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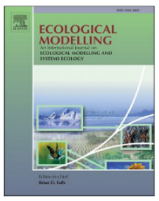

Modeling the complex associations of human wellbeing dimensions in a coupled human-natural system: In contexts of marginalized communities

Abu SMG Kibria [a,c,*], Robert Costanza [b], José R Soto [a]

[a] School of Natural Resources & The Environment, The University of Arizona, Tucson, AZ 85721, United States
[b] Institute for Global Prosperity, University College London, Maple House, 149 Tottenham Court Road, London W1T 7NF, United Kingdom
[c] Arizona Institutes for Resilience, The University of Arizona, Tucson, AZ 85721, United States

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ABSTRACT

Understanding the underlying complexity in human wellbeing formation is indispensable to maintain sustainable ecosystem services production and ensure greater human wellbeing. The interactions between wellbeing dimensions that creat the complexity are yet to be adequately understood. This study is designed to reveal the complex mechanisms shaping the wellbeing of the communities who are heavily reliant on ecosystem based livelihoods. In order to represent the robustness of wellbeing due to the economic dependency on the ecosystem services, we have taken into account six wellbeing dimensions- *food sufficiency, livelihood security, physical health, stress level* (mental), *freedom of choice*, and *social cohesion*. This study has identified the criteria of each dimension and provided empirical evidence on how the dimensions as well as their criteria influence each other. The wellbeing dimensions created a complex association that significantly shaped the wellbeing of the people. We found that *food sufficiency* was significantly influenced by not only its criteria but also the status of *livelihood security, mental health*, and *freedom of choice* which also had their own criteria sets. Similar relations were also observed in other dimensions. The findings would play a vital role in enhancing the resilience of coupled human-natural systems and thereby achieving greater sustainability.

1. Introduction

Ecosystems are capital assets that yield many "goods and services" (ecosystem services or ES) vital for world development (Suich et al., 2015; Cruz-Garcia et al., 2017). Environmental and anthropogenic changes threaten coupled human-natural systems (CHNS) sustainability and increase the vulnerability of people dependent for their livelihoods, which includes most of the world's poor (Lipper et al., 2014; Oldekop et al., 2020). In terms of wellbeing, the poor in particular have a special relationship with the ecosystems to maintain their livelihoods. Their wellbeing involves a complex set of interactions in fulfilling their material, emotional, cultural, and social needs of their families (Loveridge et al., 2020). The dynamics of wellbeing determine human reliance on ES which is a key function that influence an ecosystem's capacity to supply and societal demand for these benefits (Vallecillo et al., 2019). Sustainable ecosystem management depends on reconciling an ecosystem's capacity to supply of and demand for ES among the associated stakeholders. There is a growing emphasis in exploring the ways for attaining a balance between the supply and demand of ES (Yahdjian et al., 2015). Societal demands from the often-marginalized ecosystem dependent communities for ES are primarily decided based on their wellbeing status. Demand for specific ES varies among stakeholders who benefit from the ecosystems and thereby have an active or passive influence on the delivery of the services (Lamarque et al., 2011).

The dynamics of society and the interactions within the societal components make the interactions often unpredictable. In CHNS, societal actors influence the natural system and associated ecosystem functions through which nature supplies ES and disservices. Societal activities directly or indirectly impact the CHNS via intended management approaches or unintended side effects (Liehr et al., 2017). Hence, there is an urgent need to address the complex interactions within the ecosystem dependent communities (Martín-López and Montes 2015; Mehring et al., 2017). The Millennium Ecosystem Assessment (MA) Conceptual Framework developed a multi-dimensional concept of human wellbeing in connection with ecosystems services. The main constituents of human wellbeing identified in the MA conceptual framework are basic materials, health, social relation, security, and freedom of choice and action (MA 2005). There have been relatively few

* Corresponding author.
E-mail address: akibria@arizona.edu (A.S. Kibria).

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efforts to operationalize this multidimensional concept of human well-being (MA 2005; Leisher et al., 2013; Barrington-Leigh and Escande 2018). Furthermore, although the MA framework offers a strong foundation for a multi-dimensional nature of human wellbeing across various social-ecological dynamics, great effort is needed for revealing locally and contextually appropriate knowledge on their associations (Carpenter et al., 2009). There are significant gaps in understanding of multi-dimensional nature of human wellbeing for ecosystem dependent communities. This highlights the practical necessity of developing robust approaches for studying the dynamics of the wellbeing of ecosystem dependent communities as articulated by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Pascual et al., 2017).

Bringing upon the forest dependency study, dependence on the forest is portrayed as the function of several determinants, and foremost among them include a household's socioeconomic and demographic factors (Garekae et al., 2017; Hussain et al., 2019). For instance, Fonta and Ayuk (2013) show that the achievement of higher education reduces the dependency on forest resources because higher education attainment opens up opportunities that will ensure greater household wellbeing (Baral et al., 2019). A positive relationship shown between household size and forest dependency. Similarly, a negative association is explained between the age of household head and forest dependency (Masozera and Alavalapati 2004), though with decreasing impact after attaining a climax of physical strength (Soe and Yeo-Chang 2019). Modeling the influencing factors of forest dependency has been based on the assumption that people extract forest ES for their livelihood. But the livelihood is decided by the trade-offs of different wellbeing dimensions of the household. For instance, low level health wellbeing forces people to compromise the level of dependency and the types of services they collect from the ecosystems i.e. they fall into the illness-poverty trap (Obrist et al., 2007). Therefore, livelihood decision is also strongly dependent on the trade-offs between the wellbeing dimensions of the households.

To advance the frontiers of human-environment research we need to improve our understanding of what drives environmentally significant consumption (Stern 2000; Connolly and Prothero 2003). The research on ES and human wellbeing relations focused on the contributions of the ES provision on the wellbeing of the communities. To our best knowledge, there is no study conducted to find out how a wellbeing dimension of ecosystem dependent communities is shaped by different factors including other wellbeing dimensions (Panno et al., 2017; Wang et al., 2017; Jax et al., 2018; Fedele et al., 2021). Furthermore, most of the human well-being frameworks used in existing studies do not consider the natural environment as the platform of complex interactions of human well-being at all (Schleicher et al., 2018). Studies where the effects of natural resources management and governance on human wellbeing have been reported are founded on narrowly defined human wellbeing. These studies neither adopted a robust definition of human wellbeing (i.e. inadequate wellbeing domains), nor modeled any interactions between the wellbeing dimensions (Smith et al., 2013; Nyumba et al., 2020); thereby, are able to partially reveal the interactions between wellbeing dimensions and their indicators. Moreover, lack of robustness in defining wellbeing left many connections between the societies and nature out of the models (Maasoumi and Yalonetzky 2013).

Much of the human-ecosystem nexus research addressed the relationships between the forest and the people in terms of economic returns from ecosystems (Abdullah et al., 2016; Babulo et al., 2008). One major drawback of the traditional ecosystem-wellbeing nexus framework (Fisher et al., 2014), however is that it does not account for the multidimensional nature of wellbeing which goes beyond the financial connections between ecosystems and societies (Narayan et al., 2000). Despite growing recognition of multidimensional nature of human wellbeing, the knowledge of the interactions between the dimensions is yet conceptual (Kibria et al., 2022; MA, 2005). People negotiate the trade-offs of their dependencies on the ecosystems services according to their wellbeing needs. Hence, the understanding on wellbeing dimension interactions is crucial to explain the reasons for resource extractions by the people. This knowledge has enormous implications for designing the policies for sustainable use of ES and community development.

This is an especially concerning research gap for developing regions, challenged with multidimensional poverty and high rates of ES loss (Suich et al., 2015; Cruz-Garcia et al., 2017). This study aims to reveal the complex relations between human wellbeing dimensions and their criteria in the contexts of ecosystem dependent communities by performing regression modeling for each wellbeing dimension (Coulibaly-Lingani et al., 2011; Remröd et al., 2013). These findings would assist in understanding the dynamic nature of reconciling ecosystem-service supply and demand, and long-term strategies for ensuring the sustainability of CHNS.

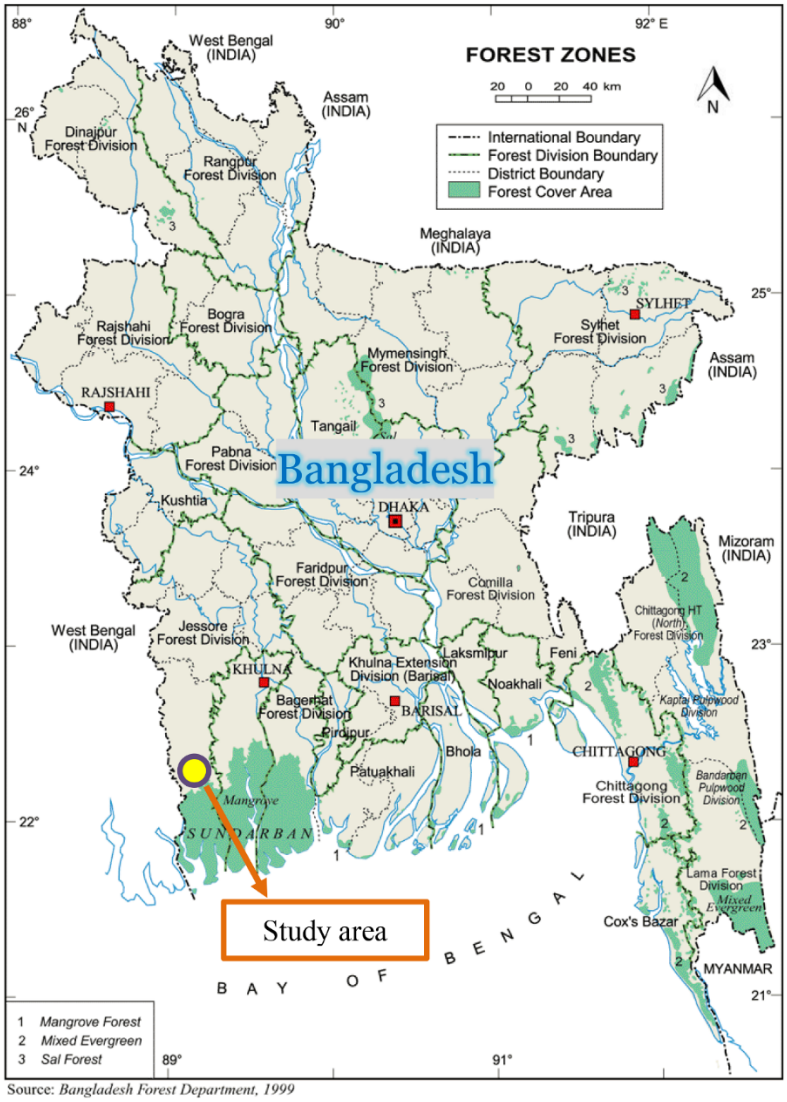
2. Methodology

2.1. Description of study area

The area along the periphery of the Sundarbans Mangrove Forest has been purposively selected for the study. This is the largest mangrove forest in the world which supplies ES to thousands of surrounding families. The households dependent on the ES mostly rely on the forests for their livelihoods, though some households engage in non-ES income (e.g. day laborer) in other areas during the lean season (Abdullah et al., 2016). It is thus an ideal coupled human-natural system for studying the interactions between the wellbeing dimensions of ecosystem dependent communities. The forest is situated in southwestern Bangladesh, located between 21°30′ and 22°30′ N and 89°00′ and 89°55′ E extending over Khulna, Satkhira, and Bagerhat districts (Fig. 1). The Sundarbans forest in Bangladesh forms the single largest contiguous mangrove forest in the world and is a unique national asset to Bangladesh in terms of its economic and ecological importance (Salam et al., 2000). It has been recognized for having such value that UNESCO declared the forest a World Heritage Site in 1999 (Hoq 2007). It covers an area of 6017km^2 among which the total land area is 4143km^2 with the remaining 1874km^2 area includesrivers, canals, and small streams (Iftekhar and Islam 2004; Wahid et al., 2007). The Sundarbans reserve forest offers a diverse resource base for local people by supplying provisioning services (PS) including honey, fish, crabs, nypa leaf, fuelwood, and timber. Shyamnagar upazila[1] was selected as a case study area due to its geographic proximity with the Sundarbans forest and amongst a network of tidal rivers (Grant et al., 2015). Shyamnagar upazila of Satkhira district is located in between 21°36′ and 22°24′ N and in between 89°00′ and 89°19′ E (Fig.1).

About 60% people of the villages around the Sundarbans forest live below the poverty line, as most of the people are unemployed (about 65%). The literacy rate of the area is between 30–45%. In the coastal environment, most people have no access to safe and clean drinking water. More than half of the villages get drinking water from sweet-water ponds (Akhter et al., 2016). The geographical location of the study area makes it prone to natural disasters (e.g. cyclones, floods, storms etc.) which cause huge losses of lives and damage livelihoods, properties, and infrastructures. One of the notable ones is Aila in 2009, which affected most of the communities along the coastline of Shyamnagar upazila (Mallick et al., 2017; Tajrin and Hossain 2017). Among the Aila-affected upazilas, Shyamnagar was the most devastated area. About 13 feet high storm surge submerged most parts of the affected areas. Consequently, almost all the water bodies became saline that left thousands of families without clean drinking water. It also caused extensive destructions of houses, roads, and embankments (Tajrin and

[1] Upazilas are the administrative entities in Bangladesh that functionally act as sub-districts. Upazilas consist of unions. Each union consists of villages.



Source: *Bangladesh Forest Department, 1999*

Fig. 1. Study area (yellow circle) on the map of the forest zones of Bangladesh (Bangaldesh Forest Department 1999) cited in (Roy et al., 2013).

Hossain 2017).

2.2. Sampling design and data collection

Our sample households were drawn from the villages of Moukhali ($N = 10$), Burigoalini ($N = 10$), Gabura ($N = 10$), Kalbari ($N = 15$), Purbo Kalinagar ($N = 10$), Kadamtali ($N = 10$), Harinagar ($N = 13$), Datinakhali ($N = 14$) and Dhankhali ($N = 12$). The list of villages and total number of households (Supplementary Table S1) in the area was collected from a local NGO record (Center for Natural Resource Studies or CNRS, Bangladesh), and from that list, we randomly selected the villages for this study. From those randomly selected villages, a total of 104 households were randomly selected. To study the dynamics of livelihood and wellbeing of the communities with livelihood homogeneity, a similar sample size has been considered representative of the population (De Oñate-Calvín et al. 2018; Kumar et al., 2019; Islam et al., 2020; Nerfa et al., 2020; Mollick et al., 2021). In general, the sample villages are homogenous in their livelihood and cultural settings. There had been intensive discussions with the local informants and NGOs to identify the village for our study. The experts from local NGOs and our team put a great amount of effort to ensure the sampling was representative and random. Instead of concentrating on a few villages, we selected 10–15 households from each village to cover larger area for capturing the full picture of the population that was similar in terms of the livelihoods and culture (USAID 2010; Abdullah et al., 2016). From the analytical standpoint, the sample size is also capable of producing robust and consistent OLS (Ordinary Least Square) model (Trædal and Vedeld 2018; Kahsay and Bulte 2019). The head of each selected household was interviewed using an interpersonal (i.e., face-to-face) communication method. The data on the different variables (Table 1) were gathered and recorded using questionnaires. In each village, we also conducted a focus group discussion (FGD), and interviewed key informants and elderly people. Key informants were selected based on their knowledge of the subject relevant to the study, and familiarity with the local people. Additional qualitative and/or quantitative data also were collected by asking additional questions about interesting issues that emerged from the original interviews.

Major ES of the Sundarbans forest are 1) Provisioning services: timber, fish, honey, crab, water, nypa leaf, and fuelwood; 2) Cultural services: scenic beauty, ecotourism, cultural traditions; 3) Regulatory Services: bio-shield against storm surges; 4) Supporting services: nutrient cycling, biodiversity conservation (Islam and Hossain 2017). Millions of people around the Sundarbans directly or indirectly live on the provisioning services (PS) supplied by the forest. In this study, we considered the PS of the Sundarbans, as the local communities were reliant on those services for their livelihood and wellbeing. We

Table 1
The model variables and their measurement units or scales.

Variable	Description	Measurement scale or unit
Ab_any	Ability to protect any threat to household livelihoods and wellbeing activities	1= always to 5= never
Ab_org	Overall ability of the organizations involved to protect ES collector's rights	1= low to 5= very high
Ag_d1	Age of the eldest daughter	Year
Ag_hh	Age of household head	Year
Ag_wf	Age of wife	Year
Bt_no	Number of own boat	No.
Cl_dw	Cleanliness level of drinking water	1= very clean to 5= very unclean
Clm_no	Number of close members in the village	No.
Cmn_12	Number of ceremonies attended last 12 months	No.
Cop_no	Number of membership of cooperatives (formal or informal)	No.
Crt_es	Certainty of finding ES in the forest	1= very certain to 5= very uncertain
Ctl_no	Number of cattle	No.
Dfd_no	Number organizations defending ES collector's rights	No.
Dis_ml	Annual disease frequency of the male members in the family	No. per year
Dst_dw	Distance of drinking water source from the house	Kilometer (km)
Ed_hh	Education level of household head	0= illiterate, 1= primary, 2= JSC, 3= SSC, 4= HSC, 5= bachelor, 6= postgraduate
Ed_s1	Education level of the eldest son	0= lliterate, 1= primary, 2= JSC, 3=SSC, 4= HSC, 5= bachelor, 6= postgraduate
Fd_pc	Amount of food required to purchase from the market	1= major, 2= moderate, 3= little, 4= not at all
FD_SUF	Level of food sufficiency	1= very sufficient to 5= very insufficient
Fem_no	Nmber of female members in the family	No.
Fin_hp	Likelihood of getting financial help from others	1= very likely to 5= very unlikely
Fin_no	Number of people provide financial help	No.
FRD_W	Freedom of choice and actions	1= very free to 5= very restricted
Frm_sz	Agricultural farm size	Hectare (ha)
Hl_aw	Level of health and disease awareness	1= very high to 5= very low
Hlp_nf	Likelihood of people provide non-financial help	1= very high to 5= very low
Liv_no	Number livelihood group a household is engaged	No.
LIV_SC	Security to continue livelihood activities	1= very secure to 5= very insecure
Lnd_sz	Total land size	Hectare (ha)
Ml_no	Number of male member in the family	No.
Oth_grp	Number of non-livelihood group a household is involved	No.
PHY_HL	Level of physical stamina/ strength of a collector	1= very low to 5= very high
Prs_sc	Level of personal security	1= very high to 5= very low
Rc_no	Number of families a household has reciprocal relations	No.
Rg_ang	Level of anger of the household head in daily life	1= very high to 5= very low
Rsk_dw	Health risk level of drinking water	1= high, 2= minor, 3= no risk
Rsk_ow	Health risk level of non-drinking water	1= high, 2= minor, 3= no risk
Rsp_oth	Level of respect between each other in the society	1= very respectful to 5= very disrespectful
Slf_cnt	Level of self-contentment	1= very high to 5= very low
Slf_est	Level of self-esteem	1= very high to 5= very low
SOC_CHS	Level of social cohesion	1= very distant to 5= very close
Src_wt	Availability conditions of drinking water sources	1= Free, safe some extent, close distance, very available; 2= unpotable, free, available, close distance; 3= costlier, safe, rare service; 4 = cheap, safe, moderate distance; 5= free, very availability, no distance, and moderately safe
STS_LEV	Level of stress felt by the household head	1= very low to 5= very high
To_inc	Total income	US$
To_mem	Total member of the family	No.
Trt_al	Overall trust level among the villagers	1= very high to 5= very low
Tst_dw	Taste level of drinking water	1= good, 2= fair, 3= bad
Wg_inc	Income from wage labor	US$

identified six types of PS such as honey, crab, shrimp fry, shrimp, mixed fish, and fuelwood collected by the people (Abdullah et al., 2016; Barua et al., 2020) by FGDs and key informant interviews in each village. Although nypa leaf was one of the major PS harvested from some specific parts of the Sundarbans, there was no nypa harvest in the study area. We considered it as a wage income here because only a few villagers migrated to others areas as day laborers for collecting nypa leaf. During collecting data on income from a particular provisioning service by the households we considered income from both sold and consumed items.

2.3. Data analysis

After collecting data and producing descriptive statistics of the model variables (Table 1, Supplementary Table S2), OLS regression models were developed to find out the associations between the criteria of their respective wellbeing dimensions. The models were formed according to the following equations (Seber and Lee 2003; McElwee 2008; Cottrell, 2003):

The simple linear model of i observations on pairs (x, y) is formalized as in Eqn. [1]:

$$y_i = \beta_0 + \beta_i x_i + \varepsilon_i \quad (1)$$

Here β_0 is the y-intercept, β_1 is the slope of the relationship, and ε is error term. The model assumptions are: $(\varepsilon_i) = 0$; $E(\varepsilon_i^2) = \sigma_i^2$; and $E(\varepsilon_i \varepsilon_j) = 0,\ i \neq j$.

In our model, x is the wellbeing dimension indicator $(x_1,\ x_2, x_3 \ldots\ldots\ldots\ldots x_n)$ and y = Wellbeing dimension $(y_1,\ y_2, y_3 \ldots\ldots\ldots\ldots y_n)$. With the estimation of coefficients values which are called $\widehat{\beta}_0$ and $\widehat{\beta}_1$, the estimated model then takes the form as in Eqn.[2]:

$$\widehat{y} = \widehat{\beta}_0 + \widehat{\beta}_1 x \quad (2)$$

The estimated error or residual associate with each pair of data values defined as in Eqn.[3]:

$$\widehat{\varepsilon}_i = y_i - \widehat{y}_i = y_i - (\widehat{\beta}_0 + \widehat{\beta}_1 x_i) \quad (3)$$

The most common technique for determining the coefficients $\widehat{\beta}_0$ and $\widehat{\beta}_1$ is OLSwhere values for $\widehat{\beta}_0$ and $\widehat{\beta}_1$ are chosen so as to minimize the sum of the squared residuals (SSR). The SSR may be written as in Eqn. [4]:

$$\sum_{i=1}^{n} \widehat{\varepsilon}_i^2 = \sum_{i=1}^{n} (y_i - \widehat{y}_i)^2 = \sum_{i=1}^{n} (y_i - \widehat{\beta}_0 - \widehat{\beta}_1 x_i)^2 \quad (4)$$

The minimization of SSR requires to calculate partial derivatives of SSR with respect to both $\widehat{\beta}_0$ and $\widehat{\beta}_1$ and set them equal to zero. This produces two equations in the two unknowns $\widehat{\beta}_0$ and $\widehat{\beta}_1$. These equations

are solved to yield the estimated coefficients. The steps are as in Eqn.[5] and Eqn.[6]:

$$\frac{\partial SSR}{\partial \widehat{\beta}_0} = -2\sum_{i=1}^{n}(y_i - \widehat{\beta}_0 - \widehat{\beta}_1 x_i) = 0 \tag{5}$$

$$\frac{\partial SSR}{\partial \widehat{\beta}_1} = -2\sum_{i=1}^{n} x_i(y_i - \widehat{\beta}_0 - \widehat{\beta}_1 x_i) = 0 \tag{6}$$

The value of $\widehat{\beta}_0$ is calculated form Eqn. [5] as in Eqn.[7]:

$$\widehat{\beta}_0 = \bar{y} - \widehat{\beta}_1 \bar{x} \tag{7}$$

The value of $\widehat{\beta}_1$ is calculated from Eqn.[6] by substituting the $\widehat{\beta}_0$ value from Eqn.[5] as in Eqn.[8]:

$$\widehat{\beta}_1 = \frac{\sum_{i=1}^{n} x_i y_i - \bar{y}\sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} x_i^2 - \bar{x}\sum_{i=1}^{n} x_i} \tag{8}$$

The complex interactions among the dimension and criteria were demonstrated by using a network analysis method. To determine the relative effect size of each criterion on the respective dimensions, standardized co-efficient values (β_i^*) was measured in Eqn.[9] for comparing the effects of different wellbeing indicator x_i on the dimension y (Fig. 2 and 3). In OLS regression model, comparison of standardized coefficients across independent variables is more appropriate because the standardized coefficients' magnitude depends on the scale of the independent variable (Kaufman 1996).

$$\beta_i^* = \widehat{\beta}_i \frac{\sigma_{x_i}}{\sigma_y} \tag{9}$$

Here, $i = 1,\ 2,\ 3$……n; and σ = Standard deviation.

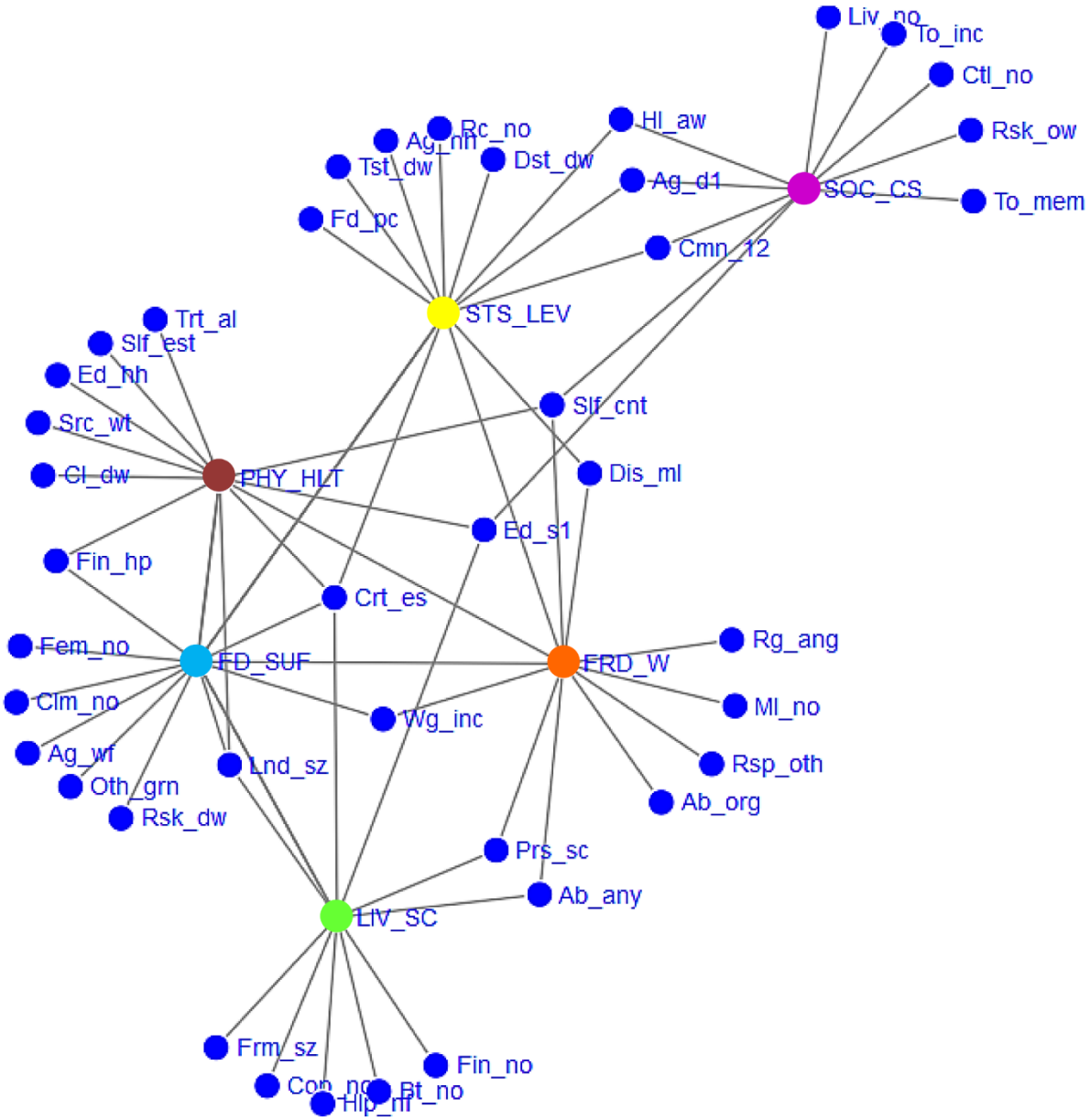


Fig. 2. Network diagram of the relations between the wellbeing dimensions and their criteria determined in the Table 3, 4, and 5. Each non-blue node is a wellbeing dimension. The blue nodes diverged from the wellbeing dimensions are the indicators of the respective dimension. The lines are showing the connections between the dimensions and indicators.

3. Results

3.1. Economic dependency on the ecosystem

The households were primarily dependent on the Sundarbans forest for their wellbeing. The average annual income of a family from the collected PS of the forest was US$934. The highest number of households was engaged in fuelwood collection (95%) followed by crab (78%), honey (49%), mixed fish (43%), and shrimp fry (31%). However, each household was engaged in collecting one or few from the list of the PS. Fuelwood was the only source of household cooking energy, hence almost all of them were engaged in fuelwood collection for their daily needs. Among the rest, crab catching required the least amount of capital (human, physical, and financial) and they were more profitable. Honey collection needed large teamwork, financial resources, and longer stay inside the forest. Mixed fish sources were in the ocean that required even more capital and time to collect. Although shrimp fry was not capital intensive, it needed the regular commitment of time and spending long hours under the scorching sun. All the PS provided relatively high income except honey and fuelwood. Shrimp fry provided the highest income (US$590yr^{-1}) composed 63% of the total family earnings followed by mixed fish (US$420yr^{-1}, 45% of total income), shrimp (US$404yr^{-1}, 43% of total income), crabs (US$310yr^{-1}, 33% of total income), fuelwood (US$156yr^{-1}, 17% of total income), and honey (US $150yr^{-1}, 16% of total income). Most of the PS accounted for high percentage of total family income because households were not collecting all the PS in the list. Only 22% families were involved in non-ES income activities (wage labor) in the lean season to earn some extra cash which accounted for only 1.94% (US$18.5yr^{-1}) of their total family income (Table 2).

3.2. Interactions among the wellbeing dimensions

3.2.1. Food sufficiency

Food sufficiency of the families was likely to be significantly and positively affected by the *stress level* of a collector, and *livelihood security*. The *stress level* of ES collectors that was caused by the daily struggles of the families forced them extracting more ES to support their family needs. Higher *livelihood security* was likely to increase *food sufficiency* of the family because of increased total income and consumption (Table 3).

On the contrary, number of non-livelihood group membership, *freedom of choice* of doing essential things for wellbeing, risk of disease from drinking water, wage income, and number of female members in the family, certainty of ES availability, and number of close member had significantly negative impacts on *food sufficiency*. Non-livelihood group membership (e.g. village club, religious group etc.) increased interactions that eventually caught up the households with more activities than their family's wellbeing. A greater level of *freedom of choice* in the society allowed them to involve in more profitable ES collection which required living inside the mangrove for an extended period leaving their families unattended to meet food demands. Increased chance of risk of water-borne diseases from drinking water would significantly reduce the *food sufficiency*, as the households were forced to invest in ensuring safe water for the family from their strained budget and/or put labor to fetch water which otherwise was used to manage food/income. Wage income was the only source of income in the lean season for many families, but the household head had to migrate to other regions of the country leaving their women and children unsecured in terms of food and nutrition. The number of female members in a family was likely to reduce *food sufficiency* of the family significantly. This was because they were not engaged in profitable ES extraction, as the job was hazardous and physically as well as mentally demanding. The certainty of ES availability in the forest hindered the necessity for going into the forest for ES thereby reducing the ability to feed the family. The close members outside one's family had strong connections and were ready to help under any circumstances. However, if the number of close members increases, households had to compromise some of their choices or actions that might reduce their family food security (Table 3).

The *stress level* of the collector (-0.314), had the largest significant positive impact on *food sufficiency* while *livelihood security* (0.286) had the least positive influence. On the contrary, the largest negative impacts on *food sufficiency* were exerted by certainty of ES availability (-0.312), reduced risk of disease from drinking water (0.292), number of non-livelihood group membership (0.236), wage income (0.206), number of female members in the family (0.20), number of close member (-0.196), and *freedom of choice* of doing essential things for wellbeing (-0.174) (Table 3).

Food sufficiency was found significantly linked not only to the demographic criteria, it also was significantly influenced by four other wellbeing dimensions (*freedom of choice, livelihood security, physical health*, and *stress level* of the collector). These dimensions were also significantly influenced by their own set of criteria. Only *social cohesion* had not had any direct significant impact on *food sufficiency* (Table 3).

The network diagram shows that *food sufficiency* was directly connected to *stress level, livelihood security, physical health,* and *freedom of choice. Food sufficiency* was also had indirect relations with *livelihood security, stress level, physical health* thorough certainty of ES availability in the mangrove forest. Household land size also played a role in connecting this dimension with *livelihood security*, and *physical health* (Fig. 2).

3.2.2. Livelihood security

The *livelihood security* was likely to be significantly and positively affected by the ability to achieve things anyway, *food sufficiency*, certainty of getting ES, non-financial assistance likelihood, personal security level, cooperative membership. The ability to achieve any desired goals or accomplish any tasks required a considerable amount of socioeconomic capitals that eventually facilitate attaining higher economic security. *Food sufficiency* was achieved by the homestead produces as well as forest ES. This sense of food security held the household heads in a better position to invest more time or money in other livelihood activities. Certainty of ES availability enhanced their sense of security in terms of livelihood activities for their wellbeing. Non-financial assistance across the society was widely available. These types of help increased the inter-personal connections in the society and led to more collaboration in livelihood activities. The tendency to helping each other tends to significantly increase the household economic security as they were mutually benefited from a higher level of cooperation and information sharing. ES collectors in the Sundarbans had to leave their families behind to collect ES from deep inside the forest. Without a good level of personal security in the village, they would not be able to engage in profitable ES collection that required 3–15 or more days living inside the forest. Memberships in cooperatives brought people together to common goals. They were also able to save money and take loans from the cooperatives. Anyone with membership in multiple cooperatives in the village tends to experience greater *livelihood security* (Table 3).

Table 2
Economic dependency of local communities on the ecosystem services of the Sundarbans forest.

Item	Average income per family (US$yr^{-1})	% of household	% of total income
Non-ES income	18.5	22	1.94
ES income	934	97	100
Honey	150	49	16
Shrimp	404	31	43
Shrimp fry	590	32	63
Mixed fish	420	43	45
Crabs	310	78	33
Fuel wood	156	95	17

Table 3
Multiple linear regression models for *food sufficiency* and *livelihood security*.

Model	Unstandardized Coefficients		Effect size	t-value	Sig.	Collinearity Statistics	
	B	Std. Error				Tolerance	VIF
Food sufficiency							
(Constant)	4.160	1.035		4.019	0.001***		
PHY_HLT	-0.154	0.087	-0.145	-1.769	0.081	0.830	1.205
STS_LEV	-0.280	0.078	-0.314	-3.600	0.001***	0.736	1.358
FRD_W	-0.115	0.056	-0.174	-2.063	0.042***	0.790	1.265
Oth_grp	0.230	0.078	0.238	2.947	0.004***	0.860	1.162
Rsk_dw	0.563	0.185	0.292	3.044	0.003***	0.608	1.645
LIV_SC	0.202	0.060	0.286	3.388	0.001***	0.787	1.270
Crt_es	-0.253	0.078	-0.312	-3.247	0.002***	0.607	1.647
Clm_no	-0.016	0.007	-0.198	-2.176	0.033***	0.680	1.470
Wg_inc	6.554E-005	0.001	0.206	2.517	0.014***	0.835	1.198
Fin_hp	-0.188	0.104	-0.155	-1.817	0.073	0.767	1.304
Fem_no	0.227	0.094	0.200	2.403	0.019***	0.808	1.238
Ag_wf	-0.014	0.009	-0.128	-1.528	0.131	0.796	1.257
Lnd_sz	-0.011	0.010	-0.090	-1.075	0.286	0.797	1.254
Model fit statistics							
Adj.R^2	*0.490*						
F-value	*7.718*						
p-value at α=0.01	*<0.001*						
Livelihood security							
(Constant)	-1.834	0.878		-2.090	0.040***		
Ab_any	0.377	0.125	0.277	3.012	0.004***	0.835	1.198
FD_SUF	0.409	0.133	0.291	3.085	0.003***	0.790	1.266
Fin_no	0.047	0.020	0.221	2.369	0.021***	0.807	1.238
Crt_es	0.384	0.104	0.348	3.694	0.000***	0.792	1.263
Hlp_nf	0.259	0.096	0.260	2.690	0.009***	0.754	1.326
Prs_sc	0.505	0.201	0.236	2.518	0.014***	0.803	1.246
Ed_s1	0.061	0.103	0.054	0.593	0.555	0.846	1.182
Lnd_sz	-0.065	0.022	-0.274	-2.878	0.005***	0.778	1.285
Frm_sz	0.012	0.005	0.246	2.598	0.011***	0.783	1.277
Bt_no	0.099	0.293	0.031	0.339	0.735	0.848	1.180
Cop_no	-0.486	0.228	-0.212	-2.135	0.036***	0.713	1.402
Model fit statistics							
Adj.R^2	*0.429*						
F-value	*6.541*						
p-value at α=0.01	*<0.001*						

*** Significant at α = 0.01 level.

On the other hand, number of people offer financial assistance, household land area, farm size (shrimp, crab) had significantly negative effects on *livelihood security* security. If the number of financially helping persons increases for a family they tend to go for more profitable ES collection which is associated with more risk and uncertainty. People with higher land area had significantly less secured livelihood activities for income primarily because they were able to compensate by doing some agricultural activities if they wanted to skip the hard work of collecting ES. Some families owned large land areas or taken over a lease often developed shrimp or crab farms and thereby decreased their *livelihood security*. Farming crabs and shrimp was albeit profitable but the production was very susceptible to total loss as they were not able to maintain scientific guidelines (Table 3).

The largest positive effect on *livelihood security* was shown by certainty of getting ES (0.348) followed by *food sufficiency* (0.291), the ability to achieve anyway (0.277), non-financial assistance likelihood (0.260), personal security level (0.236), and cooperative membership (-0.212). On the other hand, household land size (-0.274), farm size (shrimp, crab) (0.246), and number of people offer financial assistance (0.221), had a significantly negative effect on *livelihood security* (Table 3).

The network diagram shows that *livelihood security* was directly connected to *food sufficiency*. It was indirectly linked to: *freedom of choice* through the ability to achieve things anyway and personal security condition, *physical health* through certainty of ES availability and household land size, *stress level* through certainty of ES availability in the forest, *food sufficiency* through certainty of ES availability and household land size, *physical health* through certainty of ES availability, and *social cohesion* and *physical health* through education level of the eldest son (Fig. 2).

3.2.3. Physical health

It was found that any improvement in *food sufficiency*, sense of self-contentment, cleanliness of drinking water, certainty of ES, self-esteem level, and people's willingness for financial help would likely to significantly improve the *physical health* conditions of the households. The certainty of ES availability and *food sufficiency* assisted families to ensure proper food and nutrition which reduced the disease occurrence within the families. Similar, cleanliness of drinking water was likely to significantly reduce the risk of water-borne diseases in the family and society. High self-esteem inspired the collectors in collecting more profitable ES from the mangrove which might help families to maintain disease preventive measures. It was found that people were not interested or able to help each other financially. Hence, those with a lower possibility to manage some emergency money were more likely to suffer significantly from various health problems (Table 4).

It was found that any increase in the eldest son's education level, source of drinking water that is cheap and easily accessible, and household land size tend to significantly increase the risk of family members being ill. Household land gave the opportunity for farming along with the extraction of ES from the mangrove putting them into further physical and mental strains. Education level of the eldest son had also significantly negative effect on *physical health* condition of family members may be due to increased costs of educating the son and reduced

Table 4
Multiple linear regression models for *physical health* and *stress level*.

Model	Unstandardized Coefficients		Effect size	t-value	Sig.	Collinearity Statistics	
	B	Std. Error				Tolerance	VIF
Physical health							
(Constant)	8.911	0.748		11.908	0.001***		
Ed_s1	-0.170	0.063	-0.238	-2.715	0.008***	0.819	1.221
FD_SUF	-0.428	0.082	-0.450	-5.211	0.001***	0.842	1.188
Slf_cnt	-0.247	0.076	-0.296	-3.257	0.002***	0.758	1.320
Cl_dw	-0.304	0.062	-0.438	-4.878	0.001***	0.777	1.287
Crt_es	-0.309	0.071	-0.413	-4.331	0.001***	0.691	1.448
Slf_est	0.187	0.059	0.293	3.154	0.002***	0.726	1.376
Src_wt	-0.217	0.071	-0.281	-3.046	0.003***	0.738	1.356
Trt_al	-0.059	0.056	-0.091	-1.060	0.293	0.845	1.184
Lnd_sz	-0.021	0.010	-0.191	-2.108	0.039***	0.761	1.314
Ed_hh	-0.087	0.094	-0.079	-0.923	0.359	0.861	1.162
Fin_hp	-0.255	0.099	-0.222	-2.571	0.012***	0.843	1.186
Model fit statistics							
Adj.R^2	*0.485*						
F-value	*8.032*						
p-value at α=0.01	*<0.001*						
Stress level							
(Constant)	2.621	0.978		2.679	0.009***		
Ag_d1	0.036	0.018	0.205	2.043	0.045***	0.742	1.347
Rc_no	0.183	0.062	0.269	2.941	0.004***	0.895	1.117
Hl_aw	-0.370	0.122	-0.282	-3.031	0.003***	0.866	1.155
FD_SUF	-0.109	0.106	-0.102	-1.031	0.306	0.762	1.313
Crt_es	0.311	0.095	0.362	3.285	0.002***	0.615	1.626
Dis_ml	-0.131	0.055	-0.271	-2.382	0.020***	0.578	1.731
Tst_dw	-0.667	0.207	-0.325	-3.222	0.002***	0.736	1.358
Fd_pc	1.184	0.338	0.348	3.505	0.001***	0.759	1.317
Dst_dw	-0.323	0.134	-0.24	-2.407	0.019***	0.754	1.326
Ag_hh	-0.009	0.012	-0.074	-0.726	0.471	0.720	1.389
Model fit statistics							
Adj.R^2	*0.417*						
F-value	*6.586*						
p-value at α=0.01	*<0.001*						

*** Significant at α=0.01 level.

support for collecting ES (Table 4).

Food sufficiency (-0.450) showed the largest significantly positive impacts on *physical health* followed by sense of self-contentment (-0.296), cleanliness of drinking water (-0.438), certainty of ES (-0.413), self-esteem level (0.293), and people's willingness to financial help (-0.222). But the increase of the eldest son's education level (-0.238) had the highest significantly negative effect on the *physical health* condition of the households followed by source of drinking water that is cheap and easily accessible (-0.281), and household land size (-0.191) (Table 4).

Physical health was directly linked to *food sufficiency* and *freedom of choice*. It was indirectly connected to *livelihood security, stress level* and *food sufficiency* through household land size and certainty of ES availability, and *social cohesion* and *freedom of choice* through self-contentment level. The education level of the eldest son also played a role in connection with *physical health* and *livelihood security* (Fig. 2).

3.2.4. Stress level

Certainty of ES, disease frequency of male, and distance of drinking water sources would likely to have significantly negative effects on the mental stress of the household. The increasing certainty of ES in/around the forest was likely to significantly reduce the mental health condition of the collectors because higher availability of resources tempted them to collect more and thereby stimulated competitions among them. Increased disease occurance among the male members would likely to significantly increase their family *stress level.* Except for the children almost all the men were engaged in ES collection and thereby got exposed to the risks of diseases. This would not only bring them physical hardships but also limit the income of the families. With the increased water source distance, the *stress level* was likely to significantly increase mainly because of the hardship of collecting safe drinking water and extra investment that put the families under further strain (Table 4).

On the other hand, age of the eldest daughter, reciprocity with wi their neighbors, health awareness, taste of drinking water, food purchase amount would likely to have significantly positive impacts on the mental stress of the people. Raising and educating a daughter was found more expensive, hence, most of them were getting very basic primary education. With the growing age, their education and associated costs were reduced as they stopped going to school. The reduced expenditure and daughter's contributions to domestic wellbeing released some of the mental stresses of the households. In order to maintain close relations with the neighbors or close relatives, they established reciprocal relations by sharing some of their collected ES or other items. The reciprocity tends to significantly reduce their *stress level*, since it benefited them in multiple ways. Health awareness was likely to significantly improve their mental stress condition as they would be able to save their families from diseases and ensure better nutrition for all the members. Moreover, they would build trust and solidary relations with neighbors by sharing their knowledge with others. Drinking water scarcity in the study area was a constant cause of stress in the family. The job of collecting drinking water was primarily done by the female members but they all were impacted by the quality of drinking water. It was found that the improving taste of drinking water was likely to significantly relieve their *stress level*. The amount of food purchasing required for their family had significantly positive impacts on their mental health. Ability to purchase food represents the higher income of the household. In addition, they could buy their desired food items that were not available otherwise. These played multiple roles in improving their

mental health conditions (Table 4).

Certainty of ES (0.362) had the highest significantly negative impacts on mental stress of the household followed by disease frequency of male (−0.271), distance of drinking water sources (−0.24), *food sufficiency* (−0.102). On the other hand, food purchase amount (0.348) was the strongest significant contributor in improving the mental stress condition of the household followed by taste of drinking water (−0.326), health awareness (−0.282), reciprocity in the neighbor (0.269), and age of the eldest daughter (0.205) (Table 4).

Stress level was directly linked to *food sufficiency* and *freedom of choice*. It was also indirectly related to: *livelihood security, physical health, food sufficiency* through certainty of ES availability in the forest, and *freedom of choice* through the frequency of livelihood obstructing diseases of male members in the family. *Stress level* had no direct connection with *social cohesion*, however, it was indirectly related to *social cohesion* through health awareness level, age of the eldest daughter, and number of ceremonies attended last 12 months (Fig. 2).

3.2.5. Freedom of choice

Respect to each other, level of anger, general feeling of contentment, *stress level* of collectors, ability to achieve things anyway, and personal security condition of the households had significantly positive effects on *freedom of choice* of the people. Respect for each other had significantly positive impact on *freedom of choice*, as mutual respect made the collectors confident in increasing their choices of ES collection deep inside the mangrove leaving their families back in the village. It was found that anger at a moderate level had increased their *freedom of choice*. It may be because the amount of the anger was at a healthy level leading them to acquire more opportunities they deserved. Moreover, the anger level primarily was caused by the inadequacy in meeting family needs which led the household head to desperately engage in various livelihood options. The household who had a high level of self-contentment was able to maintain higher engagement in the society and thereby increased the chance of greater collaboration for maintaining their *freedom of choice* in performing the activities essential for their wellbeing. This also had reinforced their abilities in accomplishing the things that were beneficial to them. Collectors who were able to achieve desired goals by any means, experienced greater livelihood freedom than those who were not because they could overcome the challenges in involving their desired livelihood activities. The level of stress tends to significantly increase the *freedom of choice* of the collectors. In this study, we found that people had a high level of stress (2.03 out of 5) which might make them desperate to engage in livelihood and other wellbeing activities by any means i.e. the freedom increases. In order to collect profitable ES, the groups had to go deep inside the mangrove leaving their family behind for an extended period of time which not only exposed them (collectors) to forest-pirate or other hazards but also leave their remaining family members unprotected. Hence, an increased level of personal security across the society made the household head confident to freely join various ES collecting groups. In the model for *freedom of choice,* the wage income had a significantly positive impact, as this was the only way to earn a good income during the lean season (Table 5).

Disease frequency of male family members, and ability of the organization that defends them tend to had significantly negative impacts on the freedom of the households. Overall diseases occurrence in a family was the cause of increased expenditure and limited income for the families i.e. their freedom diminishes. High disease frequency of especially male members in the family was likely to significantly reduce their

Table 5
Multiple linear regression models for *freedom of choice* and *social cohesion*.

Model	Unstandardized Coefficients		Effect size	t-value	Sig.	Collinearity Statistics	
	B	Std. Error				Tolerance	VIF
Freedom of choice							
(Constant)	-4.177	1.059		-3.944	0.001***		
PHY_HLT	0.399	0.135	0.265	2.946	0.004***	0.576	1.736
Rsp_oth	0.630	0.082	0.591	7.671	0.001***	0.787	1.271
Rg_ang	0.286	0.089	0.245	3.236	0.002***	0.815	1.228
Slf_cnt	0.385	0.098	0.302	3.921	0.001***	0.787	1.271
Dis_ml	0.130	0.062	0.215	2.108	0.038***	0.449	2.228
Wg_inc	-6.652E-005	0.001	-0.144	-1.998	0.049***	0.902	1.109
STS_LEV	0.210	0.099	0.200	2.107	0.038***	0.781	1.281
Ab_any	0.277	0.108	0.163	2.570	0.012***	0.773	1.294
Ab_org	0.627	0.268	0.177	2.341	0.022***	0.821	1.218
Ml_no	-0.246	0.134	-0.130	-1.834	0.071	0.927	1.079
Prs_sc	0.376	0.177	0.156	2.122	0.037***	0.861	1.161
Model fit statistics							
Adj.R^2	*0.594*						
F-value	*12.552*						
p-value at α=0.01	*<0.001*						
Social cohesion							
(Constant)	7.679	0.874		8.786	0.001***		
Liv_no	-0.314	0.114	-0.265	-2.747	0.008***	0.894	1.119
Rsk_ow	-0.710	0.185	-0.406	-3.829	0.001***	0.740	1.351
Hl_aw	-0.513	0.124	-0.412	-4.147	0.001***	0.842	1.187
Cmn_12	-0.023	0.008	-0.270	-2.731	0.008***	0.850	1.177
To_inc	-0.001	0.000	-0.316	-3.140	0.003***	0.819	1.222
To_mem	-0.230	0.093	-0.239	-2.468	0.017***	0.884	1.131
Ag_d1	0.032	0.018	0.183	1.831	0.072	0.831	1.203
Ctl_no	-2.526	0.900	-0.276	-2.808	0.007***	0.861	1.161
Ed_s1	-0.083	0.085	-0.099	-0.975	0.334	0.807	1.240
Slf_cnt	0.226	0.102	0.233	2.215	0.031***	0.753	1.327
Model fit statistics							
Adj.R^2	*0.444*						
F-value	*6.346*						
p-value at α=0.01	*<0.001*						

*** Significant at α = 0.01 level.

freedom of choice for their livelihood. The collectors were primarily men, hence the poor health of men in the family would reduce their freedom of engaging in livelihood and other activities focusing on the family wellbeing issues. The low ability of the organizations engaged to defend people's rights was reported to significantly reduce their freedom primarily because those organizations also promoted human rights and sustainable conservation (Table 5).

Respect to each other (0.591) showed the largest significantly positive effects on *freedom of choice* followed by general feeling of contentment (0.302), level of anger of household head (0.245), *stress level* of collectors (0.20), ability to achieve things anyway (0.163), and personal security condition of the households (0.156). On the other hand, disease frequency of family members (0.265) tends to have the largest significant effects on *freedom of choice* followed by disease frequency of male members (0.215), and ability of the organization that defend them (0.177) (Table 5).

Freedom in maintaining their wellbeing activities was directly connected to *food sufficiency, physical health* of the family, and *stress level* of the household head who engaged in ES collection as well as income generation. The ability to achieve things anyway and personal security conditions created connections between *freedom of choice* and *livelihood security*, while wage income made connections between *freedom of choice* and *food sufficiency,* and self-contentment of household head established connections between *freedom of choice* and *social cohesion*, and disease frequency of male developed the relations between *freedom of choice* and *stress level* (Fig. 2).

3.2.6. Social cohesion

Increased health awareness and self-contentment was likely to significantly enhance *social cohesion*. In a closely connected society, health information were easily shared that made them more aware about the health and sanitation issues. People with greater self-contentment would likely to mentally sounder and more engaged in social activities (Table 5).

On the contrary, number of livelihood group membership, risk of non-drinking water, number of ceremonies attended annually, total income, total membership, cattle number tend to be significantly and negatively correlated with *social cohesion*. Membership for livelihood groups opened up opportunities for engaging more profitable ES collection which required the collectors to leave the house and live in a boat in the forest/ocean for 3–20 days or more depending on their personal/group choice. This made both themselves and their families less connected with society. Non-drinking water was available in common sources (e.g. village pond, river) which acted as the meeting places of the villagers. Hence, unsafe water sources restrict collegiality among the family members. Attending too many ceremonies or social events would likely to further isolate the households. This is maybe because they had to spend money from their already strained budget and thereby forced to compromise their daily social activities to engage more income generation in order to afford the increasing social costs. The number of family members was likely to reduce *social cohesion*. Larger family caused financial strain to strive for more income instead of *social cohesion*. Moreover, increased family size might create negative consequences in the family as well as their relations across the society. It is also found that increased income can significantly limit their *social cohesion*. Some families were engaged in raring cattle in domestic yard which also would like to significantly reduce their *social cohesion*, as they had less time for socializing with neighbours (Table 5).

Increased health awareness (-0.412) was the highest and self-contentment (0.233) was the least significant influencer in enhancing *social cohesion*. On the contrary, risk of non-drinking water (-0.406) had the largest negative impacts on *social cohesion* followed by total income (-0.316), cattle number (-0.276), number of ceremonies attended annually (-0.270), number of livelihood group membership (-0.265), and total family member (-0.239) (Table 5).

Social cohesion was connected to: *livelihood security* and *freedom of choice* through self-contentment of household; *physical health* and *livelihood security* through education of the eldest son; *stress level* through ceremonies attended in last 12 months, age of the eldest daughter, and awareness of health issues; and *physical health* through education level of the eldest son and self-contentment of household (Fig. 2).

4. Discussion

Ecosystem dependent communities harvest provisioning services from the ecosystem to maintain their subsistenceaccording to their wellbeing needs. Modeling the relations betweenwellbeing dimensions and their influencing factors is therefore essential to understand the relations between ecosystem and human wellbeing illustrated by the MA framework. Our study offers insights into the relations among the human wellbeing dimensions in the context of CHNS. These interactions play a vital role in determining the dynamics of CHNS (MA 2005; Kibria et al., 2018).

We developed models to analyze the relations among six wellbeing dimensions described in MA framework: *food sufficiency, livelihood security, physical health, stress level* (mental), *freedom of choice*, and *social cohesion*. In the dynamics of CHNS, none of them was mutually exclusive, as each dimension played supplementary/complementary roles to each other. Thus, we revealed both direct and indirect relations between each wellbeing dimension and the influencing factors. The studies which modeled the factors were able to find out the direct relations between the factors and outcome variables (Coulibaly-Lingani et al., 2011; Garekae et al., 2017). Such one directional interpretations of the interconnected network of components cannot be described by a few factors. Thus, the direct and indirect relations among the components capture the complexity of the wellbeing of ecosystem dependent communities (Peloquin and Berkes 2009; Gotts et al., 2019).

The *food sufficiency* dimension was strongly correlated with three (*stress level, livelihood security*, and *freedom*) out of six wellbeing dimensions which were influenced also by their own criteria. Some criteria which were not significant in the *food sufficiency* model, but found significantly affected other dimensions (e.g. household land size affected *livelihood security* but not *food sufficiency*) that indirectly influenced *food sufficiency*. Mental stress, security of continuing livelihoods, and freedom in pursuing their wellbeing offer necessary motivations and opportunities to continue managing enough food for their families (Yamanouchi et al., 2018; Abdullah et al., 2019). Such interconnectedness of the *food sufficiency* dimension with other dimensions makes food security improving programs very complex endeavors (Sage 2013). The *livelihood security* was influenced by the *food sufficiency* dimension of their wellbeing. Environmental and anthropogenic effects on food markets pose community-wide risks to the food supply of the family that eventually affects the *livelihood security* dimension (Lipper et al., 2014). Enhanced livelihood resilience of the people in CHNS can be achieved by not only addressing issues exclusive to the *livelihood security* dimension but also extending the focus on the influencing criteria of *food sufficiency* (Islam et al., 2013; Lipper et al., 2014). The *physical health* dimension was significantly influenced by the *food sufficiency* dimension. Thus, *physical health* wellbeing was the result of complex associations of the criteria of both dimensions. It is evident in many parts of the world that good *physical health* conditions of the households offer greater access to livelihood assets (Smith et al., 2017; Abdullah et al., 2019). The model of *stress level* shows that *food sufficiency* is one of the significant criteria contributing to developing the *stress level* dimension. Greater *food sufficiency* had a strong correlation with physical and mental health which eventually contributes to mental wellbeing (Nagata et al., 2019). The *freedom of choice* dimension was significantly influenced by the *physical health* and *stress level* dimensions. Higher physical and mental health make people more active in social activities and engage diverse livelihoods (Zimmerman and Bell 2006). Surprisingly, it was found that the *social cohesion* dimension was not directly connected to any other wellbeing dimension. Thus, improving *social cohesion* would be simpler

than other wellbeing dimensions. This relation can be turned into a force for collaborative governance and sustainable conservation of CHNS (Borg et al., 2015; Auer et al., 2020).

The complex associations of the household's wellbeing dimensions create a combined response to build their resilience against the vulnerabilities (Paavola 2008; Alam et al., 2018). The studies identifying the factors of human wellbeing dimensions by a single model cannot capture the complexity of the multidimensional human wellbeing (Reincke et al., 2018). The trade-offs between the dimensions eventually determine the adaptive capacity of CHNS. Given the complexity in the interrelations of social components in the dynamics of coupled CHNS, future research should focus on revealing them at various temporal and spatial scales. This also highlights the importance of exploring the complexity in the ecological systems and how both social and ecological elements interact with each other. This information would greatly benefit in achieving global environmental sustainability (Moore 2015).

5. Conclusion

Natural ecosystems offer myriad goods and services to the society and thereby playing a crucial role in shaping human wellbeing across the world. Social and ecological components of CHNS are intricately related to each other. The interactions between the human wellbeing dimensions eventually shape the resilience and adaption capacity of CHNS in the face of any anthropogenic and environmental change. MA framework hypothesized the relations and the strength of the connections between ES and human wellbeing components but lack recognition for the interactions shown within the wellbeing components. These complex relations determine the attributes of the CHNS and are vital to decide the sustainable goals for CHNS. Our study empirically revealed the complex interactions both within and between the wellbeing dimensions. There is still a very limited understanding of the formation of wellbeing dimensions and how the interactions influence the wellbeing status of the communities in the dynamics of CHNS. The study would greatly benefit in developing an indicator framework and applying it to reveal the interactions in the CHNS and thereby assist in sustainable policy decisions.

6. Limitations of the study

The interactions between the wellbeing dimensions of the ecosystem dependent communities have been presented based on a case study in the Sundarbans Mangrove Forests, the largest single mangrove forests in the world. The results presented here may not be application in other regions. In order to have greater understanding on the issues more, large transdisciplinary studies are required to perform on various ecosystems in the world.

Credit author statement

Abu SMG Kibria: Conceptualization, Methodology, Data Collection and analysis, Visualization, Writing- Original draft preparation, and Revisions; **Robert Costanza**: Review, Editing, and Critical feedback; **Jose Soto:** Critical feedback.

CRediT authorship contribution statement

Abu SMG Kibria: Conceptualization, Methodology, Visualization, Writing – original draft. **Robert Costanza:** Writing – review & editing. **José R Soto:** .

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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