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Understanding local ecosystem dynamics in three provinces of the lowlands of Nepal

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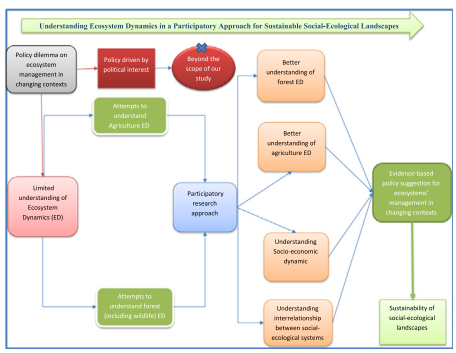
HIGHLIGHTS

- Policy failure of ecosystem management is due to a poor understanding of their dynamics (ED).
- Understanding of ED is dependent on socio-economic possessions.
- Technology is crucial in expediting ED apart from anthropogenic and climatic factors.
- Water regime dynamic finds a pivotal attribute in catalyzing ED.
- Radical alteration of ecosystems' attributes needs imminent decisions to withstand it.

GRAPHICAL ABSTRACT



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ABSTRACT

Incidences of failure of sustainable ecosystem management policies, especially in the developing world are partly attributable due to a lack of political will and inadequate understanding of ecosystem dynamics (ED) at the local levels. In this study, we endeavor to comprehend the dynamics of two ecosystems – forest and agriculture – by employing a resource-friendly participatory approach based on stake-taking the experiences of indigenous and forest-dependent local stakeholders in three lowland provinces of Nepal and is guided by the theory of socio-ecological concept. An in-depth survey ($n = 136$) was conducted using semi-structured questionnaires, key informant interviews ($n = 9$), and focus group discussions ($n = 4$) for data generation, and generalized linear models were used to test whether understanding of ED is uniform across the socio-ecological landscape. We identified that various attributes of forests and agricultural ecosystems have altered substantially earlier than 30 years (hereafter, earlier decade) relative to the present (hereafter, later decade). Apart from the natural processes including anthropogenic and climatic factors, technological innovations played a significant role in altering ecosystems in the later decade. Understanding of ED among forest-dependent stakeholders significantly varied with respect to gender, occupation, age group, gender-based water fetching responsibility, and water-fetching duration, however, no significant correlation was observed with their level of education across the landscape. The studied ecosystem attributes significantly correlate with water regime changes, signifying that water-centric ecosystem management is crucial. The attributes that observed significant dynamics in the forest ecosystem include changes in forest cover, structure and species composition, the severity of invasive species, wildfires, water regimes, and abundance and behavioral changes in mammals and avifauna. The alteration of crop cultivation and harvesting season which results in a decrease in yield, increased use of chemicals (fertilizers and pesticides), an increase in fallow land, and the proliferation of hybrid variety cultivation in the later decade are

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significant disparities in the dynamics of the agriculture ecosystem. To withstand the accelerated ED, stakeholders adopt various strategies, however, these strategies are either obtained from unsustainable sources entail high costs and technology, or are detrimental to the ecosystems. In relation, we present specific examples of ecosystem attributes that have significantly experienced changes in the later decade compared to the earlier decades along with plausible future pathways for policy decisions sustaining and stewardship of dynamic ecosystems across the socio-ecological landscape.

1. Introduction

Ecosystems are understood as the natural systems of interrelationships between and among the living and non-living elements of the environment (Guggenberger et al., 2020). These are broadly categorized into two, viz., terrestrial and water ecosystems (Walter and Box, 1976). As human beings are a part of the terrestrial ecosystem, they not only influence the natural terrestrial ecosystem by acting on it but also depend on them for livelihood (Díaz et al., 2019) by obtaining the services that people realize from the ecosystems — termed as ecosystem services (ES) (Aryal et al., 2022; Lamothe and Sutherland, 2018). As a part of the ecosystems, mankind interacts with different ecosystems differently, more frequently with agriculture and forest ecosystems (MEA, 2005). So, forest and agriculture ecosystems are relatively more concerned for people if they are being changed over a temporal and spatial scale.

Ecosystem dynamics (ED) — can be generally understood as changes in environmental conditions causing changes in the structures and/or function of ecosystems (Hobbs et al., 2013). In the natural system, wild animals play significant ecological roles that go beyond their immediate requirements for food and habitat. In many cases, they are responsible for chemical, successional, and landscape alterations that may persist for centuries (Naiman, 1988). In recent decades, however, such functioning of the ecosystem processes are accelerated by climate change and other anthropogenic disturbances (MEA, 2005; Smith et al., 2009). For examples, ED vary with different environmental conditions (Pandey et al., 2020), changing climatic variables (Zhang et al., 2019), anthropogenic disturbances (Pandey, 2021), and socio-economic realization (Paudyal et al., 2017). However, there is still a lack in understanding about the attributes of an ecosystem which has experienced radical changes as a result of various drivers. Furthermore, it is difficult to ascertain how certain ecosystem attributes can be revived/restored or adapted if they have experienced radical alteration, particularly in forest and agricultural ecosystems.

Globally, various approaches are used for monitoring ED. Some of these approaches include establishing permanent plots for the long-term monitoring (Zhang et al., 2019), using ecological-community linkage under meta-ecological theory (Massol et al., 2011), and tree dynamics modeling (Seidl et al., 2012). Other approaches include modeling ecosystem, species replacement, laboratory incubation, isotope tracers, greenhouse facilities, surveys, and space-for-time (Luo et al., 2011). These tools and techniques bear high level of resources, technical expertise and require long-term patience. In contrast, observation and experience-based assessments on ED are under practice across the world (Burrascano et al., 2013; Danell et al., 2006; Woods et al., 2020) and coordinated approaches to understand long-term ED (Luo et al., 2011) which are less resource consuming, simple and efficient as well. Studies carried out so far on ED explore distinction between structures, processes, services, benefits, and values of ecosystem attributes (Saarikoski et al., 2015), and focused on the perception in a socio-ecological context (Quintas-Soriano et al., 2018). In Nepal, they primarily focused on ES from the lens of community-ecological interactions, and economic valuation (Bhandari et al., 2016; Kunwar et al., 2020; Maraseni et al., 2014; Paudyal et al., 2018). However, these studies failed to understand ED from the perspective of dynamic socio-ecological attributes. Although, ES alters by socio-economic and demographic factors as well as a combination of these factors, such dynamics on attributes of ecosystem and their relationships with social, environmental, cultural, and technological aspects are poorly assessed so far across the world (Grigg, 2019; MEA, 2005).

Spatial and temporal knowledge of ED is crucial for the sustainable management of the ecosystems. This is because ED might follow nonlinear variation and may undergo accelerating, abrupt or irreversible changes in response to anthropogenic disturbances at a localized context (MEA, 2005) and therefore, the involvement of local people who are both the drivers and observers of the dynamism is crucial in the participatory planning process to manage ecosystems at various spatial and temporal scale (Liu and Opdam, 2014). Such variation of available ES and the potential for mediation differ in different ecosystems and regions (MEA, 2005). Thus, exploring the local level ED becomes pivotal for decision-making since some of the attributes of ecosystems have a local to global impact such as carbon sequestration (Maraseni et al., 2007, 2016; Pandey and Bhusal, 2016), water regime changes (Barnett et al., 2005), understand for safeguarding the ecological and social systems (Armsworth et al., 2007; Pandey et al., 2020), land use planning, and landscape level decision-making (Zoderer et al., 2019). In Nepal, the participatory planning and decision-making process has provided a model showcase in participatory forest resources management for >40 years (Gilmour and FAO, 2013; Pandey and Pokhrel, 2021a), and therefore, understanding ED adopting a participatory approach in reference to forest-dependent communities at local level would provide a solid foundation for facilitating decision-making to satisfy national and international commitments (Aryal et al., 2020a, b).

Life history experiences-based on perception of the local people is a credible approach in understanding ED practice across the world. For example, traditional knowledge-based historic experience in Alps Mountain in Switzerland (Bürgi et al., 2013), in Africa (Quintas-Soriano et al., 2018), and in Nepal (Aryal et al., 2021; Bhandari et al., 2016), have assessed changes and evaluates ES (Lamothe and Sutherland, 2018; MEA, 2005). Majority of them particularly focus on a single ecosystem such as a forest (Bürgi et al., 2013) or a grassland (Guo et al., 2021; Liu et al., 2019) or a wetland ecosystem (Orimoloye et al., 2020), or climate dynamics in connection to these ecosystems (Guo et al., 2021; Hoover et al., 2014). But past research lacks the understanding of: 1) combination of multiple ecosystems (forests-including wildlife dynamics and agriculture) dynamics; 2) dynamics from ecosystems' attribute-lens but not from drivers' lens; and 3) dynamics in a participatory approach at the local level from the experience of forest-dependent stakeholders' perspective across a socio-ecological landscape. Realizing these facts, this study is guided by the theory of socio-ecological system change (Costanza, 2014) that local-level institutions, norms and practices could be the drivers apart from the evolutionary process of ecosystem dynamics at local level (Ostrom, 2014) to better understand the dynamism of socio-ecological landscape.

In this context, this research is aimed to assess visible/notable changes experienced by the local level forest-dependent stakeholders. It is because, forest dependent actors have observed the changes on forest and agriculture ecosystems' attributes before 30 years (earlier decade) compared to the 30 years back (later decade — at present) across the socio-ecological landscape to address the challenges on global ecosystems management. Taking a case of lowland of Nepal, we conducted in-depth oral history interviews, employing semi-structured questionnaires, focus group discussions with local and indigenous communities, and key informant interviews to understand structural and functional changes in ecosystems under various environmental and socio-ecological interfaces as observed and experienced by forest-dependent local communities. We hypothesize that there were no significant differences on the characteristics of ecosystems before and after 30 years since the ecosystem dynamics is the natural process and required long-term experiments (Luo et al., 2011), and the understanding/realization was indifference among the forest-dependent stakeholders across the landscape. To test these hypotheses, we purposively selected three districts from three provinces (one from each) along the same socio-ecological landscape of lowland of Nepal. Then, generalized linear models (GLM) were used to test the hypotheses, and accordingly, we have discussed critical findings of the analyses and suggested few future pathways for sustainable management of ecosystems considering their dynamics.

1.1. Study area

This study was conducted in three districts of Nepal, representing the three provinces (i.e., Chitwan from Bagmati Province, Saptari from Madhesh Province, and Jhapa from Province 1) (Fig. 1). The districts were selected based on their special importance having 1) crucial importance in terms of agricultural productivity for national use; 2) plenty of forest-dependent communities; 3) having forest-dependent indigenous and marginalized communities; 4) belongings in the same socio-ecological landscape in the lowlands; and 5) had a majority of primary livelihood rely on agriculture farming. After finalizing districts for the study, the forest-dependent local stakeholders were mapped based on the National REDD+ Strategy of Nepal on local-level stakeholders mapping guideline (MoFSC/REDD, 2015). The strategy is the foremost policy document that guides mapping forest stakeholders for ES management and provides a basis for regulating forest ES such as carbon credit from the forests to the (sub)national level (13 districts out of 77) in the country (REDD/MOFE, 2018).

2. Methodology

2.1. Methodological framework

To understand the ecosystem dynamics, various approaches have been employed across the globes as mentioned earlier. Among such approaches, traditional ecological knowledge while interacting with ecosystems so as to experience by the local people throughout their life time is also a credible method (Trosper and Parrotta, 2012). Realizing the fact of resource availability for the study and the simplifying the techniques, oral history interviews were performed with the local level forest-dependent farmers as suggested by Bürgi et al. (2013).

The indicators were selected and customized for agriculture dynamics by referring the attributes on a research carried out in India examining from vulnerability lens (Swami and Parthasarathy, 2021) by slight modification and selective inclusion in the Nepalese context with the due consultation to a group of expert. Similarly, indicators for understanding forest ecosystem dynamics for this study were referred from the earlier researches (Bürgi et al., 2013; Naiman, 1988; Zeng et al., 2021) with the modification and contextualizing at local socio-ecological landscape and considering the study approach (participatory) as suggested by a group of expert during the consultation prior to the commencement of this research. We then collated the background information of the study sites; few notable and simple variables were finalized with the discussion of the stakeholders in pre-scheduled workshop and with the research team (Table 1). Because of the sparse studies on ecosystem dynamics not from the drivers and change on ecosystem service lens but from the ecosystems' attribute dynamic perspective, this study had conceptualized the inputs, process, outputs, outcomes, and impact framework of the study to enhances the understanding of ecosystem dynamics for the healthy social-ecological ecosystem stewardship in the global changing context (Fig. 2).

2.2. Empirical data collection

In the beginning, a two-day workshop was organized to aware people about the aim and objectives of our study and to collect preliminary information. Participants for the workshops were invited following the guideline of forest-related stakeholders mapping of the government of Nepal (MoFSC/REDD, 2015). Additional considerations to that of stakeholders

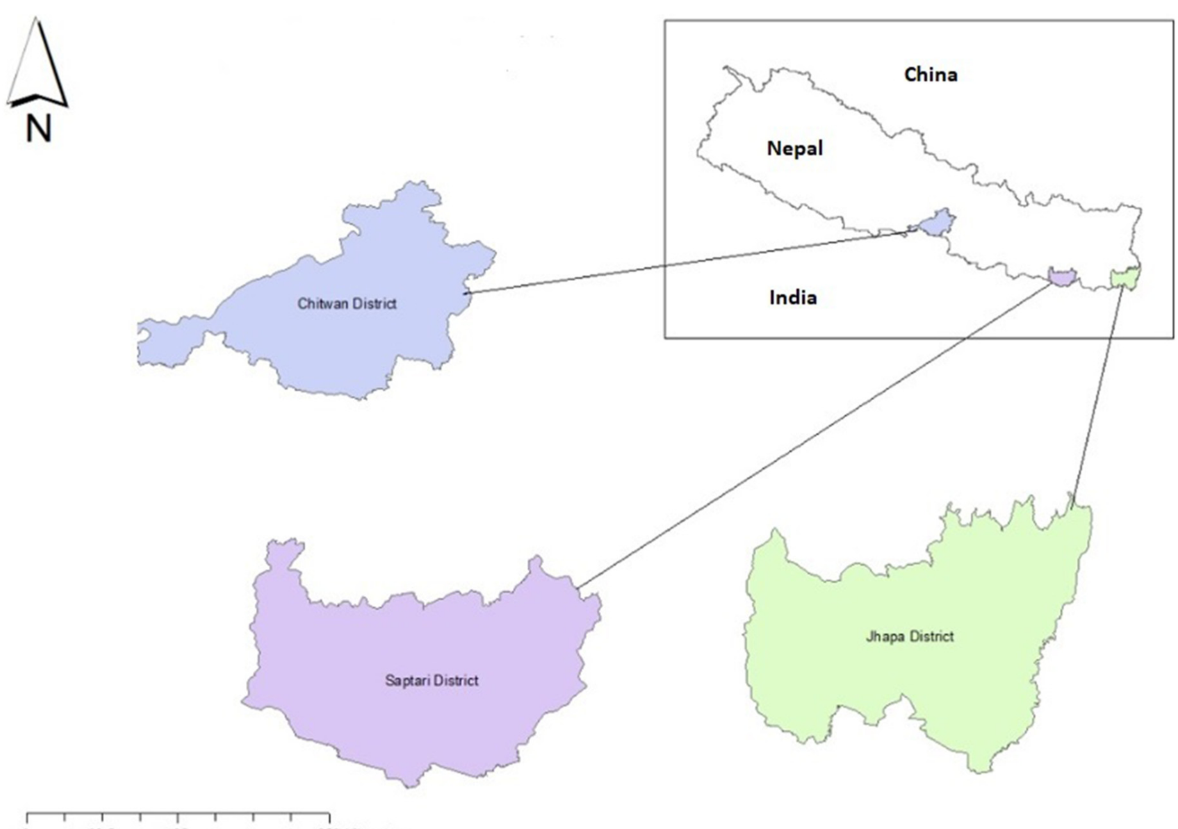

Fig. 1. The map of Nepal showing the study area sharing a similar socio-ecological landscape (lowland).

Table 1
Description of the attributes of ecosystems (both dependent and independent) those taken into consideration for the study to understand ecosystem dynamics across the socio-ecological landscape of lowland, Nepal.

Code	Dependent variables (first 4 are forest- and the last 5 are agriculture-related)	Code	Independent variables (categorical unless otherwise stated)
Ya1	Forest cover decreased (if yes = 1, 0 otherwise)	Xa1	Who involves in water fetching (if females involve = 1, 0 = males)
Ya2	Forest species composition changed (if changed = 1, 0 otherwise)	Xa2	Additional time to fetch water (hours) (numeric) compared to earlier decade
Ya3	Wildlife abundance (if changed either increase or decrease = 1, 0 = indifference)	Xa3	Reason of decreased crop production (if due to climate change = 1, 0 otherwise)
Ya4	Wildlife behavior (if changed = 1, 0 otherwise)	Xa4	Enhancing crop production (if adapted traditional adaptation measures = 1, 0 otherwise)
Ya5	Major crops cultivation season pre- or post-pone (if changed = 1, 0 = indifference)	Sex	Respondents, if females = 1, 0 = males
Ya6	Major crop harvesting season (if changed = 1, 0 = indifference)	Education	Respondents' education (if primary level = 1, 0 otherwise)
Ya7	Major crop production (if decreased = 1, 0 otherwise)	Age	If the age of respondents ≥ 50 = 1, 0 otherwise
Ya8	Crop cultivation with local adaptation strategies = 1, 0 = left fallow)	Profession	Major profession (if agriculture = 1, 0 otherwise)
Ya9	Pest infestation in agriculture crops (if increased = 1, 0 otherwise)	Address	Chitwan, Jhapa, Saptari
		Xa5	If respondents have private forests = 1, 0 otherwise
		Xa6	If household energy used by respondents was non-bioproduct and dung = 1, 0 = fuelwood)
		Xa7	Likelihood of changing household energy into cleaner energy source = 1, 0 = use fuelwood
		Xa8	Used alternative of wood/timber (if non-renewable = 1, 0 = renewable resource)

mapping policy were the participants: (1) should be old enough (>50 years of age) to witness ecosystems dynamics; (2) should be regular users of forests for over decades (>30 years); (3) should have been involved in forest-related business or direct concerns to forests for at least three decades back; and (4) have experience on the ecosystem changes and adaptation strategies against such radical ecosystem changes. This 30-year cutoff point was used because there was a different political governing system (monarchy) earlier than 30 years (the re-establishment of the democracy was held in Nepal in 1990) when there were different governing systems of natural resource management compared to later decade (after 30-year), and climatic attributes are considered at least for 30 years to understand climate change if climate change could be the prime ED driver. Stakeholders who met those criteria were invited to participate in a two-day workshop in each selected district to sensitize the participants on climate change, ED, and sustainable forest ecosystem management. Further, they were encouraged and facilitated to share their experiences on the changes that they have observed and experienced in the agriculture and forest ecosystem for their lifetime.

Oral interviews (n = 136) were carried out using a semi-structured questionnaire. The sample semi-structured questionnaire was translated into the local (Nepali) language (S1_Supplementary file). In the beginning, the draft questionnaire and checklists were pre-tested and refined with five people. Most of these questions were close-ended questions allowing respondents to choose from given possible options together with some

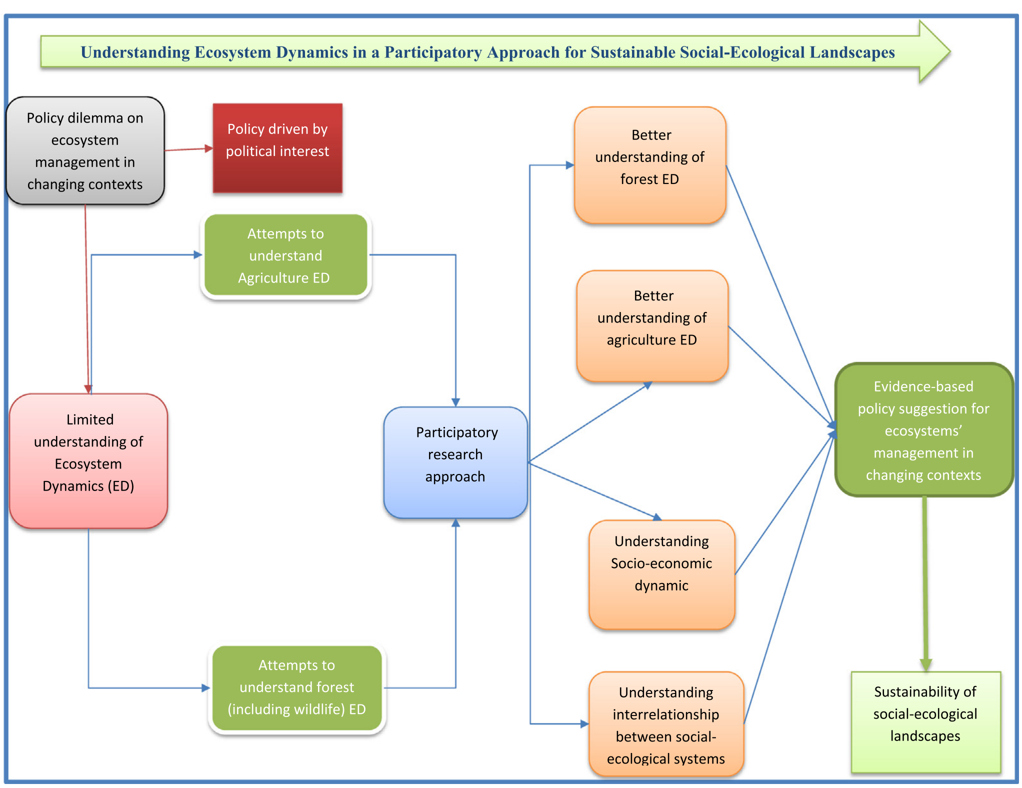

Fig. 2. The conceptual framework of the study and plausible implications.

open-ended questions to capture comprehensive information. The detailed responses to the open-ended questions (S2_supplementary file) and key summary (S3_supplementary file) are provided separately.

2.3. Attributes of ecosystem dynamics under consideration for the study

ED is context- and decision-specific for a site and its dynamism is perceived accordingly. Various ES are outlined globally and to a particular nation including Nepal. Considering the socio-economic, ecological, environmental context and variables' characteristics, selected attributes of two ecosystems (forest and agriculture) were considered (Table 1).

2.4. Characteristics of the respondents

Out of 136 respondents of a questionnaire survey, 38 %, 35 %, and 27 % were from Chitwan, Jhapa, and Saptari districts respectively, and 35 % of participants were women. Most of the stakeholders (71 %) completed their schooling and 29 % enrolled tertiary education. Similarly, the dominant occupation of the local stakeholders was agriculture (67.64 %) and was purely forest-dependent primary forest users, followed by civil servants (26.47 %) working for forest ecosystem management, political bodies (3 %), and people involved in the education field (3 %) relating to forests and agriculture in one or other ways. The rest of the respondents did not respond to their profession.

2.5. Data analysis

We developed two models to examine characteristics associated with ED. First, we tested whether the social possession of the respondents had any linear regressive relationship with other variables as defined in Table 1 using model 1.

$$Ya = f(Xa_i)\dots \tag{1}$$

where Ya refers to the binomial response variable of the profession, sex, education, and age, and the numeric variable of increased water fetching time (hours) under the context of ED; f is the function (a binomial distribution with logit function except for water fetching time (a gaussian distribution with identity link); and Xa_i ($Xa1, Xa2, \dots, Xa8$) are the predictors as defined in Table 1.

Second, model 2 was designed to capture the linear regressive relationship of the ED. Specifically, four forest-related dependent variables such as forest cover, forest species composition, wildlife abundance, and wildlife behavior were considered while five agriculture-related variables such as major crop cultivation season, major crop harvesting season, the status of major crop production, strategy if decreased crop production, and increased pest infestation in agriculture. All the response variables were customized into binomial structure (Table 1) and tested using the logit link function.

$$Yb = f(Xb_i)\dots \tag{2}$$

where Yb refers to the dependent variables considered for this study as assigned in Table 1 (attributes of forest ecosystems = $Ya1$, $Ya2$, $Ya3$, and $Ya4$; and attributes of agricultural ecosystems = $Ya5$, $Ya6$, $Ya7$, $Ya8$ and $Ya9$); f considers link function as defined in Model 1, and Xb_i ($Xa1$, $Xa2$, …, $Xa8$ and *variables of social possessions*) were the independent variables as mentioned as indicated (Table 1). Almost all response variables were customized into binomial distribution to fit generalized linear model (GLM), binomial distribution with logit-link function unless otherwise stated. These tests were tested in R (R Core Team, 2022).

3. Results

3.1. Relationship of the social possession of respondents with variables of ecosystem dynamics

The social possession (profession, sex, education, and age) and provinces are found to have significant positive linear relation with water fetching hours and understanding on forest species composition. We found significant negative relationship of those social possession and the provinces with understanding on increased use of wood alternative (non-renewable resources), age group, and reduced forest cover. The female respondents' responses show a significant positive correlation with females involved in water fetching and agriculture profession across the study area (Table 2).

We found no linear relationship of education of the respondents of any other tested variables against it. The age-group has a positive significant relationship with involvement of gender in water fetching and districts. Although there was no significant variation in gender-specificity on water fetching chores across the region, this chore has a significantly positive relationship with willingness to change household energy (fuelwood to cleaner system) and increased wildlife abundance in the forest. Increased water fetching hours response has significantly different among the profession of the respondents, however, has a negative significant relationship with the level of education (Table 2). Water fetching duration was a numerical variable that we were asked if water fetching duration increased or decreased due to ecosystem dynamics occurred in later decade compared to earlier decade? Respondents reported that there was a significantly increase ($p < 0.05$) in water fetching time on an average of 0.41 h (25 min) in later decade as compared to the earlier decade.

3.2. Relationship of major attributes of ecosystem dynamics

We found that there was a significantly different understanding on forest cover change across the region. Forest species composition dynamics were linearly but significantly associated with the proliferation of use of mine products such as iron and aluminum in place of wood (Table 3). In other words, bio-product (timber) replaced by those mine products at household's structural uses. However, there was a weak association (at 10 % significant level) of understanding on forest species composition dynamics with decreased in major crops' production primarily due to infestation of pests in recent decade. A weak relationship observed between increased wildlife abundance in the forest with the possession of private forests and use of alternative of firewood as a primary energy source at household. There was weak linear association of changes in major crops' harvesting season with increased use of mine products as an alternative of timber across the socio-ecological landscape (Table 3).

3.3. Examples of perceived dynamics of remarkable ecosystem attributes

Most of the experiences were reported on the forest cover change and observation of wildlife behavior dynamics. Increased infestation of invasive species, forest cover, and species composition dynamics observed by the forest-dependent local community across the landscape (Table 4). Some of the adaptation strategies against radical ecosystems' attributes change in later decade were; adopting new crops varieties, increased use of chemical fertilizers and pesticides, maintaining greenery around the houses, increased used of electric appliances, increasing investment in cooling domestic systems, limiting mobility on hot days, wearing seasonal clothes, and increasing water consumption for domestic purposes. The details and district-specific findings have been presented separately as supplementary files (S2_supplementary file and S3_supplementary file).

4. Discussion

We find a significant linear relationship of understanding of ED based on social possession of the respondents and variables of ecosystems. The

Table 2
Response against the social possession of the respondents upon various variables of ecosystems considered for the study (both forest ecosystem and the agriculture ecosystem).

Variables (dep. in rows/indep. in column)	Profession	Sex	Education	Age	Gender involves in water fetching	Increased water fetching hours
Xa1	−1.855e+00. (1.077e+00)	4.5894** (1.5171)	7.691e+01 (9.548e+04)	2.4762* (1.0517)	–	−0.218038 (0.171164)
Xa2	1.904e+00** (6.050e−01)	−1.9394** (0.7436)	−3.815e+01 (3.957e+04)	0.7045 (0.5651)	−2.191e−01 (7.000e−01)	–
Xa3	−3.001e+00. (1.576e+00)	−2.0832** (0.7857)	1.592e+01 (8.071e+04)	−1.3245* (0.6452)	5.090e−01 (1.026e+00)	−0.179720 (0.115926)
Xa4	1.469e+00 (1.085e+00)	−0.6696 (0.8154)	4.551e+01 (4.531e+04)	−1.8412* (0.9029)	−4.649e+01 (2.915e+04)	0.086040 (0.152264)
Xa5	−1.305e+00 (1.107e+00)	0.2410 (0.8493)	−2.658e−01 (2.706e+04)	−0.7462 (0.7311)	7.022e−01 (1.162e+00)	0.092114 (0.134962)
Xa6	−1.883e+00 (1.284e+00)	−0.2017 (0.8988)	−5.179e−01 (5.183e+04)	−0.6875 (0.9948)	−1.796e+01 (4.800e+03)	0.008970 (0.176118)
Xa7	1.505e+00 (9.941e−01)	0.9810 (0.7154)	2.868e−01 (3.738e+04)	−0.3233 (0.7228)	3.455e+00* (1.673e+00)	−0.092849 (0.119855)
Xa8	−2.337e+00* (1.147e+00)	−1.3196 (1.0241)	4.248e−02 (5.081e+04)	−1.2599 (0.9025)	2.521e−02 (1.231e+00)	0.031409 (0.165467)
Sex	3.581e+00* (1.689e+00)	–	−7.854e+00 (1.003e+05)	−1.0379 (0.7537)	1.570e+00 (1.643e+00)	−0.125212 (0.144182)
Education	2.575e+01 (2.381e+03)	−1.3183 (1.1212)	–	3.5137** (1.1339)	2.659e+01 (2.688e+04)	−0.473104** (0.172880)
Age	−3.584e+00* (1.730e+00)	−0.6801 (0.8111)	2.609e+01 (8.633e+04)	–	−8.438e−01 (1.657e+00)	0.016732 (0.133303)
Profession	–	4.2846*** (1.0994)	1.004e+02 (7.013e+04)	−0.4700 (0.7499)	−2.692e+00 (1.758e+00)	0.472275** (0.150434)
Address Jhapa	3.408e+00 (2.542e+00)	−3.8637*** (1.1001)	−6.274e+01 (7.886e+04)	4.5241*** (1.3448)	−1.340e+00 (1.334e+00)	−0.040232 (0.163022)
Address Saptari	7.077e+00* (2.976e+00)	−5.6979*** (1.3556)	−7.529e+01 (7.954e+04)	2.1749. (1.1287)	2.203e+01 (5.718e+03)	0.096037 (0.174086)
Ya1	−4.056e+00* (1.594e+00)	−1.2427 (1.3716)	6.157e−01 (8.651e+04)	−2.2752* (0.9988)	−3.194e+00 (2.602e+00)	0.192199 (0.198528)
Ya2	4.901e+00* (2.376e+00)	1.9710 (1.7367)	2.212e+00 (1.237e+05)	0.4180 (1.2749)	3.757e+00 (3.138e+00)	−0.006282 (0.268234)
Ya3	1.421e+00 (1.437e+00)	0.6379 (1.1365)	1.686e−01 (5.287e+04)	0.1626 (1.2649)	4.535e+00* (2.188e+00)	0.217452 (0.201223)
Ya4	−2.601e+00. (1.330e+00)	−0.5791 (1.0678)	−1.213e+00 (6.447e+04)	−2.0111* (0.9594)	1.851e−01 (1.566e+00)	−0.054348 (0.180802)
Ya5	−2.053e+01 (1.741e+05)	21.3876 (1937.64)	1.893e+01 (2.815e+05)	58.6659 (6199.61)	1.916e+01 (3.538e+04)	0.676841 (0.445765)
Ya6	−3.561e+00 (1.739e+05)	−2.1869 (1.4614)	−8.907e+00 (1.252e+05)	−45.8868 (3297.70)	4.532e+00 (2.764e+04)	0.492701 (0.274913)
Ya7	2.387e+01 (3.748e+03)	−1.6774 (1.3571)	−4.080e+01 (1.957e+05)	20.1505 (2089.72)	3.103e+01 (2.858e+04)	−0.217835 (0.232276)
Ya8	2.599e+01 (2.381e+03)	−4.2643*** (1.2678)	−8.398e+01 (7.193e+04)	1.3652 (1.0053)	−2.169e+01 (7.690e+03)	−0.066025 (0.192736)
Ya9	4.029e+01 (1.231e+04)	−7.9209 (2752.97)	−1.035e+02 (2.767e+05)	1.8492 (6960.32)	1.667e+01 (3.098e+04)	−1.281940** (0.459242)

[Note: dep. = dependent variables, indep. = independent variables, values in the table are estimates and values in the parentheses are standard errors, (.) = 10 %, (*) = 5 %, (**) = 1 %, (***) = 0.1 % significant level, distribution = binomial, link = logit, bold data signify the significant relationships of the variables, and significant level of 5 % is considered throughout the article unless otherwise stated].

findings reveal that there is a weak linear regressive relationship between forest ecosystem dynamics with agriculture ecosystem dynamics over the decades indicates that they are mutually exclusive in dynamism. We observe that dynamism on the attributes of ecosystems largely governed by the anthropogenic disturbances and changes occurred in climatic elements, however recent technological innovations have significant influence on triggering ED. We argue that the differential ED at site level has little impact on the compounding ED than the global changing contexts. This suggests that differential interventions are required even in a same socio-ecological landscape for implementing site-specific strategies to withstand rapid ED for social and ecological sustainability.

4.1. Social possession matters on understanding the ecosystem dynamics

The farmers are the most vulnerable group of people who are severely impacted by reduction of structural timber from the forests in later decade. They tend to shift household energy systems from fuelwood to cow dung and construction materials as the bamboos and other low-quality products or mine-source materials instead of timber because of shortage of wood or increased price of that. Further, females are negatively impacted by the accelerated ED either by increased consumption in household water management or facing trouble in seasonal shifting in major crop cultivation and harvesting. Although females involve in a significantly higher proportion to fetch household requirements of water than males; however, males engage in water fetching for longer hours (in distant sources) in Jhapa but not in the Saptari district. In contrast to our finding of Jhapa, women tend to engage more water fetching as observed in Melamchi Watershed Area of Nepal (Shrestha et al., 2019). But gender balance as observed in Jhapa in this study for household chores management such as water fetching which is a very positive sign of maintaining gender equity, that should be replicated in other regions, is a great sign to attain national and international commitments (NPC, 2019; UN, 2015). This may be due to the higher gender equality index in Jhapa and Chitwan than Saptari district. Meanwhile, female respondents who are mostly involved in water fetching chores have a greater willingness to change household energy systems (fuelwood) to other advanced means as they may have

Table 3
Outputs of regression analyses on the responses upon dependent variables presented in columns as defined in Table 1 with the various independent variables presented in the rows as describe in Table 1.

Row (dep.)/col. (indep.)	Ya1	Ya2	Ya3	Ya4	Ya5	Ya6	Ya7	Ya8	Ya9
Xa1	−0.30382	−0.06250	0.2525	0.2259	4.171e+01	20.77890	28.5020	−2.540e+02	3.677e+01
	(0.84236)	(1.13182)	(1.7378)	(0.9263)	(1.491e+05)	(2668.54)	(12,635.49)	(8.722e+04)	(4.791e+04)
Xa2	0.59305	0.48415	2.0316	−0.1276	−7.577e+00	2.68389	−26.0578	−8.509e+01	−1.797e+01
	(0.51650)	(1.21113)	(1.5340)	(0.5347)	(2.595e+05)	(1.91702)	(6246.14)	(2.730e+04)	(6.166e+04)
Xa3	−0.8760	−2.16557.	0.8777	−0.2643	−4.087e+01	−0.19387	−28.0767	−8.398e+01	−3.582e+01
	(0.6265)	(1.20824)	(1.1305)	(0.7535)	(1.341e+05)	(1.28451)	(6246.1417)	(2.270e+04)	(5.201e+04)
Xa4	−0.93796	−2.45236	1.2226	−1.5833	−4.022e+01	−16.58493	23.4048	8.764e+01	−1.383e+01
	(0.73342)	(1.63744)	(1.0877)	(1.1980)	(1.885e+05)	(3979.59)	(19,692.08)	(4.795e+04)	(2.484e+05)
Xa5	−0.98754	19.59886	−1.9738.	18.9771	−9.361e−01	−0.84910	20.6799	1.894e−04	4.951e−01
	(0.60588)	(3687.05)	(1.1088)	(2791.34)	(4.389e+04)	(1.00076)	(5185.06)	(1.029e+04)	(5.112e+04)
Xa6	−16.9810	−19.57537	2.1146.	−19.3441	7.783e−01	1.26410	−0.8965	1.212e+00	1.183e+00
	(1485.37)	(5909.95)	(1.2434)	(4132.42)	(3.219e+04)	(1.28408)	(1.1570)	(2.126e+04)	(3.643e+04)
Xa7	0.71403	1.74064	−40.4201	−0.3749	9.543e−02	0.32774	−0.6685	6.862e−01	2.778e−02
	(0.58889)	(1.06751)	(5076.77)	(0.6440)	(2.703e+04)	(0.82580)	(1.0001)	(1.281e+04)	(2.959e+04)
Xa8	−0.28524	3.72023**	20.6089	−18.8895	−1.235e+00	−2.34960.	21.8675	−6.339e−02	−1.644e+00
	(0.72977)	(1.14742)	(3181.52)	(3132.72)	(4.738e+04)	(1.29921)	(5185.069)	(1.359e+04)	(6.099e+04)
Sex	0.34751	0.08671	−0.4932	0.3530	4.783e+01	−0.08222	−19.7586	−4.541e+01	−9.202e−04
	(0.73103)	(1.27369)	(1.2654)	(0.8218)	(8.054e+04)	(1.19108)	(23,570.99)	(4.394e+04)	(1.172e+05)
Education	1.54653	0.33618	1.7011	0.2414	−3.964e+01	−17.56192	4.7323	−2.522e+02	−1.586e+01
	(1.08478)	(1.74974)	(1.9409)	(0.9890)	(1.942e+05)	(2668.55)	(30,011.42)	(7.631e+04)	(2.259e+05)
Age	−1.03678	0.19718	−0.4110	−0.5539	4.187e+01	−1.47035	−14.3748	1.273e+02	3.668e+01
	(0.64002)	(1.22582)	(1.1505)	(0.6876)	(1.397e+05)	(1.19103)	(3123.071)	(3.344e+04)	(5.050e+04)
Profession	−0.51953	1.34505	1.0439	−0.5783	−4.662e+01	−0.47161	38.1237	1.679e+02	1.701e+00
	(0.71654)	(1.60052)	(1.2425)	(0.9059)	(6.336e+04)	(1.42483)	(26,937.72)	(6.422e+04)	(8.796e+04)
Address	1.81792*	2.04601	38.9349	−0.8404	5.683e+01	0.61137	79.2419	−2.997e+02	7.171e+01
Jhapa	(0.85986)	(1.31495)	(5457.79)	(0.8441)	(3.764e+05)	(1.30212)	(15,424.57)	(8.130e+04)	(1.038e+05)
Address	0.07368	18.046	1.6142	−0.8143	7.514e+00	14.10129	−19.6941	−1.297e+02	−3.090e−01
Saptari	(0.85984)	(3517.35)	(1.6411)	(1.0837)	(2.262e+05)	(3564.044)	(23,570.99)	(5.902e+04)	(6.598e+04)

[Note: dep. = dependent variables, indep. = independent variables, (.) = 10 %, (*) = 5 %, (**) = 1 % significant level, distribution = binomial, link = logit, values presented in the table are estimates and parentheses contain standard errors, significant level of 5 % is considered unless otherwise stated].

been facing double burden, such as water and fuelwood fetching or cooking. Likewise, they believe that the abundance of wildlife has changed compared to other members of the society across the study area. Similar findings were reported from a study carried in rural area of Nepal and India that gender and social group specific differential understanding on the natural resources management (Upadhyay, 2005). Education has no significant difference to other variables, suggesting that interventions withstanding radical ED should be applied irrespective of the education level but need gender specificity and other social possession such as profession of the stakeholders.

4.2. Understanding forest ecosystem dynamics and their implications

We found that forest cover has significantly increased in the Jhapa district. However, forest cover perceived as indifference in Chitwan and Saptari districts. People have a variety of interests and motives in ES (Liu and Opdam, 2014), resulting to perceive forest cover changes varied in later decade compared to earlier decade. The changes in forest cover and associated dynamics are not only due to natural processes but also accelerated by the increasing immigration trajectory of human population density in the lowland area in later decades (CBS, 2021). This is due to the fact that the internal migration happens from the hilly and mountainous regions that have resulted in depopulation and underutilization of the forest ES in those regions of Nepal (Kunwar et al., 2020; Poudel et al., 2018). While the increase in population in lowland areas and city centers (CBS, 2021) which might have resulted in increased pressure on the forest, consequently, decreased forest cover and depletion of forest ecosystem services in this lowland landscape. Reduced forest cover corroborates with the evidence of national forest statistics that the forest cover has been decreasing across the lowland area including this study sites in later decade (DFRS, 2014) compared to the earlier decade (NFI/DFRS, 1999). However, overall net gain in forest cover of almost 5 % for the same period on national average in Nepal (DFRS, 2015) for which the government has been implementing a conducive policy to promote community-based-, urban-, avenue-, public-, private- and agroforestry programs and the Jhapa district has the greatest number of private forests in Nepal (Aryal et al., 2023; DoFSC, 2019). In the context of forest cover dynamics, promotion of active and sustainable management in the forested area and development of public forest, avenue plantation, urban forestry, agroforestry, and private forestry in the abundant areas could be promising strategies to reduce the pressure on the existing forest and to cope against global environmental issues.

We find that species composition has largely altered and has been invaded by invasive species such as *Mikania micrantha* and *Eupatorium species* during the later decade. Such invasion and its severe impacts have also been reported in central Nepal (Shrestha and Shrestha, 2021). Reduction in natural regeneration status and changes in species composition of the tree species in the forests have also been observed by the local stakeholders largely due to the infestation of invasive species over time. Respondents reported that old-growths were dominating in the forests, and poor or nil regeneration experienced by the forest-dependent community compounded by the recurring anthropogenic disturbances such as deliberate wildfires, illegal logging, and grazing in the forest ecosystem across the landscape. Similar findings of the forest structure and composition changed were reported in the moist temperate forests across the globe (Burrascano et al., 2013) whereas Pandey (2021) reported that anthropogenic disturbance significantly increase forest biomass removal through lopping and fodder collection, and disturbs natural structure under the forests ecosystem despite using forest products for domestic purpose in the mid-hills of Nepal. Such forests likely to be over-stocking and consequently, unsustainable due to lack or poor regeneration or dominating old growths (Burrascano et al., 2013). To overcome such challenge, enrichment plantation and some other interventions such as intermittent thinning and maintaining size gradation, creating crown space – removing crown cover for natural regeneration could be viable options (Pandey and Pokhrel, 2021b). In general, active forest management intervention facilitates the promotion of biodiversity, the minimal impact of invasive species, and the promotion of natural regeneration of native species (Pandey et al., 2022; Rana et al., 2017) without jeopardizing the customary use and to regulate the infestation of invasive species in the forest ecosystem.

The extraction and use of mine-based products have been increased over plant-based products which might have a serious local economic impact and have global environmental implications. For instance, the use of petroleum products instead of firewood, and the use of iron/aluminum/tin instead of timber and other forest products (bio-products) increase financial pressure and trade deficit at local level and greenhouse gas emission fostering global warming at global scale. As a result, local renewable products underutilize and decay in the forests whereas imported resources soar the trajectory of country's trade deficit (NPC, 2019). This is partly due to the disproportional distribution of forest resources in the country (DFRS, 2015), dilute policy in the forestry sector (Laudari et al., 2020), and question on governance system and socio-economic status of the stakeholders (Dhakal and Masuda, 2009) and technological advancement on the livelihood options. To maximize the use of forest products at household level, and promote green jobs from the forests, an enhancement in participatory policy decision and perpetuate execution of active and sustainable forest management with improved forestry governance can be the future pathways.

Using cattle dung as household energy has serious socio-economic and environmental implications which was pre-dominantly used by the families primarily rely on the agriculture particularly from Madhesh Province (Saptari district). This strategy negatively affects the sustainable organic production and food security system (Raj et al., 2014), in one hand, and more likely to prone human health issues (produce deleterious smoke) and contribute climate change through relatively high production of greenhouse gases (Sfez et al., 2017) and require chemical fertilizers to supplement the nutrient deficit in the farmland in lieu of cow dung. This is also a worrisome situation across Nepal, particularly in lowland, that about 10 % of the population still rely on cattle dung for household energy sources (CBS, 2021) despite the country harbors >45 % of forested areas (DFRS, 2015) of which 50 % forests are believed to be accessible. Most of the local forest-dependent users use lops and tops, agriculture residue, and the remaining of fodder for energy sources in Mid-hills of Nepal (Pandey, 2020) and believe to be similar across the rural area of the country. These fuel management strategies supposed to have relatively little environmental impact compared to burning cow dung. The former strategy would more or less neutralized through annual regrowth that absorb carbon dioxide in the next growing season (Maraseni et al., 2016). Using cattle dung for fueling purposes in the household not only challenges organic agricultural production and food security but also demands imported chemical fertilizers, and consequently, economic burden at household level to catalyze the trade deficit at national scale. Producing such inorganic fertilizers need an enormous amount of energy, resources, transportation facilities and thereby they are the sources of greenhouse gas emissions (Maraseni, 2010; Maraseni et al., 2007; Maraseni and Cockfield, 2011), and therefore, has serious environmental implications. In this instance, execution of regulations allowing the year-round forests resources collection, promotion of biogas using cow dung and the agricultural residue as suggested by Sfez et al. (2017) together with improved cooking stoves, promotion of agroforestry, private plantation, vegetation restoration (Pandey et al., 2022) and incentivizing greenery programs with the provision of insurances, subsidies, grants, and technical supports should be established and enhanced.

4.3. Agriculture ecosystem dynamics and their implication for local livelihood

We observe remarkable dynamics on attributes of agriculture ecosystem. For example, major crop varieties are being changed such that majority of forest-dependent local stakeholders have started to cultivate a single variety of a crop (i.e., hybrid paddy). Other dynamics were introduction of new crop varieties (hybrid paddy and corn), adjusting the crop cultivation cycle to environmental changes especially for paddy planting concurring with the onset of monsoon rainfall since monsoonal patterned changed (became irregular or unpredictable) in later decades, and diversifying family income by engaging in non-farm and off-farm activities such as employment in private and public service, and establishing a private business (grocery shop, sewing-cutting skill, poultry farming). In corroboration with our observation, a study across the Himalayas regions of Nepal (Aryal et al., 2016) reported similar findings and various adaptation strategies in response to agriculture dynamics are being practiced. For example, stakeholders select drought-tolerant varieties (hybrid paddy and corn) for cropping as the common climate-response strategies also reported in South Africa (Elum et al., 2017). Budhathoki and Zander (2020) have argued that the changes in crop varieties and cropping patterns in Nepal are related to technological and market-related factors rather than a response to climate change. However, the selection of drought-resistant and high-yielding varieties can increase crop production (Khanal et al., 2018), suggesting that technology availability has little influence on diversified cropping management. But, new varieties of crops can be a threat in maintaining agrobiodiversity as local varieties may disappear soon (Shah et al., 2021). In line to this, we noted from the Chitwan district that the area and amount of *mustard* (*Brassica rapa*) cultivation was reduced, and trend of fallowing land has been increased in later decade. This trend not only vanish the local variety of the crops and traditional knowledge associated with the species but also increase the threat of food insecurity (Negi and Maikhuri, 2013). Instead, stakeholders are attracted towards tomato farming, especially in the greenhouse, or poultry farming. Although these strategies incur higher investment to set up the business, require advance technologies, these promote diversifying ES over conventional farming (Kremen and Miles, 2012). But impact of climate change particularly can be a silent risk for the socio-economy and future livelihoods of the local people (Aryal et al., 2020a, b; Debela et al., 2015), suggesting that this requires a climate-smart food production system and resilient livelihood options to obtained dual benefits — biodiversity conservation and the climate action (Pandit et al., 2021; Pörtner et al., 2021).

4.4. Examples of wildlife dynamics and its implications

The wild animal dynamics found significant linearly and positively correlated with the changed forest cover and plant species compositing in the forest ecosystem in later decade compared to earlier decade. Loss of large-sized wild mammalian species from the forests experience by the forest-dependent stakeholders across the study area. Stakeholders recalled that *water buffalo*, *tiger*, lowland *deer*, *honeybee, wild pig*, and antelope (*blackbuck*) disappeared from the wild in their locality (see detail in Table 4 and Supplementary files-S2 and S3). Large animals such as elephants, wild water buffaloes, and one-horned rhinoceros tend to have a substantial negative impact on rapidly changing ecosystem due to their size, long life span, amount of food, and larger habitat requirements (Stork et al., 2009). Both the animals' feeding behaviors and their physical alterations, affect plant and animal community composition, which in turn, alters the biogeochemical cycling of nutrients and ions in soils, sediments, and water (Naiman, 1988). As a result, such animals not only influence directly to the provisioning services but also foster the alteration and/or acceleration of the other ES such as supporting, regulating, and sometimes, cultural ES as well (Bauer and Boye, 2014; Danell et al., 2006). To retard the rate of such biological extinction from the locality, governments and stakeholders need to execute affirmative actions, considering biological principles of species conservation into their pre-historic sites, and adopt the management interventions considering changing contexts. In short, proper land-use planning is a key for co-existence of human and wildlife (Stork et al., 2009).

We found that an increase in a particular type of species (*wild boar* and *blue bull*), as a result, increasing incidences of crop depredation, collision along the roads and negative interaction between human and wildlife. These two species are prolific breeders and as a consequence of decreasing number of their predators such as tiger and common leopards particularly in Saptari and Jhapa districts, negative interaction noted, although the number of tigers in Terai Arc Landscape of Nepal reported increasing in trend (Thapa and Tuladhar, 2021). But to maintain the natural balance

Table 4
Examples of the ecosystem dynamics or adaptation strategies if the ecosystems' attributes have been changing over the earlier decade to later decade as perceived by the forest-dependent local stakeholders across the socio-ecological landscape of lowland, Nepal.

What is the major ecosystem changes you experienced in recent decades compared to earlier decades?	If frequently used species disappeared, what are alternative strategies?
• *Banmara* (*Eupatorium species*), an invasive species, proliferated. • Reduced a few and disappeared some of the species of non-timber forest products. • Wild *Khayar* (*Acacia catechu*) and sissoo (*Dalbergia sissoo*) disappeared. • Mikania (*Mikania micrantha*) newly appears and is widespread. • Phonological changes in *Chiuri* (*Diklonema butyracea*) — multiple holy years for fruiting observed. • Reducing and vanishing the production of mustard (*Brassica rapa*) in the study area, particularly in the Chitwan district. • *Paulania*, an exotic species introduced, *eucalyptus* gained popularity for private plantations. • Sal (*Shorea robusta*) is frequently infested by a disease — heartrot. • Sissoo (*Dalbergia sissoo*) infected with diseases — wilting, heartrot, rootrot. • *Hadjora* (Veld grape) and *Bombax ceiba* disappeared.	• Soil testing prior to species planting. • While the Sissoo seedling perished The *Shorea robusta* seedling sprouted and thrived. • Replantation and restoration. • Alternative species plantation instead of Sissoo. • Protection for *Shorea* seedlings grown up instead of Sissoo. • Iron, aluminum, and tin have been used instead of wood/timber for household structural purposes. • As a low-cost alternative to wood, bamboo is occasionally utilized in construction. • Conservation efforts started for forest and agrobiodiversity. • Hybrid species, chemical fertilizers, and inorganic pesticide use increased. • Increased investment in irrigation and household water management. • Introduced and adapted technological advances for adapting to radical changes in ecosystems' attributes.

What is the wildlife behavior that you noticed the changes at later compared to earlier decades?	Why are you using the alternative of timber in your household for structural use?
• The black bear and tiger disappeared from Saptari and Jhapa, and wild water buffalo from the Chitwan district. • *The sanimunia* bird (Scaly-Breasted Munia) early sings. • Vulture is extinct from Saptari and Jhapa. • Red bear new for the landscape. • Red deer appear, and wild boar proliferated. • Blue-bull proliferated wild man, bear, tiger, and water buffaloes were extinct. • Early sings – *Koili* (Asian Koel) – seasonal singing pre-ponded. • Early egg hatching and brooding by dove and jungle fowl. • Honey-bees and spotted deer disappeared, and very low honey production in the later decade was experienced. • Human-elephant conflict increased in Jhapa and should be addressed and mitigated. • Wild boar and blue bull should be controlled which raid agricultural crops.	• Wood is not affordable because the forest faces a lack of manpower due to the outward migration of youths for sustainable forest management – labor--intensive work – forest management, and not mechanized yet. • Wood is expensive and not readily available. • Because of low-income status, wood in the market is quite expensive, so attention went towards private forestry. • To save forests, alternative use of forest products is crucial. • Deficit of quality wood, the suggestion given by us should be reflected in the legal provision not only use it for study purposes. • Wood is too expensive and not readily available. • Easy and readily available bamboo is on our own land for use. • Other materials are cheaper than wood such as iron, aluminum, and tin. • Banning to harvest trees from forests and policy dilemma. • Wood is not available so as to promote plantation and awareness programs for forest generation. • Wood is not available, insurance for plantation to reduce the cost of seedling production and distribution must be provisioned. • Good quality (required species) is not found readily in the forests.

between prey and predators, implementation of land-use planning is a key (Stork et al., 2009). Besides, proliferation of small mammals species may be due to successful implementation of community-based forest management policy in the last 40 years across Nepal (Pandey and Pokhrel, 2021a) including in the study sites as these forests provide the suitable habitats for these small-sized species and contribute enhancing forest cover (DFRS, 2015) and combat global climate change (Maraseni et al., 2014, 2019). In some instances, the frequency of some wild animals such as *blue bull* (*Boselaphus tragocamelus*) and *wild boar* are reported increasingly visiting water pumps (set for the household purpose) in settlement areas to drink water or to graze fresh grass around the water sources. Such incidents were very rare in the earlier decade but more frequently observed in the later decade. This might be due to the drying out of the natural water system or fragmentation of habitat (Acharya et al., 2017) or occurrence of ED triggered by several factors such as climate change (Ledee et al., 2021) and anthropogenic disturbance (Pandey, 2021), indicating that integrity and sustainable management of habitat for wildlife is dire need. Although increasing abundance could be a promising sign for conservationist but increasing frequency of encountering them in the human settlement areas is definitely an alarming sign for both wildlife and human beings (Acharya et al., 2017; Dhungana et al., 2022). Such incidences increase negative human-wildlife interactions and develop a negative thought towards wildlife conservation. To reduce the human-wildlife negative interaction and promote co-existence, effective implementation of the stewardship giving policies to the local community to conserve and manage the wildlife in the natural environment and recognize them as community conserved area (CCA) (NPC, 2019) as OECM (other effective conservation measures). This strategy can be a milestone not only to the local community because they can realize the ownership on wildlife conservation and can be connected to locally driven eco-tourism (nature-based tourism that contribute for conservation and to the enhance local livelihood of the surrounding community, but also these area could significantly contribute for attaining national and international commitments such as the SDGs' targets (UN, 2015) and proposed global biodiversity conservation framework 2030 for collective wildlife conservation efforts and realization of co-existence.

Avifauna is crucial and integral part of ecosystem function, but their ecological and reproductive behavior has changed in later decade. Stakeholders from Madhesh Province report that they are not seeing vultures anymore in recent decade, but they used to see them before. The birds, viz. *Scaly-Breasted Munia* and *Asian Koel* start singing earlier than the usual season in later decade whereas doves start hatching and brooding later than the usual season. Such behavioral dynamics observes on avifauna may be due to the impact of climate change, especially the rise in temperature and the early onset of summer, among others as reported in Australia and other parts of northern hemisphere (Chambers et al., 2005; Møller et al., 2010). Early brooding phenomena have also been reported on the avifauna in the southern world (Wormworth et al., 2011), across environmental gradients on migratory birds (Maggini et al., 2011), and prepone breeding season in many bird species (Møller et al., 2010) due to climate change. Birds require specialized dietary requirements during the breeding and brooding period (Cosolo et al., 2011; Pierotti and Annett, 1991). The alteration or fluctuation of diet availability may influence breeding performance, and consequently, have long-term ecological implications for the sustainability of such bird species. Pro-active human interventions for managing dietary requirements for those risk-zone avifauna could lead to protecting critical avifauna for the functional ecosystem.

This study portrays ED across socio-ecological landscape with reference to forest-dependent local stakeholders (farmers), which is unique to the available literature, a reference from developing country for the lessons to the global communities. This enhances the understanding on socio-ecological system theory that local level institutional and changes on customary practices (technological inputs) significantly influence on the ecosystem dynamics. However, this study could not cover all the attributes of forest and agriculture ecosystems, and would be the opportunities to tally the systematic ecosystem monitoring mechanism for future area of research. Also, findings are site-specific, and responses may be influenced by the socio-economic status of the respondents so that the findings need round the year field verification to generalize the inferences. However, taking the sample from each provinces is limited, we considered the respondents across the districts representing the general condition of the local forest-dependent stakeholders which is reported to be sufficient to study the pattern in the local context (Bürgi et al., 2013). Understanding and participation of local people in mapping ED would be a crucial step for engaging and ownership of local stakeholders for ecosystem integrity and their involvement in decision-making for local resources management (Liu and Opdam, 2014) to attain the local, national to international goals such as SDGs (NPC, 2019), which is a remarkable step on understanding ED in a participatory approach across the socio-ecological landscape. In this instance, understanding the local level ED using the best available options — the life experience interviews approach could be a valid source and credible means for shaping future pathways in better understanding local level ED and their sustainable management in the local to global changing contexts. Similar studies are recommended in a wider scale to extend further the understanding of ED at local level for the plausible way forward for the sustainability of socio-ecological landscapes.

5. Conclusion

We compared the ecosystem attributes' status in earlier decade (before 1990) and the later decade (in the last 30 years) by gathering the reflection of old age people in the lowlands region of Nepal. Lowlands region shares the socio-ecological system that provides about 60 % of food security of the country and is one of the diverse landscapes in terms of social, cultural, and biological diversity. However, the understanding of perceived ecosystem dynamics (ED) varies significantly across the landscape and largely guided by the socio-economic background and technological interventions in the later decades compared to the earlier decades. This study is unique in terms of 1) including forest-dependent local stakeholders in understanding ecosystem dynamics; 2) demonstrating an example of a participatory approach that provides additional asset on top of station-based ecosystem monitoring system because of getting reflection on adaptation strategies for withstanding radical ED in global changing contexts; 3) exploring peculiar examples of attributes of ecosystems that faces significant changes over time to prioritize the limited resource on decision making to the particular attributes for the sustainable socio-ecological landscape; and 4) understanding ED from ecosystem attributes' lens but not from the indicators' or drivers' perspectives. The study affirms the participatory approach for understanding ED is an efficient (participatory tool), effective (low-cost and time), and enhanced methodology (inclusion of agriculture ecosystem dynamics) for sustainable management of ecosystems across the socio-ecological landscapes.

Results reveal that forest ecosystem has been altered by anthropogenic interventions and climate changes but confounded by the recent technological innovations in recent decades. Specifically, changes in forest cover, increase in invasive species, changes of water regime and wildlife dynamics are notable attributes, among other, which showed significant changes on forest ecosystem in short time span (30 years). Increased infestation of pests and diseases, seasonal change on major crop cultivation and harvesting, species variety changes, and increase in use of chemical in the farming (fertilizers and pesticides) are the attributes of agriculture ecosystem experiencing significant changes in later decades compared to earlier decades in the study area. These attributes collectively lead the changes in structure and function of the ecosystems. Local people adopt various strategies against accelerated changes on attributes of ecosystems; however, these are insufficient to combat the changes because either these strategies require high level of technology or unaffordable financially for the ordinary forest-dependent farmers in the third world like Nepal. Some of the strategies that the local people are being adapted either obtain from unsustainable sources (non-bioproduct) or cause serious health and environmental challenges, indicating that decision makers should consider this local level ED and adaptation strategies to the global changing contexts. The findings would provide insights for policy decisions and knowledge reference for local to global communities for landscape planning and sustainable ecosystem management.

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CRediT authorship contribution statement

The HPP conceives, data curates, perform analysis, and manuscript drafts; KA writes-up discussion and introduction, and edits the whole manuscript; SA thoroughly reviews the manuscript, and contributed to the discussion section; and TM overall supervises the research, edits, and proofreads. All authors read the manuscript and agree to publish.

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Ethical consent

The first author obtains verbal consent from respondents who participated in the questionnaire survey and in-depth discussion to disclose their responses anonymously and for study purposes.

Ethical approval

Authors adhere to the publishing ethic and approve as per the ethical guideline of the journal.

Consent to participate

The authors were informed to the participants/respondents pre-prior and obtained consent for data acquisition and use of provided information for academic use. All of the participants had given their approval and consent to participate as per their will.

Consent to publish

The authors informed to the participants/respondents pre-prior and obtained their consent on the publication of the information provided by them anonymously.

Data availability

Data will be made available on request.

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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