation of standard financial indicators.

The first aim for this paper was to describe cropping patterns, input use characteristics, yields obtained, and the nature of dependence on forest and highland aquatic resources of typical households in Buxa engaged in agriculture. Financial returns generated under this baseline case were then evaluated in a systematic manner, using bioeconomic modelling and the impact of selected scenarios on financial returns tested. The sensitivity of returns to changing commodity prices and product values was tested to assess the resilience of the livelihoods strategies presented. Prospects for sustainable agricultural intensification and development of resilient highland communities were discussed, and potential opportunities and threats to conserving aquatic biodiversity and sustaining ecosystem services were critically reviewed.

2. Material and methods

Building on a household survey with a sample of 30 households from each of three village clusters and 10 focus groups with women, men, girls and boys in each cluster (Punch and Sugden 2013), a high-level livelihoods map was produced to guide supplementary bioeconomic modelling data collection and associated enquiry (Figure 2). Typical livelihoods activities for households in the village clusters were included, and material and waste flows connecting elements were depicted. Livelihoods maps were formulated to produce a composite picture of predominant livelihood strategy components. Not all households engaged in all the activities; some activities were deemed to have potential based on past interaction with the communities, even though they had not been implemented (e.g., fish culture in ponds) or only by certain households (e.g., providing ecotourism home-stay accommodation and guide services).

[Figure 2]

Focus group discussions with members of farming households and meetings with key informants were arranged to elicit supplementary information and a better understanding of the variable adoption of apparently viable production activities (Table 1).

[Table 1]

The baseline was formulated to reflect typical cropping patterns (seasonal rotations and mixtures of varieties) cultivated (Table 1) and the typical land-holding of households (0.9 ha), which was relatively uniform owing to historical aspects of land allocation (Table 2). Households had access to communal grazing and forest areas to collect fodder for livestock. Households dependent on rainfed farming often engaged in fishing for food or to generate income. Consequently the first diversification and intensification scenario assumed that households spend 20 days fishing annually in accessible rivers, streams and wetlands, estimated to cover 50 ha, with an anticipated catch of 2 kg per day.

The System of Rice Intensification (SRI) is being promoted in India as a means of increasing rice yields, with reduced water requirements and more efficient fertiliser and seed use (National Consortium on SRI 2012). Therefore, the second scenario assumed that 0.35 ha of *kharif* paddy would be converted to SRI cultivation, with seed and fertiliser savings of 68 and 24 kg ha^{-1}, respectively, and intermittent flooding and drying to minimise water use, but higher farmyard manure application prior to planting of 9.2 t ha^{-1} as compared to 4.3 t ha^{-1} for conventional cultivation. These input levels for SRI cultivation were tested in Jalpaiguri District and yielded 5.2 t ha^{-1} of rice as compared with 2.9 t ha^{-1} for conventional rice cultivation (CDHI 2012).

The need for greater water control with SRI crop management and consequently more storage capacity for water requires the establishment of permanent irrigation structures. SRI advocates have proposed linking irrigation systems development for SRI and selected cultivation activities to the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) whereby households could apply for government payments (Rs.110 d^{-1}) to cover labour costs.

Despite many households engaging in fishing, local fish capture does not meet demand in Buxa, and fish are brought in from outside (Ray *et al*. 2010). Small-scale fish culture in Buxa was proposed previously under a World Bank initiative to reduce pressure on forest resources. Assuming that ponds suited to fish culture could be constructed for water storage also to enable SRI cultivation, which requires only supplemental intermittent irrigation rather than continuous flooding of paddy fields, it was decided that a third scenario should evaluate such a combination.

The impact of allocating 0.1 ha of *rabi* cultivation land to a multi-purpose pond for water storage and fish culture was assessed. Semi-intensive culture of indigenous fish, namely calbaush (*Labeo calbasu*), catla (*Catla catla*) and rohu (*Labeo rohita*) in ponds could yield 3 t ha^{-1} annually (Azim *et al*. 2001) and would require only modest fish seed numbers (1.15 m^{-2}) estimated to cost Rs.1 each and organic fertiliser and supplementary feed inputs formulated from locally available resources.

[Table 2]

Bioeconomic model development was undertaken using Microsoft Excel spreadsheets arranged logically following the conceptual framework in Figure 3. Financial assessment entailed the calculation of standard indicators, including capital costs, variable and fixed operating costs, income, profit (including and excluding depreciation), rates of return (%) on capital and operating costs, and the pay-back period. Cumulative annual net cash-flows were evaluated over 10 years by calculating the Net Present Value (NPV) at discount rates of 5%, 10% and 20%, thus:

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

where *n* is the number of assessment periods and *i* the assessment period duration (set as annual here), *values* represents the net cash-flow per period, and *rate* the discount rate (as a decimal) assumed for the assessment.

[Figure 3]

The Internal Rate of Return (IRR) (%) at which the NPV of the investment is zero over 10 years was calculated with the iterative function in Excel and used to compare the performance of different scenarios. Sensitivity analysis was conducted by changing the expected cost of a single input or value of crops and product groups (e.g., agricultural crops, livestock co-products, fish and other highland aquatic resources) and comparing the resulting 10-year IRR with the baseline.

Stakeholder consultations were undertaken in Sadarbazar (Buxa cluster), Santhalabasti (Adma cluster), and 28 Basti (Jayanti cluster) from 26-28 June 2013 to systematically review bioeconomic modelling outcomes. There were 30-45 participants representing different stakeholder groups at each consultation. A local language report was prepared, findings were presented in a lecture, and feedback was elicited through focus group discussions and a participatory rural appraisal activity.

3. Results

Financial assessment outcomes demonstrated that capital costs (excluding land) were comparable for all scenarios (Table 3). Profits for households engaged in low-level fishing increased by Rs.4780 as compared with the baseline. Savings on paddy seed, inorganic fertiliser, and irrigation charges with SRI cultivation of Rs.570 are modest, given the total annual operating costs of Rs.37,290 for the baseline situation. Increased income from enhanced rice and fodder production in combination with reduced operating costs resulted in a profit (excluding depreciation) of Rs.79,460 when SRI was adopted, a 9% increase over the baseline. Integrating native fish culture with SRI generated an additional Rs.30,150 of income and contributed to a 70% increase in profits as compared with the baseline.

Rates of return on capital and operating costs - at 58% and 201%, respectively - were marginally higher when fishing was practiced as compared with the baseline. Introduction of SRI cultivation gave rates of return of 62% and 213% on capital and operating costs, respectively, and an estimated pay-back period of 1.6 years as compared with 1.8 years for the baseline. The shortest pay-back period of 1.3 years was obtained with combined SRI and fish culture, and rates of return under this scenario for capital and operating costs were 78% and 262%, respectively.

Over ten years, the NPV for the baseline was Rs.251,280, with a discount rate of 10%, but NPV increased to Rs.405,390 with combined SRI and fish culture. The IRR over 10 years was 53.7% for the baseline, which constitutes a reasonable return, and it only increased to 56.5% when fishing was included. With broadly comparable capital and operating costs, rainfed farming incorporating SRI and combined SRI and fish culture generated IRRs of 61.1% and 77.3%, respectively, over 10 years.

[Table 3]

Sensitivity analysis showed that including capital costs for land resulted in all scenarios failing to generate a positive IRR over 10 years (Table 4). Factoring in a 50% increase in inorganic fertiliser costs resulted in a small (1%) decrease in the 10-year IRR in all cases, whilst a comparable decrease, envisaged perhaps owing to higher government subsidies, resulted in an equivalent increase in the 10-year IRR. Similar percentage changes in seed costs across all crops result in a negligible (<1%) change in the 10-year IRR.

A change of 20% in the value of crops resulted in a corresponding change of 5% in the 10-year IRR. A change of 20% in the value of livestock co-products (eggs, manure and milk) resulted in a small change to anticipated returns. An increase of 50% in the value of fish caught or cultured resulted in a 2% and 10% increase in the 10-year IRR, respectively, reflecting the relative amounts of fish caught over 20 days (40 kg) or cultured in a 0.1 ha pond annually (300 kg). Similar reductions in the 10-year IRR were predicted with a fall in the value of fish, but the overall return remained at 67.8% for rainfed farming with SRI and fish culture.

Assuming that households engaged in rainfed farming and rainfed farming and fishing undertake 100 days of work paid for by the MGNREGS scheme on community or infrastructure projects resulted in a 9% increase in the 10-year IRR. Loss of the modest allocation assumed to aid SRI adoption resulted in a small drop in the level of return. Changes in revenue from forest and aquatic resources of 50% had the greatest impact on the 10-year IRR in all cases, a 50% decrease resulted in a 13-14% decrease in returns and a 50% increase resulted in comparable increases. Considering all baseline variations tested, the anticipated 10-year IRR indicated quite a reasonable rate of return (40-67%) that appears resilient to shocks and adverse tends.

[Table 4]

4. Discussion

4.1. Prospects for sustainable agricultural intensification

Rainfed farming is widely practiced around settlements in Buxa. Assessment of financial returns from the baseline considered here, however, demonstrated a modest annual net benefit (Rs.70,250 or US$ 1257). To put this in context, the international poverty line of US$1.25 d^{-1} or US$456 y^{-1} per head, signifies extreme poverty, and households in rural Jalpaiguri, India typically have between four and five members (GoI 2013). With limited access to land and other resources, the 'equilibrium of survival' (Sen 2000, p. 164) or balance between cash and subsistence crop production is critical.

Decisions over which crops to cultivate and what levels of return to expect will be dictated largely by input costs, environmental conditions, logistical and marketing considerations, anticipated levels of food and income required, and perceived production and distribution risks. Communications in highland areas of northern West Bengal are often disrupted by seasonal climatic conditions and extreme weather events and floods; political strife and civil unrest are also not unknown in such border areas (see Saikia 2007).

It is apparent from the sensitivity analysis, however, that financial returns generated by the range of crops cultivated over multiple growing seasons are reasonably resilient to external influences, owing to the avoidance of excessive dependence on externalising technology. The diversity of agriculture-based livelihoods could be enhanced further with SRI and small-scale culture of native fish species, helping to secure higher returns on investments in agricultural systems, even when adverse trends are foreseen.

Allocating a relatively small amount of time to fishing can make a notable contribution to livelihoods with modest investment and minimal exposure to risks. Most households engage in fishing to some extent. The opportunity cost of labour could be factored in to assessments, but fishing is potentially lucrative, with catches of 20 kg in one night possible by damming braided river channels and collecting the stranded fish (Sugden 2010). This requires concerted action often involving the help of other community members, and hence catches must be distributed accordingly. Although catches are probably highly variable and unpredictable, the collective act of fishing may convey other benefits upon participants, strengthening family ties and social capital and providing an opportunity for play for children, respite from agricultural activities for adults, and an occasion for ecological knowledge transfer across generations.

Fishing strategies such as damming channels, pesticide application, and using nets with a fine mesh are indiscriminate and destructive, however, and they may threaten the future of stocks of fish and other aquatic species in these highland rivers. As fish stocks decline, not only would communities suffer owing to their smaller and less dependable catches; the culturally important aspects of fishing as a collective and traditional activity would be lost too.

Horizon scanning with agricultural development specialists raised the question ‘What are the most practical and economic methods for managing soil fertility in paddy soils and upland production systems in the tropics?' (Pretty *et al*. 2010, p. 224). An apparent strength of SRI cultivation is the reduction in use of agrochemicals and inorganic fertiliser and much-reduced seed inputs, resulting in lower input costs. Improved soil conditions owing to enhanced microbial activity under SRI cultivation have been identified as critical for yield gains (Uphoff 2012).

SRI cultivation with wider spacing of plants has been seen to double production of rice and fodder as compared with conventional paddy cultivation, despite reducing dependence on externalising inputs. This may seem counter-intuitive and could constitute a weakness when trying to promote adoption of SRI cultivation, making awareness-raising and provision of appropriate support services even more critical in ensuring that farmers do not revert to past agrochemical and fertiliser application regimes. Deficiencies with current government support for agriculture were noted during stakeholder meetings and appropriate capacity-building is warranted. Investment in establishing permanent irrigation systems and new equipment is needed for SRI cultivation, and this may present a significant barrier to poor and marginal farmers.

Prospects for SRI cultivation may be enhanced as experience gained locally and knowledge exchange amongst farmers helps them better define potential returns and associated risks. Action research and farmer trials could help in adapting SRI cultivation to local climatic and environmental conditions, hydrological regimes, and soil types. The National Consortium on SRI (2012) elaborated potential synergies between SRI and the MGNREGS programme in India, both in terms of financing physical changes to irrigation systems and paying for labour costs during the transition phase, and in respect of capitalising on administrative and support mechanisms established for MGNREGS across the country.

It was noted, however, that extra support may be required to adapt SRI cultivation to local social and economic settings. Where it is not possible to access MGNREGS funding and institutional mechanisms and payment systems, this may be seen as a lost opportunity. Experiences of the MGNREGS programme in Buxa have not been wholly positive, with some community members not being able to secure guaranteed work and payments for completed work being severely delayed. This legacy may hinder SRI promotion locally where it is linked to MGNREGS and may cast doubt on the wider promise of this strategy nationally.

Stakeholder consultation outcomes appeared to suggest that recent improvements to implementing the MGNREGS scheme may be transient as they were related to the electoral process. Inorganic fertiliser subsidies may be a disincentive to SRI adoption, but government commitments to reduce subsidies across the board should enhance prospects for more efficient agricultural practices. Care should be taken to ensure that unrealistic expectations are not instilled in prospective farmers. Unintended consequences of SRI adoption, irrigation system development, and increasing water storage capacity should be reviewed regularly and appropriate adaptive management systems instituted. Impounded water may harbour animal or human parasites or disease agents, whilst intermittent flooding of fields may deter or exclude rice pest predators or encourage weeds.

Small-scale fish culture is well established in West Bengal with techniques devised to produce a range of species in the array of freshwater environments that characterise the state. Availability of fish seed is increasing even in remote areas, and the government supports aquaculture development with financial incentives and subsidised inputs. Extension services are active in most areas, and there is a huge market for cultured fish in burgeoning towns and cities in the plains. Possible constraints include a lack of experience, knowledge and skills locally and the availability of quality fish seed originating from local stocks of indigenous species. Poor soils would require appropriate conditioning and fertiliser regimes, whilst accessible resources for feed and organic fertiliser formulation may be sub-optimal.

The proposal for small-scale fish culture adoption depends greatly on irrigation system development funded by MGNREGS, but further work would be required to elaborate how to balance water storage and delivery for SRI cultivation with fish culture. We specify using native species, ideally originating from local populations, so that they are genetically as close to the wild stock as possible, for culture owing to the ecological risks posed by non-native species. Even though non-native species are present in many wetlands in West Bengal and have contributed to short-term yield increases, it has been noted that indigenous species populations have declined (Bhakta and Bandyopadhyay 2007) whilst the medium- to long-term impacts have not been evaluated. Integrating production of small indigenous fish species (e.g. *Amblypharyngodon mola*) with established cultured species could yield an additional source of 'micronutrient-dense' food for farming households to enhance human nutrition and counter micronutrient deficiencies (Roos *et al*. 2007, p. S280).

Combined rice and fish culture has potential to enhance food and nutritional security locally and further diversify cash-crops, contributing to greater agricultural systems resilience. As well as making more efficient use of appropriated water and water storage infrastructure, residues of inorganic fertiliser and supplementary feed applications to fishponds would enhance nutrient levels in water for SRI irrigation. Enriched fishpond sediments can be an important source of nutrients in low-input farming systems (Nhan *et al*. 2007).

Covering infrastructure development and initial labour costs under the MGNREGS programme and capitalising on established capacity-building and support mechanisms would enhance prospects for successful adoption. Given that Buxa is a net importer of fish, increased local supplies of fresh fish, of greater nutritional value, could contribute to enhanced well-being. Potential opportunities must, however, be judged against attendant risks to fish culture, including: extreme weather; prospective diseases, pests and predators; pollution originating upstream; potential for conflict with other users; practical issues of transporting inputs, including live seed, to remote communities and fresh fish to market; and worsening climate-change-induced impacts.

4.2. Resilient highland communities - household finances, food security, and socioeconomic development

Financial returns from the baseline and scenarios appear reasonable but probably constitute an underestimate of net benefits accruing to wealthier households as intermittent meat sales from livestock were not accounted for, and other income from guiding, labouring and remittances was not included. Excessive livestock numbers are cited as a threat to the reserve forest area (National Tiger Conservation Authority 2013), and modelling livelihoods without livestock could identify appropriate responses and coping mechanisms should the authorities clamp down on animal numbers that households can own.

Poor households and those in marginal communities, less well endowed with natural resources, are unlikely to have significant livestock, and consequently the baseline presented here may better reflect their situation. Certain households, particularly in socially marginalised and geographically remote communities at higher elevations, may have access to less agricultural land that is able to sustain cropping levels assumed for the baseline, and consequently it must not be assumed that all families could achieve the returns predicted in this assessment.

Where households are able to cultivate the baseline crop combinations, the financial returns generated appeared resilient to the changes tested in the sensitivity analysis. This might be a good example for other highland communities, demonstrating that livelihoods are more resilient when multiple harvests of mixed cash and subsistence crops are possible throughout the year; but also that continued access to common property and highland aquatic resources is an added imperative. Such insights are critical given the anticipated worsening of climate-change impacts and other pressures that face communities throughout highland areas of Asia. Although potential returns from fishing and MGNREGS participation are modest in overall cash-flow terms, households engage in such activities as opportunity costs of labour are low and risks are minimal.

Fishing is widely practiced in the livelihoods strategies of farming households in the three village clusters under consideration. Selling catches of large specimens or valuable species can realise important income for poor and marginal households in highland areas. Of 46 fish species recorded at the site, just over half (24) are utilised for subsistence, a similar number (23) are sold providing some income, whilst a small number (6) generate a high level of income (Ray and Mishra 2011). Modest catches of small fish and other animals can make an important contribution to household nutrition, particularly for infants and pregnant women (Roos *et al*. 2002). Fish catches may be valued by certain households more for their nutritional value and cultural significance than their market value. Collective fishing activity and associated rituals may help promote community cohesion and enhance social capital.

Similar benefits might be associated with MGNREGS participation, and community members may be capitalising on the scheme to achieve shared objectives such as constructing better pathways and bridges, whilst payments for work undertaken may be regarded as a secondary benefit. Where community-development is the objective, households not really in need of additional payments may feel compelled to contribute to avoid negative connotations associated with not being involved. Despite the guaranteed provision of 100 days of MGNREGS employment, households in Buxa undertake a relatively low number. This may be due to a lack of suitable activities, or because households do not require greater provision. Problems recounted by local participants concerning MGNREGS payments may deter prospective involvement in the programme.

Should MGNREGS contributions to cover irrigation systems development and labour costs not be accessible, estimated returns from SRI adoption of 61% for the 10-year IRR still appeared to justify investment by households. Potential land-savings achieved through SRI adoption could present an opportunity to safeguard staple food security in highland communities and release agricultural land for the establishment of perennial cereals that ’provide a stable yield, generate biomass for fuel or livestock feed, increase carbon sequestration and species richness, and reduce costs of seeds, fertilisers and herbicides’ (Sutherland *et al*. 2011, p. 15).

A further global conservation priority identified for 2012 by these authors (p. 16) was the deployment of ‘in-stream hydrokinetic turbines’, thus highlighting the need to avoid excessive interference with stream and river flows. Similarly, when water is appropriated for SRI cultivation and fish culture, safeguards should be in place to ensure that environmental flows are maintained. Environmental flow assessment case-studies and an approach to calculating the environmental water requirement are presented elsewhere (Atapattu *et al*. 2013).

Should fish culture prove successful, there may be a desire to intensify production in pursuit of higher returns, but this could entail greater exposure to risks and exceed the carrying capacity of the culture system and supporting ecosystem area. There is an added danger that more affluent and better positioned households will capture the majority of benefits from integrated SRI and fish culture, further bolstering their position at the expense of others.

4.3. Opportunities to conserve aquatic biodiversity and sustain ecosystem services

Threats to aquatic biodiversity from current agricultural practices in Buxa were assessed and included soil erosion, water pollution, pesticide use for crops on exposed river beds, and washing pesticide containers in the river (Ray *et al*. 2010). Adopting SRI cultivation would reduce pesticide and water use and require marginally lower inorganic fertiliser inputs as compared with conventional paddy culture. A significant proportion of accessible freshwater resources in India, and indeed globally, estimated at 70% by the United Nations (2003) is diverted away from natural ecosystems for irrigation.

Measures to minimise this could make a marked contribution to restoring degraded wetlands and to conserving aquatic biodiversity and sustaining stocks and flows of ecosystem services that support communities and socioeconomic activity both locally and downstream (Findlayson *et al*. 2013). Substantially smaller irrigation water discharges could significantly reduce the risks posed by fertiliser and agrochemical runoff to receiving highland aquatic ecosystems.

Fish culture in small-scale reservoirs in irrigation systems would increase the productivity of water appropriated for agricultural purposes. But it must be strongly recommended that indigenous species that are suitable for pond culture are used (such as *Cirrhinus mrigala, C. catla* and *L. rohita*) rather than non-native species that have previously been used in many areas of the Himalaya region, such as the grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*) and Thai magur *(Clarias gariepinus*). This is particularly important given the flow-through nature of small-scale fishponds integrated into irrigation systems where intermittent releases of water are foreseen, and it would be unrealistic to expect that fish would not be released unintentionally.

Anticipated worsening of climate change impacts must be factored into risk assessments and appropriate provisions made in systems configuration and management plans. The escape of domesticated or introduced strains of indigenous fish species can impact biodiversity through competition and predation, whilst inbreeding with wild populations of the same species can cause genetic degradation and reduce fitness to local environmental conditions. Establishment of 'species specific management units, which define the genetically distinct wild sub-populations of the cultured species' was proposed in response to ensure undue risks to local populations are avoided (Mattson *et al*. 2005, p. 130) but a number of constraints to adopting this can be envisaged.

Other aspects of biosecurity also demand attention, including risks posed by the inadvertent introduction of invasive species and disease agents, pathogens and pests carried on infected animals and equipment. Impounded water may harbour parasites and vectors presenting an increased public health risk. Appropriate Better Management Practices (BMPs) guidelines could help promote responsible, resilient and safe culture practices and integration strategies.

Cultured fish production might alleviate pressure on wild stocks if fishing pressure was reduced as a consequence. Not all households would be interested or able to engage in fish culture, however, and for them allocating effort to fishing would still be worthwhile as options for alternative income-generating activities are limited. Cultured fish are not necessarily a ready substitute for wild fish, and demand for fish caught in Buxa is probably set to intensify owing to the burgeoning population of increasingly affluent consumers in the adjacent plains. This is important as efforts to promote responsible fishing practices with local communities should be pursued to safeguard future fish stocks and avoid environmentally-damaging fishing practices.

The abundance of nearly all species is declining, and although none are globally threatened at present, six species (*Ailia coila*, *Bagarius bagarius*, *Chitala chitala*, *Ompok bimaculatus*, *Tor tor* and *Wallago attu*) are classified as Near Threatened (IUCN 2013). Identification of flagship species, and highlighting their vulnerability and potential financial losses and threats to food security for local communities should populations continue to decline, could prove an effective means to raise awareness and change behaviour. Distribution of fish rulers could help inform retailers and consumers about what species and sizes of fish it would be advisable to purchase, with a view to reducing demand for endangered and juvenile fish.

Opportunities to earn income are limited locally and a wide range of ecosystem services are exploited from common-property highland aquatic and forestry resources to consume, sell, use to enhance agricultural production or process into value-added products. Fodder and firewood are frequently gathered by young people, and this means that they often make an important contribution to livestock production and provisioning activities sustaining households.

Ecosystem services exploitation can cause extraction impacts and entail modification and management of ecosystems to enhance access to desirable products. Coppicing and weeding-out unwanted species may be practiced, and seedlings may be nurtured and planted-out or relocated to promote growth of useful material. Grazing by draft and transhumance animals can favour unpalatable species of plants and hinder regeneration. Indiscriminate methods of catching fish, for example, damming braided river channels, can eradicate other aquatic animals. Continuing access to provisioning ecosystem services appears critical to maintaining resilient communities in Buxa, but further assessment is warranted concerning the extraction methods being used, their impacts, and how to mitigate these. Promotion of the agrobiodiversity concept amongst communities may further highlight the interdependence of people and biodiversity and contribute to awareness-raising and more considered interactions with the reserve forest.

Authorities in control of the reserve face an apparent dilemma of how to conserve biodiversity whilst permitting communities to continue living in the forest. A policy to relocate willing communities was introduced in this regard, while socioeconomic development appeared to be stifled. Given that communities have not taken up the offer to relocate and have a constitutional basis to remain in the forest, it may be more prudent to promote sustainable agricultural intensification on land already in production and to support appropriate livelihoods diversification to alleviate pressure on provisioning ecosystem services and promote biodiversity conservation.

Studies within the Buxa reserve have demonstrated that scrub and village-edge forest areas had the highest populations of birds as compared to hill and riverine forest, plantation, and semi-evergreen forest habitats (Sivakumar *et al*. 2006). Reductions in agrochemical use with SRI and further diversification through small-scale fish culture could help conserve biodiversity and enhance agrobiodiversity. Questions remain, however, over the relative contribution of conventional versus SRI paddy to agrobiodiversity with its modified hydrological regimes, and whether environmental health concerns associated with small-scale fish culture in highland areas can be effectively managed. Threats to biodiversity under each scenario are apparent, but the assessment presented here is not comprehensive and the magnitude of risks is difficult to quantify. Where there is uncertainty, the precautionary principle must take precedence, and wherever possible, BMPs based on available knowledge and information should be promoted.

4.4. Bioeconomic modelling as an assessment approach

Bioeconomic modelling was not an attempt to replicate the practices and financial dealings of a particular farm or cluster of farmers, but to present a structured evaluation of costs and returns associated with typical cropping schedules and combinations, to produce cash-flow projections upon which to base critical reflection by farmers and other stakeholders. The stakeholder consultation demonstrated that this is possible to a certain extent, but care is needed to ensure that findings are presented in appropriate formats with technical terms explained, and that participants are supported in interpreting outcomes.

Findings presented here show that small-scale farmers in highland areas in India are not wholly engaged in subsistence agriculture; there is a clear focus on cash-crops that can be sold with staple foods purchased in return. In this context, bioeconomic modelling is a useful approach to structuring the assessment of representative production systems and associated cash-flows. Assigning monetary values to NTFPs and highland aquatic resources was justified as it helped explain the true benefit of agricultural-based livelihoods that would otherwise appear marginal, given the net financial returns generated, and vulnerable to rising input costs and falling commodity prices.

Assessment of innovative agricultural systems must, however, go beyond financial and technical appraisals. Considering options for the sustainable intensification for global agricultural development, it was noted that ’global agriculture demands a diversity of approaches, specific to crops, localities, cultures and other circumstances’ and that this necessitates ’that the breadth of relevant scientific enquiry is equally diverse, and that science needs to be combined with social economic and political perspectives’ (The Royal Society, 2009).

Further, horizon scanning for agricultural development raised the question of ’How should the options of intensification, extensification, habitat restoration or the status quo be chosen and how can we best combine measures of economic, environmental and social benefits to make the choice?’ (Pretty *et al*. 2010, p. 225). Bioeconomic modelling was used here to simulate options for the sustainable intensification and diversification of highland agricultural systems and was effective in combining assessments of biological production with financial indicators. Greater understanding concerning the dependence of highland agricultural systems on agrobiodiversity and ecosystem services was achieved, and critical reflection regarding possible socioeconomic impacts was possible.

Bioeconomic modelling could be used at a community or regional scale to test the demands that certain sustainable intensification and diversification options might place on agrobiodiversity and ecosystem services, thus helping answer a critical research question ’What is the relationship between productivity and biodiversity (and/or other ecosystem services) and how does this vary between agricultural systems and as a function of the spatial scale at which land is devoted mostly to food production?' (Pretty *et al*. 2010, p. 225). The feasibility of options should, however, be tested with farming households and other stakeholders to evaluate prospects for sustainability as well as social, technical, environmental and institutional or political conditions required for successful uptake.

Bioeconomic modelling outcomes may be useful in this regard as they could form the basis for joint assessment and decision-making. It would be important to specify the limitations of bioeconomic modelling outcomes in such a process, paying particular attention to areas of uncertainty and risks. Joint review and verification of bioeconomic modelling outcomes with stakeholders is needed, however, to check whether assumptions, input prices, and commodity values remain valid, and to engender greater trust in findings and subsequent deliberations. Prior to large-scale implementation, it would be prudent to engage in appropriate action research involving field trials and biodiversity monitoring with prospective adopters.

5. Conclusions

The baseline scenario devised for agricultural systems in the BTR appeared resilient and suited to supporting households in this challenging highland environment. This could constitute a useful example for other communities having to contend with living in the highlands of Asia, especially given the intensifying socioeconomic pressures being experienced in such areas and the anticipated worsening of climate change impacts.

Adoption of integrated SRI cultivation and small-scale fish culture is promising, but support is needed to refine management approaches to local physical and environmental conditions and to build capacity locally to deal with problems as they arise and mitigate risks. Continued access to ecosystem services is essential for the well-being of households, and options to reconcile biodiversity conservation with wise-use of highland aquatic resources are paramount.

Problems identified with fishing highlight the issues of concern - declining stocks, overexploitation, and the impacts of indiscriminate practices on biodiversity and supporting ecosystems. Assessment outcomes should be of interest to policy-makers and authorities governing the BTR, enabling the identification of actions that would promote sustainable agricultural intensification and mitigating impacts of ecosystems services appropriation. Measures are needed to ensure that environmental flows and stocks of ecosystem services are maintained, which will demand assessment against reliable baselines and monitoring and adaptive governance to avoid overexploitation.

Bioeconomic modelling constitutes a promising approach to evaluating agricultural systems productivity and associated financial costs and returns. It is possible to allocate costs and benefits to the appropriation of ecosystem services from common property and highland aquatic resources. This helps explain the dynamics of livelihood strategies and to emphasise the interdependence of communities and biodiversity, notably in terms of agrobiodiversity and ecosystem services.

A limitation to bioeconomic modelling in this context is the need to characterise a representative agricultural system for generic assessment, whilst the land-holding of each household is unique and the approach to farming is influenced by particular factors. Such an approach can help demonstrate the options available to households and the underlying principles. Further assessment with individual households could identify the most promising choices for them given their circumstances.

Having defined what sustainable agricultural intensification or livelihoods diversification options appear financially viable, such information could be used by policy-makers and service providers to allocate resources and target capacity-building. Stakeholder consultations concerning modelling outcomes identified gaps between service providers and local communities, and the distillation of threats to biodiversity, opportunities for sustainable agricultural intensification, risks and mitigation options in BMPs, and policy-briefs would address this issue and bridge the interface between research, policy and practice.

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Table 1. Data from producer focus groups and key informant interviews in Buxa, West Bengal, India

Tools used	Operating procedures and inputs assessed	Practices employed and costs incurred
Focus group discussion	Cropping patterns for rainfed agriculture	Cultivation typically involves 3 crops per year, pre-*kharif* (summer) from mid-Feb to mid-June, *kharif* (rainy season) from mid-June to Sept and *rabi* (winter) Oct to mid-Feb; with sowing and harvest dependent on prevailing weather
	Bed preparation prior to crop planting	Farmers apply 4.3 and 9.2 t ha^{-1} of manure to fields for conventional and SRI rice at a cost of Rs.600 per tonne (US$10.7 t^{-1}); manure applications for pre-*kharif* ginger, non-rice *kharif* crops, *rabi* crops and homestead garden plots were 80, 280, 200 to 400 and 160 kg ha^{-1}, respectively
	Extent of extracting products from forest and aquatic common-property resources	Households in Buxa can access 2000 ha of forest and 200 ha of wetlands and rivers; timber extraction is permitted for domestic use and was valued at Rs.9500 (US$170) per household annually
Key informant interview	Cost for land and access rights	Land values were estimated at Rs. 1 million per hectare (US$17,890 ha^{-1}), but in practice land is not bought and sold freely, only *de facto* rights to cultivation are permitted
	Cost of production enhancing inputs	Urea and potassium chloride cost Rs.20 kg^{-1} (US$0.36) and superphosphate Rs.15 kg^{-1} (US$0.27 kg^{-1}); irrigation charges were Rs.514 and Rs.251 ha^{-1} for conventional and SRI paddy, respectively
	Value of agricultural and livestock production	Ginger, maize, mustard, potato and rice were valued at Rs.30 (US$0.54), Rs.12 (US$0.21), Rs.20 (US$0.36), Rs.10 (US$0.18) and Rs.10 (US$0.18) per kilogram, respectively; eggs were worth Rs.2 each, milk Rs.20 per litre and manure Rs.5 per kilogram in local markets; fish was valued Rs.80 (US$1.43) and Rs.120 (US$2.15) for cultured and wild varieties, respectively
	Value of forest and highland aquatic resources in local markets	Amounts of NTFPs collected (e.g. mushrooms and honey) were 40 kg y^{-1} per household; grazing biomass, fodder products and highland aquatic resources were valued at Rs.4000 (US$72), Rs.7200 (US$129) and Rs.12,000 (US$215) per year

Note: exchange rate of Rs.55.9 to US$1 for 2012 used for currency conversions (IRS, 2013)

Table 2. Operating parameters for agriculture-based livelihoods and diversification and intensification options indicated

Operating parameter		Rainfed farming	Rainfed farming and fishing	Rainfed farming and SRI	Rainfed farming, SRI and fish culture
Land area owned (ha)		0.9	0.9	0.9	0.9
Land area cultivated (ha)		0.8	0.8	0.8	0.8
Pre-*kharif* (summer monsoon) (ha)		0.2	0.2	0.2	0.2
Kharif (rainy season) (ha)		0.35	0.35	0.35	0.35
Rabi (winter season) (ha)		0.72	0.72	0.72	0.62
Fishpond area (ha)		-	-	-	0.1
Fishing effort (d y^{-1})		-	20	-	-
MGNREGS contribution (d y^{-1})		-	-	10	10
Homestead garden area (ha)		0.02	0.02	0.02	0.02
Plantation (banana plants)		80	80	80	80
Livestock:	cattle	2	2	2	2
	pigs	1	1	1	1
	goats	4	4	4	4
	chickens	6	6	6	6

Table 3. Financial indicators from bioeconomic modelling for management regimes indicated

Characteristic		Rainfed farming	Rainfed farming and fishing	Rainfed farming and SRI	Rainfed farming, SRI and fish culture
Capital costs (Rs.)					
Land		-	-	-	-
Storage building		45,000	45,000	45,000	45,000
Implements and tools		48,000	48,000	48,000	48,000
Livestock and poultry		23,180	23,180	23,180	23,180
Plantation establishment		12,000	12,000	12,000	12,000
Fishing nets		0	2000	0	0
Total		128,180	130,180	128,180	128,180
Operating costs (Rs. y^{-1})					
Seed and seedlings		9590	9590	9270	9020
Fish seed		0	0	0	1150
Bed preparation		1080	1080	2110	2080
Fertiliser		3020	3020	2860	2760
Pesticides		960	960	440	440
Livestock and poultry feed		7750	7750	7750	7750
Livestock treatment		3500	3500	3500	3500
Irrigation charges		180	180	90	90
Maintenance and miscellaneous*		10,880	10,900	10,880	10,880
Fixed costs		330	330	330	330
Total		37,290	37,310	37,230	38,000
Income (Rs. y^{-1})		107,540	112,340	116,690	137,690
Net benefit - excluding depreciation (Rs. y^{-1})		70,250	75,030	79,460	99,690
Pay-back period (y)		1.8	1.7	1.6	1.3
Return on capital costs		55%	58%	62%	78%
Return on operating costs		188%	201%	213%	262%
10 year NPV at discount rates of:	5%	353,490	382,450	415,820	552,750
	10%	251,280	273,360	299,480	405,390
	20%	129,170	142,890	160,100	228,050
IRR (%) over:	10 y	53.7	56.5	61.1	77.3

*miscellaneous items noted by producers included casual labour, market taxes and travelling costs

Table 4. Sensitivity of 10-year IRR (%) to changing costs, commodity prices and management regimes

Parameter	Rainfed farming	Rainfed farming and fishing	Rainfed farming and SRI	Rainfed farming, SRI and fish culture
Baseline	53.7	56.5	61.1	77.3
Land cost included	-	-	-	-
Fertiliser cost (+50%)	52.4	55.3	60	76.2
Fertiliser cost (-50%)	54.9	57.7	62.3	78.4
Seed cost (+50%)	53	55.8	60.6	76.8
Seed cost (-50%)	54.4	57.2	61.7	77.9
Crop production value (+20%)	58.9	61.6	66.3	82.4
Crop production value (-20%)	48.4	51.4	56	72.2
Livestock/poultry co-product value (+20%)	54.7	57.5	62.1	78.3
Livestock/poultry co-product value (-20%)	52.6	55.5	60.1	76.3
Fish caught/harvested value (+50%)	53.7	58.4	61.1	86.8
Fish caught/harvested value (-50%)	53.7	54.6	61.1	67.8
MGNREGS participation (100 days)	62.6	65.3	69.1	85.2
MGNREGS participation (0 days)	53.7	56.5	60.3	76.5
Forest & aquatic resources revenue (+50%)	67.1	69.7	74.5	90.5
Forest & aquatic resources revenue (-50%)	39.8	42.9	47.5	64

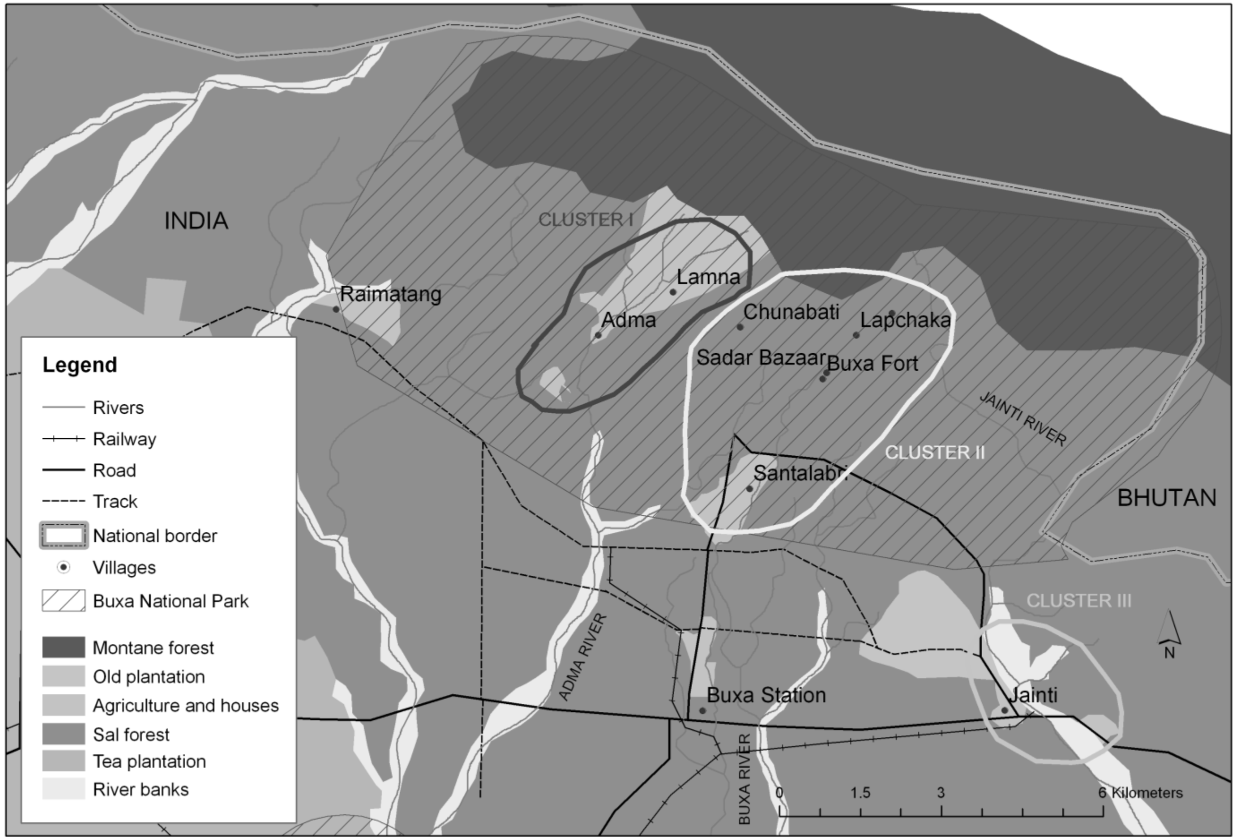
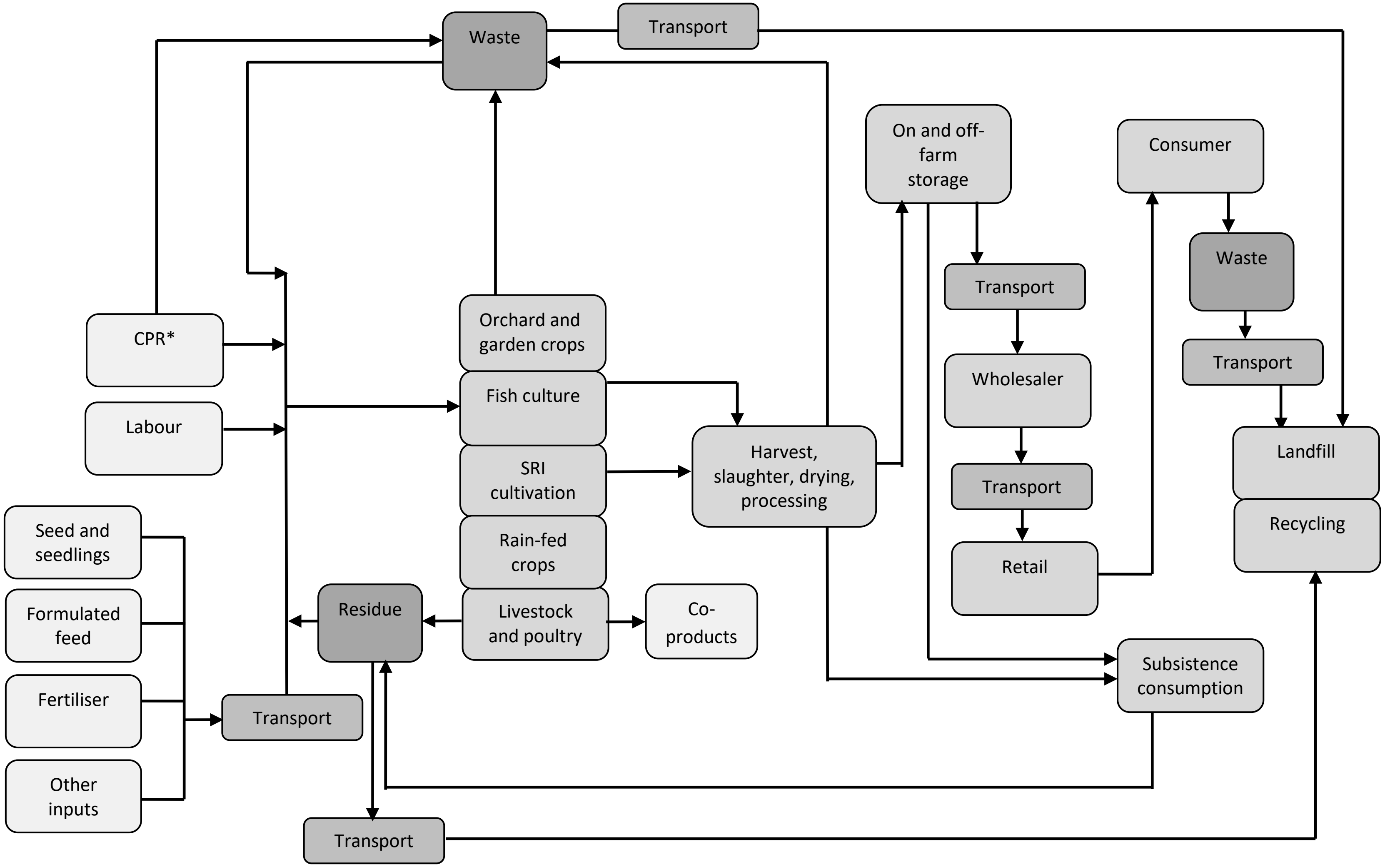


Figure 1. Map of the Buxa region (source: Ray and Mishra, 2011)



*Common Property Resources - grazing, fodder, fuel wood, aquatic resources, construction materials, NTFPs, etc…

Figure 2. High-level livelihoods strategy map for farming households in Buxa, North Bengal

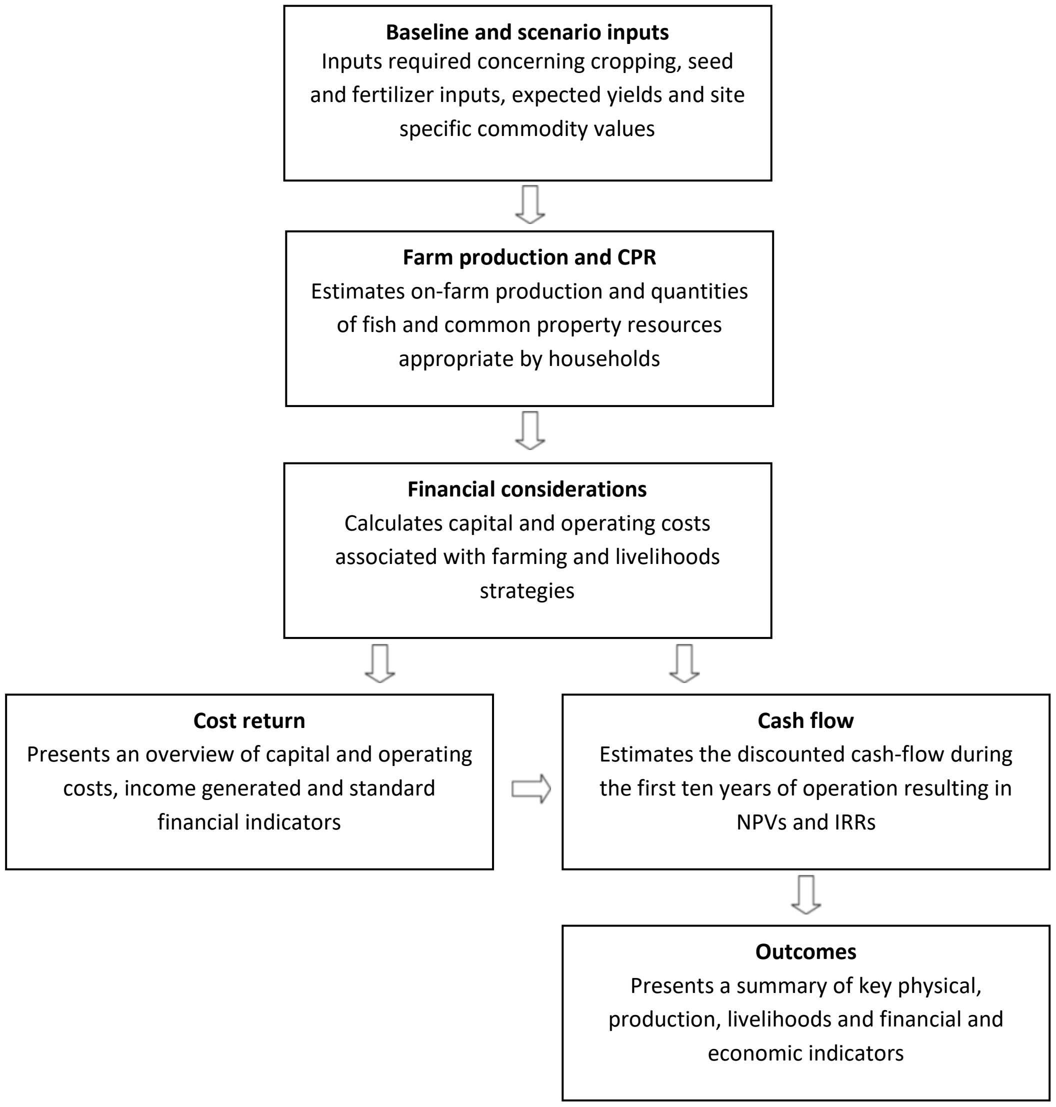


Figure 3. Bioeconomic model framework