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Present status of inland fisheries and its linkage to ecosystem health and human wellbeing in North Central of Vietnam

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ABSTRACT

The sustainability of inland fisheries in Asia requires a better understanding of the dual role of inland fisheries as a valuable source of ecosystem services and as an indicator of ecosystem health. This study investigates the present status of inland fisheries and their importance to local communities in Lam, the largest river basin in the northern part of Central Vietnam. We found 150 fish species during two sampling seasons in 2020. Biotic and abiotic metrics indicated satisfactory to good water quality status in the Lam river. Inland fisheries contributed around 152 tons per year of fish yields for food consumption and trading based on 120 surveyed households. In addition to food services and income for local communities, fish biodiversity was also valued for cultural services supported by a long-term fishing tradition transferred among generations. Surveys suggested reductions in inland fishery yields and the size of caught species, likely driven by high harvests using unsustainable methods, hydropower dam construction and operation, and climate change. Our findings highlight the need for continued long-term monitoring of understudied river ecosystems and a strengthening of governance and fisheries law enforcement to preserve biodiversity and ecosystem services in inland fisheries.

1. Introduction

Land-use and climate change are primary drivers of habitat destruction, the degradation of ecosystem health, and losses of aquatic biodiversity in the Anthropocene (Young et al., 2010; Vörösmarty et al., 2010; IPBES, 2019). Along with increased demands on goods and services to sustain the growing human population, these stressors also threaten fundamental ecosystem services provided by rivers to human wellbeing worldwide, such as drinking water, irrigation, fishing, and aesthetic values (EC, 2015; Hanna et al., 2018; Kaval, 2019). To facilitate the long-term protection of these invaluable riverine ecosystem services, it is thus important to evaluate their status and their linkage to the degradation of ecosystem health, and subsequent effects on human wellbeing (Dang et al., 2021; Vári et al., 2021).

Among the ecosystem services of rivers, inland fisheries (i.e., the extraction of living aquatic organisms from all types of natural inland water bodies, excluding those from aquaculture facilities) provide a source of a low-cost nutrition, livelihood and income for local residents (MA, 2005; Díaz et al., 2015; Lynch et al., 2016; FAO, 2020a; FAO, 2022). Inland fisheries are particularly important for local communities in regions with low GDP and undernourished populations (McIntyre et al., 2016; FAO, 2022). It is estimated that the annual production of fisheries from inland waters contributed 12 % of the total global fisheries production (FAO, 2020b; FAO, 2022). Aquaculture and inland fisheries products also provide dietary protein for 158 million people worldwide (McIntyre et al., 2016; Vári et al., 2021). Meanwhile, biodiversity contributes to increased ecosystem service provision and resilience, i.e., more diverse ecosystems support higher fish productivity

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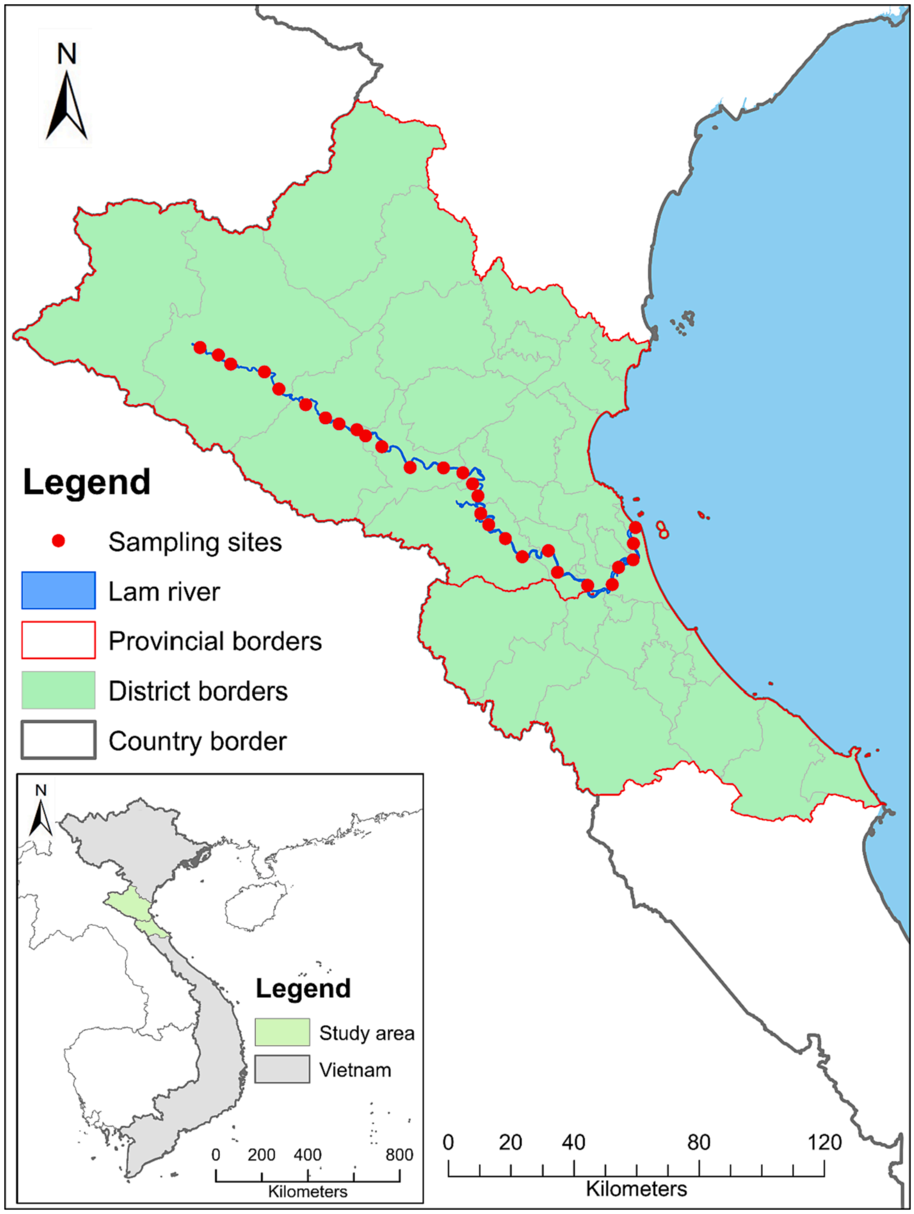

Fig. 1. Location of the study area at the Lam river in the northern areas of Central Vietnam.

(Dudgeon et al., 2006; Vörösmarty et al., 2010). High biodiversity and better ecosystem health are thus important interlinked factors affecting ecosystem services of inland fisheries and supporting long-term socio-economic security and stability of the global population (TEEB, 2010; Lynch et al., 2017; Dang et al., 2021).

Ecosystem health and biodiversity are often considered to be in conflict with inland fisheries exploitation (McIntyre et al., 2016; Phang et al., 2019). This conflict is however often ignored, causing many ecosystems and their services to lose out to more economically valuable water resource projects. Intensive fishing and overexploitation can particularly undermine efforts to conserve biodiversity in regions where rivers are already degraded by other stressors (e.g., Darwall et al., 2011; EC, 2015; Brooks et al., 2016). On a global scale, 90 % of fish catches came from rivers with above-average stress levels (McIntyre et al., 2016). There is an interconnected linkage between biodiversity resources, ecosystem services, and societal poverty (Dudgeon et al., 2006; Phang et al., 2019). Propagating sustainable fishing might allow for increased synergy between inland fisheries exploitation and biodiversity by unifying joint economical, social and environmental interests (Brooks et al., 2016). However, applying this approach in understudied regions, such as countries with low-income economies, is particularly challenging due to a significant shortage of information on the status and trends of inland fisheries in relation to human wellbeing and ecosystem health (Miao et al., 2010; Brooks et al., 2016; Dang et al., 2021).

Southeast Asia is the second richest freshwater biodiversity area in the world and the demand for ecosystem services from inland fisheries has risen substantially (FAO, 2020b; FAO, 2022; McIntyre et al., 2016). The Mekong, for instance, is one of the three highest yield fisheries catch river basins in the world (Hortle and Bamrungrach, 2015; McIntyre et al., 2016; Cooke et al., 2016). However, it was estimated that fish overexploitation in this region, similar to many areas in Asia, has already greatly surpassed the recommended sustainable rate for fish and fisheries resource conservation (Sodhi et al., 2004; Sodhi and Brook, 2006; Miao et al., 2010). Available data from studies in some Southeast Asian countries (including Indonesia, Malaysia, Myanmar, Philippines, and Thailand) revealed a significant decline in fish abundance, diversity, and body size as a consequence of overfishing, pollution, erosion, alien species, and habitat destruction from constructed dams (Coates, 2002;

Sodhi et al., 2004; Sodhi and Brook, 2006). Meanwhile, we often know little of how inland fisheries have contributed to human wellbeing, ecosystem health, and ecosystem functioning in other Southeast Asia countries, primarily due to a lack of information on fish biodiversity and their ecosystem services (e.g., Coates, 2002; Nguyen et al., 2012; Allen et al., 2012). To find solutions to better manage inland fisheries in Southeast Asia, it is necessary to explore and record the status of fish diversity and its trends in rivers since they are highly impacted and continuing to disappear under the increasing pressures of environmental stressors and fast-growing populations (Petrtýl et al., 2011; Allen et al., 2012; Cooke et al., 2016).

This study provides the first interdisciplinary research of the status of inland fisheries in the Lam river in the northern areas of Central Vietnam, and their relation to river ecosystem health, ecosystem services, and human wellbeing. The specific aims of this study were: (1) to assess the current status of inland fisheries and particularly fish diversity along the river course; (2) to analyse the linkage between the status of inland fisheries and environmental stressors at the river scale; and (3) to investigate the relationship between the ecosystem services of the fisheries and the human wellbeing of local communities. Our results reveal the relative importance of inland fisheries to human wellbeing in relation to the environmental conditions of rivers, which supports decision making and the development of sustainable inland fisheries management plans for large rivers in Asia.

2. Methods

2.1. Study area description

The Lam River is one of the nine main rivers in Vietnam and is the largest river in the northern part of Central Vietnam (Fig. 1). The river covers an area of 27,200 km^2 and has a total length of 361 km. The main parts of the river flow through two provinces of Nghe An and Ha Tinh, and it ends its course at the Cua Hoi estuary. The climate is tropical and is characterized by hot and humid summers (April-October) and temperate and dry winters (November–March). The mean annual precipitation in the region is 1400 mm, with flood events primarily occurring in April and between July and October (Dang et al., 2021). The study area is located in a region with the second lowest monthly income per capita in the country (i.e., after the Northern midland and mountain regions; GSO, 2021), which represents a typical environment of Northern highland areas in Vietnam where local communities heavily rely on ecosystem services provided by nature's biodiversity for their livelihoods (Petrtýl et al., 2011; Nguyen et al., 2012).

2.2. Data collection

Field data was collected along the main river course from the river outlet at the Cua Hoi estuary to the headwaters within Vietnam (Fig. 1). In total, 28 sites along the Lam river were selected for this study, with a mean distance of approximately 13 km between sites based on the guideline of the Directorate of Fisheries (No. 251/QD-TCTS-BTPTNL issued on 15th May 2019). Samples were collected in the wet season (from 26/05/2020 to 08/07/2020) and in the dry season (from 12/11/2020 to 25/12/2020). The collected data included fish abundances, physico-chemical data, and socio-economic data relevant to inland fisheries ecosystem services in the Lam river.

2.2.1. Fish data

To collect representative samples of fish assemblages distributed along the Lam river, three sub-samples (i.e., at the left bank, right bank, and middle river parts) were collected at each site over the two sampling periods (i.e., dry and wet seasons) during 2020. Different gears were used for fish sampling, depending on the local river structure and flow velocities. Trawl nets and seine nets (net size of 200 m length and 6 m width, mesh sizes of 2–10 cm) were used in areas with large surface areas and low current velocities. Nets were settled for eight to sixteen hours in the river before samples were collected. For narrow river sections and areas hard to approach by boat, fish collection was done with a cast net of size 5–6 m length and 3.5–4 m width (mesh size of 1 cm). The cast net was thrown into the river until it was totally submerged, then the net was gradually dragged out of the water and samples were collected into the net bag. Finally, a drag frame net (net size of 34 m length and 0.5 m width, fish bag length of 4 m) was used when collecting samples in deep water areas. Boats stopped at the designated sampling locations, then the drag frame net was dropped into the water from behind the boat using a cable with a length of three to four times the water depth. Next, the boat moved forward for ten to fifteen minutes to collect the fish samples.

Fish from gears were identified to the species levels. When it was not possible to identify individuals in the field, photos and information of species characteristics were recorded, and samples were retained for laboratory identification. Species identification was based on various region-specific identification sources, such as Mai (1978), Kottelat (2001), or Nguyen (2005), and species names were checked against the Catalog of fish databases (e.g., IUCN, 2021; Froese and Pauly, 2022; Fricke et al., 2022). Endangered and rare fish species were determined based on the National Decree (No. 26/2019-ND-CP), Vietnam's Red Data Book (year 2007), and IUCN (2021) classes. Economically valuable species were defined using the report 'Fisheries resources of Vietnam' issued by the Ministry of Fisheries (version year 1996) and information from survey questions with local fishers. Economically valuable species were defined as species that are heavily exploited and that have market value (MoF, 1996; Froese and Pauly, 2022). Additional samples were collected from locally sourced fish markets along the Lam river to verify the economic values of studied fishes.

2.2.2. Physico-chemical data

GPS coordinates were recorded for each location, together with information of site characteristics. Physico-chemical data were collected from the same sites and dates as the fish samples, including water temperature (Temp) (°C), pH, dissolved oxygen (DO) (mg/L), salinity (mg/L), and electrical conductivity (EC) (mS/cm). Biological oxygen demand (BOD_5) (mg/L), orthophosphate-phosphorus (PO_4^{3-}) (mg/L), and nitrate-nitrogen (NO_3^-) (mg/L) samples were also collected and quantified in the laboratory using a spectrophotometer. Data sampling and analyses followed the standard guidelines recommended for monitoring rivers in Vietnam (Appendix, Table A1).

2.2.3. Socio-economic data

Socio-economic data relevant to inland fishery activities at the Lam river included data collected from field surveys and literature data collected from annual administrative, socio-economic, and statistical reports. Surveys were conducted at each study site by three interviewers, including experts from the research team and local fisheries managers. The number of surveys was determined based on the number of households involved in inland fisheries activities in the study area. A survey on general activities of inland fisheries in the Lam river was conducted once, while investigations on fishers' communities, fish yields and catch intensities were conducted in both the dry and wet seasons of 2020. This resulted in a total of 150 survey records. Before starting the interview, the study and its purposes were introduced to respondents who were local fishers (randomly chosen irrespective of age, gender, education background and fishing experiences) and local managers of fisheries activities (i.e., at the provincial, district, and commune levels).

The main aim of the survey was to collect information on inland fisheries activities at the Lam river in association with human wellbeing and river health status. The collected information included: total number of fishers and the demographic characteristics of fisher communities, mean household income from inland fisheries, and the occupations and

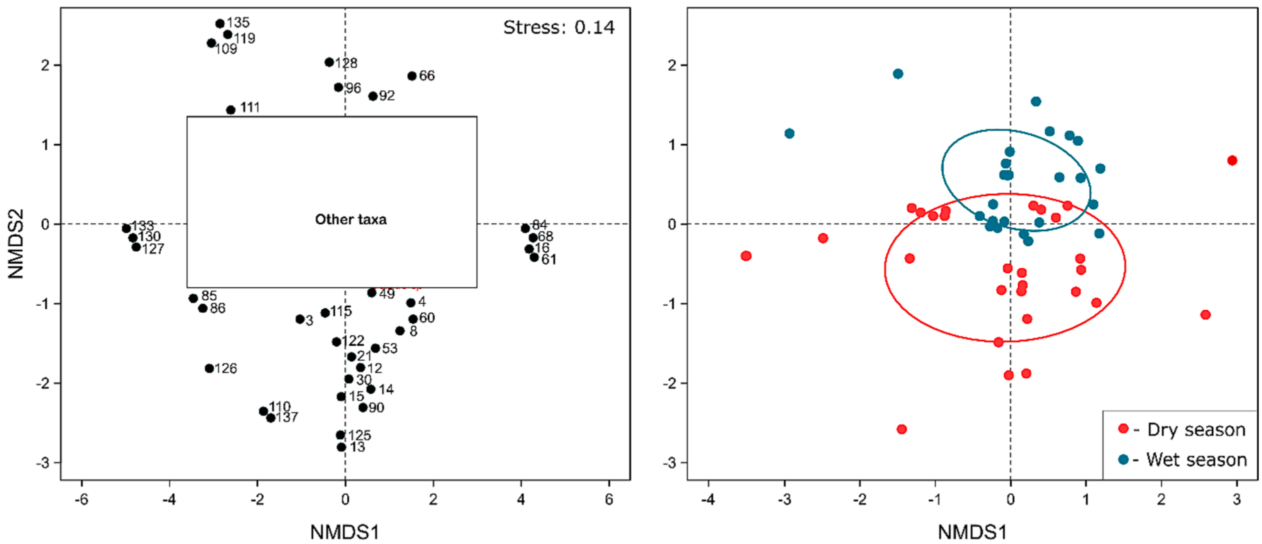

Fig. 2. Non-metric multidimensional scaling (NMDS) plot of fish community composition at Lam river in 2020. The numbers on the left panel indicate fish taxa (for taxa names refers to Appendix- Table A3).

services relating to inland fisheries. To estimate fish yields based on survey results, data on the types of fishing gear, mean yields per day, number of days and months of catch per year, and number of fishers in the region were included in the surveys. The survey outputs were verified and approved by the scientific expert committee assigned by the Directorate of Fisheries, Vietnam.

2.3. Data analyses

2.3.1. Fish species assemblages and diversity

To visualize fish assemblages at each site and differences between sampling seasons, we used non-metric multidimensional scaling (NMDS) constrained to two axes (Legendre and Legendre, 2012). Species presence/absence data were standardized using the decostand function ('pa' method) and rare species (i.e., those occurred only once in the whole dataset) were eliminated for the NMDS analysis (Legendre and Gallagher, 2001). Fish diversity at the studied sites was represented using species richness and Shannon–Wiener diversity metrics. To analyze the difference in fish diversity between the studied seasons, we used a non-parametric Wilcoxon–Mann–Whitney test (U-Test; p-value < 0.05). All analyses were completed in R, version 4.1.0 (R Core Team, 2021).

2.3.2. Fish yield estimation

To quantify fish yield as a provisioning service, i.e. the proportion of production removed for human use over a given period of time, we used the catch per unit of effort (CPUE) approach proposed by the Food and Agriculture Organisation (FAO) (Statamatopoulos, 2002):

$$Y_i = CPUE_i x\ [D_i x\ B_i x\ BAC_i] \quad (1)$$

in which: Y_i: Catch yield of fishing gear i in the study area.

$CPUE_i$: Catch yield (kg) per catch intensity unit (i.e., day) of fishing gear i.

D_i: Effective days of catch activity using fishing gear i (days).

B_i: Total number of boats participating in the catch activity using fishing gear i.

BAC_i: Activity factor, which was a catch frequency per boat in any given day of the studied period and was set-up as 1.

D_i value was defined as the average number of catch days per month of activity using fishing gear i, while B_i was calculated as a sum of all households TF_i participating in the catch activity. The abovementioned equation is thus adjusted for fish yield calculation based on different fishing gear types as follows:

$$Y_i = CPUE_i{*}\ TF_i{*}\ D_i \quad (2)$$

The input data of $CPUE_i$, TF_i, and D_i were collected from surveys of fishers at the Lam river (Appendix, Table A2).

2.3.3. Relationship of inland fisheries to environmental stressors and human wellbeing

Spearman's rank correlation coefficient was used to explore the relationship between non-collinear physico-chemical parameters (i.e., correlation $r < 0.50$) and fish richness and Shannon diversity. Two parameters (DO and EC) were excluded due to high correlation with the temperature and salinity parameters ($r = 0.5$ and 0.9 respectively). The analysis was run using the method 'ggpairs' provided in the built-in package 'HighstatLibV13.R' (Zuur et al., 2017). A redundancy analysis (RDA), which is analogous to a multiple regression with multivariate response data, was used to visualize this relationship (Legendre and Legendre, 2012). In addition, we used an automatic stepwise model for constrained ordination methods (ordiR2step) to identify the statistically most influential stressors in the RDA (Blanchet et al., 2008).

3. Results and discussion

3.1. Status of inland fisheries

3.1.1. Diversity of inland fish fauna

We observed a diverse composition of fishes at the Lam river in 2020. Previous investigations by Nguyen Thai Tu in the period from 1975 to 1978 identified 157 different fish species, which is comparable to the total of 150 fish species found in this study along the main river course (Fig. 2, Appendix – Table A3). These included 62 freshwater species, which accounted for 41.3 % of total species. Among the 150 identified species from 55 families, the most frequently occurring species were *Squalidus argentatus*, followed by *Toxabramis swinhonis*, and *Sillago sihama*. Meanwhile, 10 out of 150 species belonged to other widely distributed taxa, including *Toxabramis swinhonis*, *Squalidus argentatus*, *Onychostoma simum*, *Xenocypris davidi*, *Barbodes semifasciolatus*, *Anabas testudineus*, *Cirrhinus mrigala*, *Mastacembelus armatus*, *Saurogobio immaculatus*, and *Onychostoma gerlachi*. At the family level, the most common groups in the Lam river were the Cyprinidae, Gobiidae, Xenocyprididae, Gobionidae, and Sciaenidae. Most fish species found in the Lam are widespread in Vietnam and adjacent areas, especially in

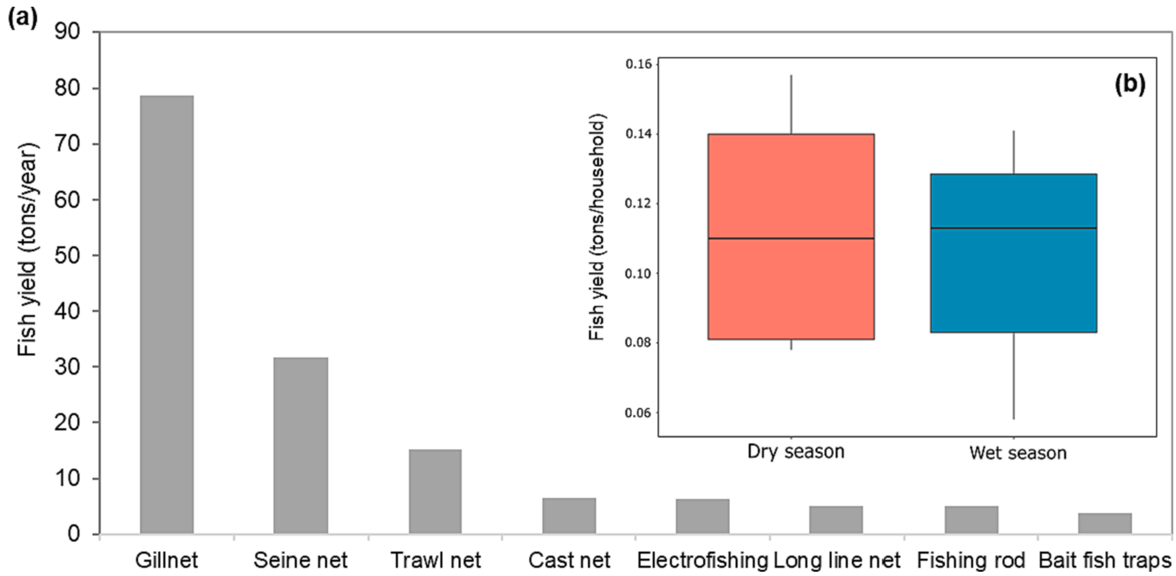

Fig. 3. Fish yield estimations by gear types (a) and seasons (b) at Lam river.

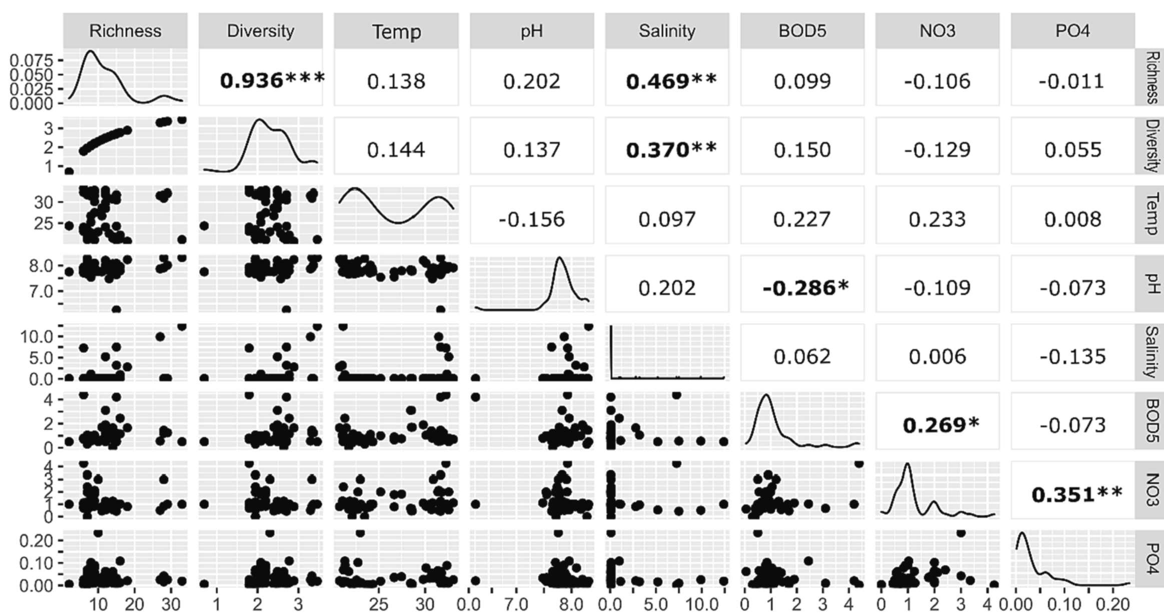

Fig. 4. Relationships of fish richness and Shannon–Wiener diversity metrics with non-collinear physico-chemical parameters at Lam river in 2020. Statistically significant correlations are marked with an asteric in bold. Temp – temperature, pH – acidity, BOD5 - Biochemical Oxygen Demand, NO3 - Nitrate, PO4 - Phosphate.

southern China (e.g., Coates, 2002; Miao et al., 2010; Allen et al., 2012). In contrast, 63 species contributed only one to two individuals in the samples collected at 28 sampling sites (Appendix – Table A3).

A notable variation in species composition was observed between dry and wet seasons as revealed by our NMDS analysis (Fig. 2). In particular, 92 species were collected during the dry season, among which 39.1 % were freshwater species. Most dominant species found during the dry season were *Rhinogobius similis*, *Onychostoma simum*, *Toxabramis swinhonis*, and *Saurogobio immaculatus*. In the wet season, 102 species were identified, of which 49.0 % belonged to freshwater species. The three most common species identified during the wet season were *Squalidus argentatus*, *Sillago sihama*, and *Barbodes semifasciolatus*. In total, only 44 species were found in both sampling seasons along the Lam river. However, we found no statistically significant differences in species richness or Shannon-Weiner diversity between the dry and wet seasons (based on U-tests; p-values = 0.19 and 0.19 respectively). These results suggested that the Lam river was characterized by seasonal differences in species composition, but the overall diversity of inland fish fauna remained high across seasons, thus supported ecosystem services for human wellbeing.

3.1.2. Endangered, rare, endemic and economically valuable fish species

Table A4 (Appendix) provides the official figures on the number of endangered and rare species we identified. According to Vietnam's Red Data Book, the Lam river had three species at the Vulnerable level (*Konosirus punctatus*, *Hemibagrus guttatus*, and *Bagarius rutilus*) and one species at the Endangered level (*Clupanodon thrissa*). Meanwhile, IUCN 2021 suggested that the Lam river had two species in the Vulnerable class (*Leptobotia elongata* and *Channa orientalis*) and one species in the Endangered class (*Coilia mystus*). National Decree No. 26/2019/ND-CP also considered nine species as endangered and rare, of which two species (*Carassioides acuminatus*, *Paraspinibarbus macracanthus*) were

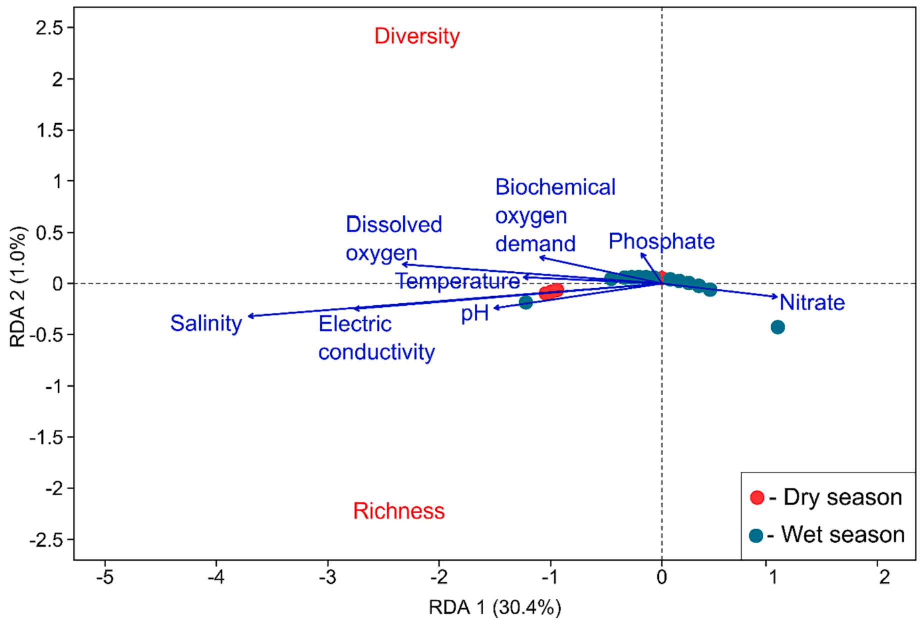

Fig. 5. Status of richness and diversity metrics in relation to environmental stressors at Lam river in the dry and wet seasons of 2020.

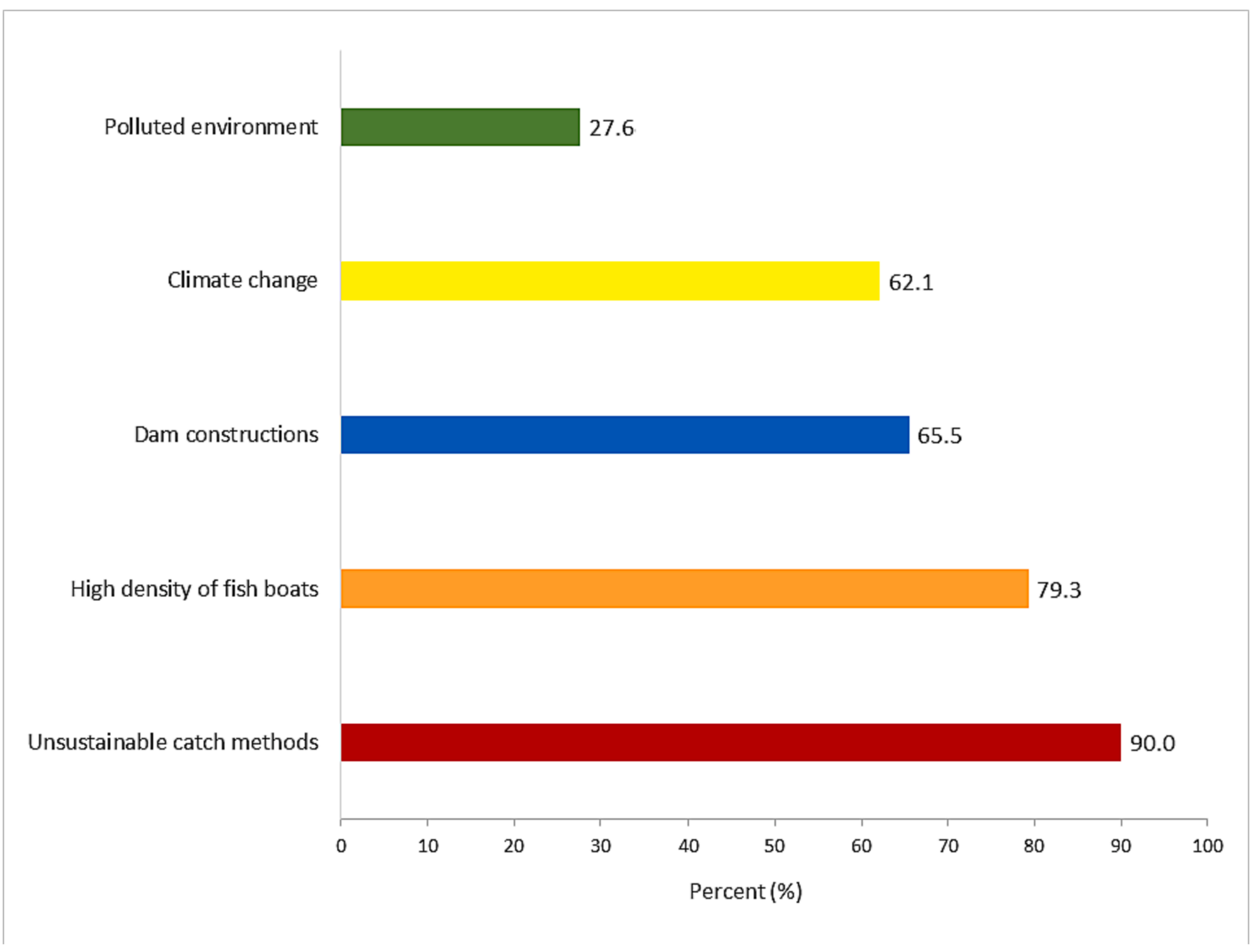

Fig. 6. Stressors causing decreases in yields and size of fisheries at the Lam river according to 120 surveyed households in 2020.

valuable endemic species located in the south-central coast and mountainous provinces of Northern Vietnam. Vulnerable and rare species were primarily freshwater species, that were predominantly distributed in the middle and upper parts of the river. Three endangered species were identified only at the two outlet sites (S1 and S2), including *Clupanodon thrissa*, *Coilia mystus*, and *Channa lucius*.

Table A1
Analyses methods of physico-chemical data at the Lam river.

No	Parameters	Analyses methods*
1	Temperature	• SMEWW 2550B:2012
2	pH	• TCVN 6492:2011
3	Dissolved oxygen (DO)	• TCVN 7325:2005
4	Electric conductivity (EC)	• SMEWW 2510B:2012
5	Salinity	• SMEWW 2520B:2012
6	Biological oxygen demand (BOD_5)	• SMEWW 5210D:2012
7	Nitrate (NO_3^-)	• SMEWW 4500-NO3- .D:2012 SMEWW 4500-NO3- .E:2012
8	Phosphate (PO_4^{3-})	• SMEWW 4500-P.E:2012

* SMEWW - Standard Methods for the Examination of Water and Waste Water; TCVN - Vietnamese National Standard. These are recommended and commonly applied methods for monitoring environmental parameters in rivers in Vietnam (e.g., https://iopscience.iop.org/article/https://doi.org/10.1088/1755–1315/444/1/012054/pdf; https://www.boa.gov.vn/sites/default/files/372tt1019.pdf).

Our surveys also indicated that the Lam river had numerous economically valuable species that belonged to both freshwater and brackish water environments (Appendix - Table A4). The most common economically valuable species representing the marine and freshwater environment were *Sillago sihama* and *Bagarius rutilus*, respectively. Overall, 74 high economic value species were collected, except *Channa orientalis* that was not often found in local markets during our investigations. Economically valuable fish species belonged primarily to three orders: Cypriniformes, Siluriformes, and Gobiiformes.

Considering the scarcity of fish fauna data and the existence of undescribed fish biodiversity in Vietnam (e.g., Petrtýl et al., 2011; Allen et al., 2012), this study provides a thorough assessment of a current status of fish assemblages of the largest river in the northern part of Central Vietnam, covering diverse habitats from upstream to downstream in the river during 2020. The diverse fish fauna of the Lam river provides varied sources of provisioning and cultural services for local households through catching, processing, trading, research and socio-cultural activities.

3.2. Inland fish yields

Fishers reported that fishing activities were undertaken in all months of the year using diverse type- and mesh-size- fish gears (Fig. 3a). The most common gear types were gillnets and seine nets, while the least common gears (comprising 9 % of the total fish yield) were fishing rods, long line nets, and bait fish traps. Although eletrofishing is illegal, there were still incidences of electrofishing, which contributed approximately 4 % of the total annual catch. Trawl net also contributed 10 % of total annual fish yields. 16.7 % of fishers reported using fish gears with a smaller than recommended mesh-size. The average rates of catch from all gear types were reported to be from five to ten kg fish/day, which is comparable to the average catch rates of three to ten kg fish/day reported at the two nearby rivers in Northern Vietnam, including the Da River and Ma River (Nguyen et al., 2012). Overall, the total fish yield at the Lam river based on the 120 surveyed households was estimated at approximately 152 tons in 2020.

Seasonally, fish yields were comparable between the dry (November-March) and wet (April-October) periods (Fig. 3b). In particular, the wet season of 2020 exhibited a slightly higher yield of 57.7 % of the total annual catch compared with 42.3 % of the total catch collected during the dry season. The slightly higher yield during the wet period was likely affected by the higher contribution of flows released from upstream dams and the resulting higher water levels at the upper and middle sections of the Lam river, which ultimately supported higher fish yields. According to local fishers, inland capture fishery activities were conducted regularly on an annual basis (as recorded by 92.9 % of correspondents), but the most productive months were from March to June.

3.3. Status of ecosystem health and linkage to inland fisheries

The ecosystem health of the Lam river in 2020 was analyzed through fish biodiversity metrics and physico-chemical parameters that were collected in-situ at the same sites and times as the fish samples. Results of physico-chemical parameters suggested relatively good ecosystem condition, with most monitored values occurring within the classes A1 (very good) and B1 (satisfactory) of the National technical regulation on surface water quality QCVN08-MT 2015/BTNMT (Appendix, Table A5). EC and salinity values respectively varied between 11.8 and 2265.0 mS/m (mean 214.1 mS/m) and 0.1 to 12.4 (mean 1.0 mg/L), indicating a shift from freshwater near the upstream areas to saline water conditions near the Cua Hoi estuary. pH varied from neutral to slightly alkaline (6.3 to 8.3) and did not differ between the two sampling seasons. Meanwhile, NO_3^-, PO_4^{3-}, and BOD_5 in the two sampling seasons were within the threshold of A1 classes, with mean values of 1.2 mg/L, 0.03 mg/L, and 1.1 mg/L, respectively. DO monitoring results, however, indicated effects of hydrological dams, a well-known anthropogenic stressor threatening both biodiversity and food ecosystem services (e.g., McIntyre et al., 2016). Most sites had DO values that varied between the A1 ($\geq$6 mg/L) and B1 ($\geq$4 mg/L) classes, but some values near the headwater (e.g., sites S20 to S28) were below 4 mg/L during the dry season due to low water levels caused by water stored in upstream dams. The most-upstream site S28 had the lowest DO values in comparison to the rest of the sampling sites in the dry season of 2020.

Regarding fish diversity, the results of the Spearman correlation suggested that richness and Shannon diversity were significantly correlated to salinity level (corr = 0.5), while the relationships with the other physico-chemical parameters were weak (corr $\leq$ 0.2) and not statistically significant (Fig. 4). This result was further confirmed by our RDA analyses showing that salinity was the most influential environmental gradient affecting fish biodiversity, in particular during the dry season (ordiR2step test for salinity: R^2 adjusted = 0.46, p-value = 0.002). At the most upstream site (S28), the lowest DO in the dry season corresponded to the lowest values of richness and Shannon diversity. Although RDA analysis indicated that NO_3^- did not influence fish community as much as the DO stressor, the relationship between richness/Shannon diversity and NO_3^- was still negative, suggesting that NO_3^- may

Table A2
Estimated fish yields based on gear types at the Lam river in 2020.

Gear types (1)	Catch yield/ day/household (kg) CPUEi (2)	Number of households TFi (3)	Effective days of catch/month Di (4)	Number of catch months/year (5)	Catch yield/year (kg) (6) = (2)*(3)*(4)*(5)
Gill net	9.50	46	15	12	78,660
Seine net	6.30	28	15	12	31,752
Traw net	5.30	16	15	12	15,264
Cash net	5.10	7	15	12	6,426
Electrofishing	5.80	9	10	12	6,264
Long line net	5.50	5	15	12	4,950
Fishing rod	5.50	5	15	12	4,950
Bait fish traps	5.20	4	15	12	3,744
Total					152,010

Table A3
List of fish taxa collected at the Lam river in 2020.

No.	Taxa	Family	No.	Taxa	Family
1	*Telatrygon zugei*	Dasyatidae	76	*Glossogobius giuris*	Gobiidae
2	*Notopterus notopterus*	Notopteridae	77	*Glossogobius olivaceus*	Gobiidae
3	*Clupanodon thrissa*	Clupeidae	78	*Mugilogobius* sp.	Gobiidae
4	*Konosirus punctatus*	Clupeidae	79	*Odontamblyopus rubicundus*	Gobiidae
5	*Sardinella gibbosa*	Clupeidae	80	*Oxyurichthys microlepis*	Gobiidae
6	*Coilia grayii*	Engraulidae	81	*Parachaeturichthys polynema*	Gobiidae
7	*Coilia mystus*	Engraulidae	82	*Psammogobius biocellatus*	Gobiidae
8	*Leptobotia elongata*	Botiidae	83	*Rhinogobius similis*	Gobiidae
9	*Cobitis* sp.	Cobitidae	84	*Rhinogobius* sp.	Gobiidae
10	*Misgurnus anguillicaudatus*	Cobitidae	85	*Tridentiger barbatus*	Gobiidae
11	*Schisura* sp.	Nemacheilidae	86	*Trypauchen vagina*	Gobiidae
12	*Barbodes semifasciolatus*	Cyprinidae	87	*Mastacembelus armatus*	Mastacembelidae
13	*Barbonymus gonionotus*	Cyprinidae	88	*Monopterus albus*	Synbranchidae
14	*Barbonymus* sp.	Cyprinidae	89	*Anabas testudineus*	Anabantidae
15	*Carassioides acuminatus*	Cyprinidae	90	*Channa lucius*	Channidae
16	*Carassioides* sp.	Cyprinidae	91	*Channa orientalis*	Channidae
17	*Carassius auratus*	Cyprinidae	92	*Channa striata*	Channidae
18	*Cirrhinus mrigala*	Cyprinidae	93	*Sphyraena forsteri*	Sphyraenidae
19	Cyprinidae sp.	Cyprinidae	94	*Sphyraena putnamae*	Sphyraenidae
20	*Cyprinus carpio*	Cyprinidae	95	*Polydactylus sextarius*	Polynemidae
21	*Garra orientalis*	Cyprinidae	96	*Pseudorhombus malayanus*	Paralichthyidae
22	*Labeo rohita*	Cyprinidae	97	*Tarphops oligolepis*	Paralichthyidae
23	*Onychostoma gerlachi*	Cyprinidae	98	*Aseraggodes dubius*	Soleidae
24	*Onychostoma lepturus*	Cyprinidae	99	*Solea ovata*	Soleidae
25	*Onychostoma simum*	Cyprinidae	100	*Zebrias zebra*	Soleidae
26	*Osteochilus salsburyi*	Cyprinidae	101	*Cynoglossus abbreviatus*	Cynoglossidae
27	*Paraspinibarbus macracanthus*	Cyprinidae	102	*Cynoglossus bilineatus*	Cynoglossidae
28	*Puntius brevis*	Cyprinidae	103	*Cynoglossus cynoglossus*	Cynoglossidae
29	*Spinibarbichthys denticulatus*	Cyprinidae	104	*Alepes kleinii*	Carangidae
30	*Aphyocypris dorsohorizontalis*	Xenocyprididae	105	*Atule mate*	Carangidae
31	*Chanodichthys erythropterus*	Xenocyprididae	106	*Scomberoides tala*	Carangidae
32	*Chanodichthys flavipinnis*	Xenocyprididae	107	*Oreochromis niloticus*	Cichlidae
33	*Hemiculter elongatus*	Xenocyprididae	108	*Hyporhamphus quoyi*	Hemiramphidae
34	*Hemiculter leucisculus*	Xenocyprididae	109	*Osteomugil perusii*	Mugilidae
35	*Megalobrama terminalis*	Xenocyprididae	110	*Planiliza subviridis*	Mugilidae
36	*Metzia formosae*	Xenocyprididae	111	*Drepane punctata*	Drepaneidae
37	*Opsariichthys bidens*	Xenocyprididae	112	*Leiognathus berbis*	Leiognathidae
38	*Squaliobarbus curriculus*	Xenocyprididae	113	*Leiognathus equula*	Leiognathidae
39	*Toxabramis swinhonis*	Xenocyprididae	114	*Nuchequula gerreoides*	Leiognathidae
40	*Xenocypris davidi*	Xenocyprididae	115	*Nuchequula nuchalis*	Leiognathidae
41	*Xenocypris macrolepis*	Xenocyprididae	116	*Leiognathus ruconius*	Leiognathidae
42	*Acheilognathus tonkinensis*	Acheilognathidae	117	*Scatophagus argus*	Scatophagidae
43	*Rhodeus ocellatus*	Acheilognathidae	118	*Siganus fuscescens*	Siganidae
44	*Gobiobotia kolleri*	Gobionidae	119	*Lagocephalus spadiceus*	Tetraodontidae
45	*Hemibarbus medius*	Gobionidae	120	*Takifugu ocellatus*	Tetraodontidae
46	*Hemibarbus songloensis*	Gobionidae	121	*Pelates quadrilineatus*	Terapontidae
47	*Saurogobio dabryi*	Gobionidae	122	*Terapon jarbua*	Terapontidae
48	*Saurogobio immaculatus*	Gobionidae	123	*Terapon theraps*	Terapontidae
49	*Squalidus argentatus*	Gobionidae	124	*Pempheris nyctereutes*	Pempheridae
50	*Plotosus lineatus*	Plotosidae	125	*Ambassis kopsii*	Ambassidae
51	*Hemibagrus guttatus*	Bagridae	126	*Ambassis macracanthus*	Ambassidae
52	*Hemibagrus pluriradiatus*	Bagridae	127	*Ambassis vachellii*	Ambassidae
53	*Mystus gulio*	Bagridae	128	*Epinephelus sexfasciatus*	Serranidae
54	*Tachysurus virgatus*	Bagridae	129	*Ostorhinchus novemfasciatus*	Apogonidae
55	*Bagarius rutilus*	Sisoridae	130	*Sillago sihama*	Sillaginidae
56	*Silurus asotus*	Siluridae	131	*Lutjanus johnii*	Lutjanidae
57	*Clarias fuscus*	Clariidae	132	*Lutjanus russellii*	Lutjanidae
58	*Arius arius*	Ariidae	133	*Gerres filamentosus*	Gerreidae
59	*Cranoglanis bouderius*	Cranoglanididae	134	*Gerres limbatus*	Gerreidae
60	*Cranoglanis henrici*	Cranoglanididae	135	*Gerres oyena*	Gerreidae
61	*Leucosoma chinensis*	Salangidae	136	*Acanthopagrus pacificus*	Sparidae
62	*Salanx longianalis*	Salangidae	137	*Acanthopagrus schlegelii*	Sparidae
63	*Saurida macrolepis*	Synodontidae	138	*Acanthopagrus* sp.	Sparidae
64	*Trachinocephalus trachinus*	Synodontidae	139	*Scolopsis taenioptera*	Nemipteridae
65	*Butis koilomatodon*	Eleotridae	140	*Dendrophysa russelii*	Sciaenidae
66	*Eleotris fusca*	Eleotridae	141	*Johnius carouna*	Sciaenidae
67	*Eleotris melanosoma*	Eleotridae	142	*Nibea albiflora*	Sciaenidae
68	*Eleotris oxycephala*	Eleotridae	143	*Nibea soldado*	Sciaenidae
69	*Eleotris* sp.	Eleotridae	144	*Pennahia aneus*	Sciaenidae
70	*Oxyeleotris marmorata*	Eleotridae	145	*Callionymus curvicornis*	Callionymidae
71	*Acanthogobius* sp.	Gobiidae	146	*Callionymus hindsii*	Callionymidae
72	*Acentrogobius caninus*	Gobiidae	147	*Trichosomus trachinoides*	Tetrarogidae
73	*Aulopareia unicolor*	Gobiidae	148	*Hoplichthys langsdorfii*	Hoplichthyidae
74	*Eviota storthynx*	Gobiidae	149	*Inegocia* sp.	Platycephalidae
75	*Glossogobius aureus*	Gobiidae	150	*Platycephalus indicus*	Platycephalidae

Table A4
Conservation status of economically valuable species at the Lam river. Economically valuable species are marked with an 'x'.

No.	Species	Family	Order	Endangered status				
				National Decree 26/2019[(1)]	Vietnam's Red Data Book 2007[(2)]	International Union for Conservation of Nature[(3)]	Endemic	Economic valuable[(4)]
1	*Notopterus notopterus*	Notopteridae	Osteoglossiformes					x
2	*Clupanodon thrissa*	Clupeidae	Clupeiformes	II	Endangered			x
3	*Konosirus punctatus*	Clupeidae	Clupeiformes	II	Vulnerable			x
4	*Coilia grayii*	Engraulidae	Clupeiformes					x
5	*Coilia mystus*	Engraulidae	Clupeiformes			Endangered		x
6	*Leptobotia elongata*	Botiidae	Cypriniformes			Vulnerable		x
7	*Misgurnus anguillicaudatus*	Cobitidae	Cypriniformes					x
8	*Barbodes semifasciolatus*	Cyprinidae	Cypriniformes					x
9	*Barbonymus gonionotus*	Cyprinidae	Cypriniformes					x
10	*Carassioides acuminatus*	Cyprinidae	Cypriniformes				x	x
11	*Carassius auratus*	Cyprinidae	Cypriniformes					x
12	*Cirrhinus mrigala*	Cyprinidae	Cypriniformes					x
13	*Cyprinus carpio*	Cyprinidae	Cypriniformes			Vulnerable		x
14	*Garra orientalis*	Cyprinidae	Cypriniformes					x
15	*Labeo rohita*	Cyprinidae	Cypriniformes					x
16	*Onychostoma gerlachi*	Cyprinidae	Cypriniformes	II				x
17	*Onychostoma lepturus*	Cyprinidae	Cypriniformes					x
18	*Onychostoma simum*	Cyprinidae	Cypriniformes					x
19	*Osteochilus salsburyi*	Cyprinidae	Cypriniformes					x
20	*Paraspinibarbus macracanthus*	Cyprinidae	Cypriniformes	II			x	x
21	*Puntius brevis*	Cyprinidae	Cypriniformes					x
22	*Spinibarbichthys denticulatus*	Cyprinidae	Cypriniformes					x
23	*Chanodichthys erythropterus*	Xenocyprididae	Cypriniformes					x
24	*Chanodichthys flavipinnis*	Xenocyprididae	Cypriniformes	I				x
25	*Hemiculter elongatus*	Xenocyprididae	Cypriniformes					x
26	*Hemiculter leucisculus*	Xenocyprididae	Cypriniformes					x
27	*Megalobrama terminalis*	Xenocyprididae	Cypriniformes	II				x
28	*Opsariichthys bidens*	Xenocyprididae	Cypriniformes					x
29	*Squaliobarbus curriculus*	Xenocyprididae	Cypriniformes					x
30	*Toxabramis swinhonis*	Xenocyprididae	Cypriniformes					x
31	*Xenocypris davidi*	Xenocyprididae	Cypriniformes					x
32	*Xenocypris macrolepis*	Xenocyprididae	Cypriniformes					x
33	*Hemibarbus medius*	Gobionidae	Cypriniformes					x
34	*Saurogobio dabryi*	Gobionidae	Cypriniformes					x
35	*Plotosus lineatus*	Plotosidae	Siluriformes					x
36	*Hemibagrus guttatus*	Bagridae	Siluriformes	II	Vulnerable			x
37	*Hemibagrus pluriradiatus*	Bagridae	Siluriformes	II				x
38	*Bagarius rutilus*	Sisoridae	Siluriformes	II	Vulnerable			x
39	*Silurus asotus*	Siluridae	Siluriformes					x
40	*Clarias fuscus*	Clariidae	Siluriformes					x
41	*Arius arius*	Ariidae	Siluriformes					x
42	*Cranoglanis bouderius*	Cranoglanididae	Siluriformes					x
43	*Cranoglanis henrici*	Cranoglanididae	Siluriformes					x
44	*Leucosoma chinensis*	Salangidae	Osmeriformes					x
45	*Salanx longianalis*	Salangidae	Osmeriformes					x
46	*Eleotris fusca*	Eleotridae	Gobiiformes					x
47	*Eleotris melanosoma*	Eleotridae	Gobiiformes					x
48	*Oxyeleotris marmorata*	Eleotridae	Gobiiformes					x
49	*Acentrogobius caninus*	Gobiidae	Gobiiformes					x
50	*Glossogobius aureus*	Gobiidae	Gobiiformes					x
51	*Glossogobius giuris*	Gobiidae	Gobiiformes					x

(*continued on next page*)

Table A4 (*continued*)

No.	Species	Family	Order	Endangered status				
				National Decree 26/2019[(1)]	Vietnam's Red Data Book 2007[(2)]	International Union for Conservation of Nature[(3)]	Endemic	Economic valuable[(4)]
52	*Glossogobius olivaceus*	Gobiidae	Gobiiformes					x
53	*Mastacembelus armatus*	Mastacembelidae	Synbranchiformes					x
54	*Monopterus albus*	Synbranchidae	Synbranchiformes					x
55	*Anabas testudineus*	Anabantidae	Anabantiformes					x
56	*Channa lucius*	Channidae	Anabantiformes					x
57	*Channa orientalis*	Channidae	Anabantiformes			Vulnerable		–
58	*Channa striata*	Channidae	Anabantiformes					x
59	*Solea ovata*	Soleidae	Carangiformes					x
60	*Cynoglossus bilineatus*	Cynoglossidae	Carangiformes					x
61	*Oreochromis niloticus*	Cichlidae	Cichliformes					x
62	*Planiliza subviridis*	Mugilidae	Mugiliformes					x
63	*Drepane punctata*	Drepaneidae	Acanthuriformes					x
64	*Leiognathus equula*	Leiognathidae	Acanthuriformes					x
65	*Nuchequula gerreoides*	Leiognathidae	Acanthuriformes					x
66	*Leiognathus ruconius*	Leiognathidae	Acanthuriformes					x
67	*Scatophagus argus*	Scatophagidae	Acanthuriformes					x
68	*Terapon jarbua*	Terapontidae	Centrarchiformes					x
69	*Terapon theraps*	Terapontidae	Centrarchiformes					x
70	*Epinephelus sexfasciatus*	Serranidae	Perciformes					x
71	*Sillago sihama*	Sillaginidae	Perciformes					x
72	*Lutjanus johnii*	Lutjanidae	Perciformes					x
73	*Lutjanus russellii*	Lutjanidae	Perciformes					x
74	*Acanthopagrus schlegelii*	Sparidae	Perciformes					x
75	*Nibea albiflora*	Sciaenidae	Perciformes					x

Sources:
(1) Decree No. 26/2019/ND-CP of the Government Regulating a number of articles and measures to implement the Fisheries Law. https://faolex.fao.org/docs/pdf/vie191156.pdf.
(2) Ministry of Science and Technology & Vietnamese Academy of Science and Technology, 2007. Vietnam Red Data Book. Part I - Animals. p 516.
(3) IUCN, 2021.
(4) MoF, 1996.

Table A5
Values of physico-chemical data at the Lam river in 2020.

	Temperature	Acidity (pH)	Salinity	Electric conductivity (EC)	Dissolved oxygen (DO)	Nitrate (NO_3^-)	Phosphate (PO_4^{3-})	Biological oxygen demand (BOD_5)
Average	26.5	7.8	1.0	214.1	4.8	1.2	0.03	1.1
Max	33.1	8.3	12.4	2265.0	6.6	4.3	0.2	4.4
Min	20.7	6.3	0.1	11.8	2.2	0.3	0.0	0.1
QCVN08 (A1)	–	6.0–8.5	–	–	≥6	2	0.1	4
QCVN08 (B1)	–	5.5–9.0	–	–	≥4	10	0.3	15

cause impacts if concentrations continue to increase (Fig. 5). Other stressors showed no significant impacts on fish diversity in both dry and wet seasons of 2020. Overall, low stressor values seemed to facilitate diverse and more stable sources of provisioning ecosystem services from the inland fisheries in the Lam river.

3.4. *Status of ecosystem services of inland fisheries and linkage to human wellbeing*

The Lam river survey revealed a fishing community structure common to many Southeast Asian regions (e.g., Coates, 2002; MARD, 2009; Nguyen et al., 2012; Teh and Pauly, 2018). Firstly, results revealed that fishers in the Lam river were primarily men, who comprised 95.5 % of respondents. The lower proporition of women and children in fishing (4.5 % of respondents) was likely because these groups were primarily occupied in fish processing and trading rather than catching. Secondly, the respondents were generally between 40 and 60 years of age (59.7 % total respondents), with a lower proportion of respondents below 40 (26.8 %) and above 60 years of age (13.5 %). The dominance of 40–60 age category may have occured because younger people were primarily involved in agriculture and other services, whereas older people could not participate in long fishing journeys due to adverse health conditions. The educational level of the Lam community was characterized by 93 % of respondents with a secondary schooling level (or below) and 4.4 % of respondents having never attended school. Another typical characteristic of the Lam community was a small household size, i.e., households of one to four persons accounting for 56.7 % of the total community. Meanwhile, large families (i.e., more than six persons/hoursehold) remained common in this area, accounting for 13.3 % of the total community.

Surveys confirmed that inland fisheries provided important provisioning and cultural services. Inland fisheries along with agriculture and other service activities provided an important income source for the local communities. 39 % of respondents answered that inland fisheries earned below five million Vietnam Dong (VND)/month, while the other 30.5 % said that this job earned five to 10 million VND, or more than 10 million VND per month, depending on the catch months. Households with below average income contributed only 1.3 to 4.3 % of inhabitants at the surveyed communes. Fish also contributed to low-income households directly through daily meal consumption (83.3 % of respondents), i.e. providing a main protein source and helping to save daily expenses on other foods. Furthermore, inland fisheries were considered a traditional job in the area, with more than two-thirds of respondents having more than 20 years of experience in professional fishing transferred from previous generations. Inland fisheries played an important role in shaping people's identities and provided a feeling of belonging and connectedness in the society among generations. Half of the correspondents said they would continue professional fishing even if the fish yields and income might change over time.

Similar to findings from previous local research and official reports in this area, 100 % of respondents of this survey said that fish yields have been decreasing through time. 86.2 % of respondents said that the body size of caught fishes in the recent five years from 2015 to 2020 has decreased, as opposed to 10.3 % reporting that size had not changed and 3.5 % reporting that the size of certain fishes has increased. However, no detailed field investigations over a long-term period have been conducted in this study area, making it difficult to confirm these reports. The principal stressors causing negative effects on the fisheries were reported to be high competition among participating boats, the use of unsustainable catch methods, and the effects of upstream dams (Fig. 6). In fact, the use of explosive and electrical methods, and small net sizes in fishing, catching small-size fish, and fishing in breeding seasons are particularly problematic and are considered as illegal in this region, thus requiring a more stringent management by local authorities to address (Ngo and Pham, 2005; MARD, 2009). Next, climate change was also a commonly agreed stressor. Environmental pollution was another common stressor along the Lam river, which as suggested by 27.6 % respondents might cause a notable decrease in fish yields in intensive land-use areas. Overall, we believe that declines in fish yield and body size along the Lam river were driven primarily by overfishing using unsustainable methods, and to a lesser extent were linked to potential deterioration of ecosystem health or to decline in fish biodiversity due to climate and land-use changes. This information urges for more evidence-based decisions, legislations, and enforcement to ensure the continued health of the inland fisheries and that natural resources are extracted within ecosystem boundary limits. Such efforts would also help to preserve fish biodiversity and ecosystem health under the various threats of anthropogenic activities and natural disasters.

4. Conclusions

Our case study of the Lam river provides a thorough overview on the status of inland fisheries in a typical large river in the northern part of Central Vietnam, and the linkage between its ecosystem services and ecosystem health and human wellbeing. Our results suggest that low-stress and resilient ecosystems might support a high biodiversity of fish fauna. In return, diverse inland fisheries would provide key provisioning and cultural services to human wellbeing. Fisheries provide food, employment, and income for local people living along the Lam river. Apart from food and income sources, fishing in the Lam river is considered as the symbol of the Nghe An province because this profession is transferred across generations, providing a sense of belonging to local communities and a cultural attraction for the region. Surveys with local fishers indicated increasing pressures on the sustainable fishery due to a high density of fishing boats and increasing usage of unsustainable methods. Dam construction and operation, climate change, and environmental pollution were potentially less impactful, but were also commonly listed reasons causing decreasing trends in annual fish yields and fish body sizes. We believe that these results provide a better understanding of the biodiversity status of fish fauna of understudied areas, as well as the importance of fish biodiversity and ecosystem health in providing ecosystem services and socio-economic benefits to human wellbeing.

To ensure the sustainable future development of inland fisheries in large rivers, it is important to further investigate long-term variability in the composition and diversity of inland fisheries, the linkage between fish biodiversity and ecosystem services, and the impacts of multiple stressors on ecosystem health and functioning. Such information provides important lines of evidence to establish effective fisheries management and law enforcement, ensuring the long-term supply of food and other services provided by inland fisheries. Legislative and enforcement measures can include bans on illegal fishing and setting specific regulations on the allowed minimum catch sizes, types of fishing gear, the fishing periods during the year, and preventing fishing in biodiversity-hotspot conservation areas. More importantly, local governments are charged with building community-based co-management with local people, in which local governments play a central role in monitoring, enforcement, incentives, and punishments in case fishers do not conform to regulations. Lastly, future research also needs to provide evidence-based information regarding historical and future changes of ecosystem services of inland fisheries under various scenarios of implementing regulations and enforcement laws to support future local and regional planning.

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.

Data availability

Data will be made available on request.

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Appendix

References

Allen, D.J., Smith, K.G., Darwall, W.R.T., 2012. The Status and Distribution of Freshwater Biodiversity in Indo-Burma. IUCN, Cambridge, UK and Gland, Switzerland.

Blanchet, F.G., Legendre, P., Borcard, D., 2008. Forward selection of explanatory variables. Ecology 89, 2623–2632.

Brooks, E.G.E., Holland, R.A., Darwall, W.R.T., Eigenbrod, F., 2016. Global evidence of positive impacts of freshwater biodiversity on fishery yields. Glob. Ecol. Biogeogr. 25 (5), 553–562. https://doi.org/10.1111/geb.12435.

Coates, D., 2002. Inland capture fishery statistics of Southeast Asia: Current status and information needs. Asia-Pacific Fishery Commission, Bangkok, Thailand. RAP Publication No. 2002/11, 114 pp.

Cooke, S.J., Allison, E.H., Beard, T.D., Arlinghaus, R., Arthington, A.H., Bartley, D.M., Cowx, I.G., Fuentevilla, C., Leonard, N.J., Lorenzen, K., Lynch, A.J., Nguyen, V.M., Youn, S.J., Taylor, W.W., Welcomme, R.L., 2016. On the sustainability of inland fisheries: Finding a future for the forgotten. Ambio 45, 753–764. https://doi.org/10.1007/s13280-016-0787-4.

Dang, A.N., Jackson, B.M., Benavidez, R., Tomscha, S.A., 2021. Review of ecosystem service assessments: pathways for policy integration in Southeast Asia. Ecosyst. Serv. 49, 101266 https://doi.org/10.1016/j.ecoser.2021.101266.

Darwall, W., Smith, K., Allen, D., Holland, R., Harrison, I., Brooks, E., 2011. The Diversity of Life in African Freshwaters: Underwater, Under Threat – An Analysis of the Status and Distribution of Freshwater Species Throughout Mainland Africa. IUCN, Cambridge, United Kingdom and Gland, Switzerland, p. 364.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Ram Adhikari, J., Arico, S., Baldi, A., et al., 2015. The IPBES Conceptual Framework — connecting nature and people. Curr. Opin. Environ. Sustain. 14, 1–16. https://doi.org/10.1016/j.cosust.2014.11.002.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.-I., Knowler, D.J., Lévêque, C., Naiman, R.J., Soto, D., Stiassny, M.L.J., Sullivan, C.A., 2006. Freshwater biodiversity: Importance, treats, status and conservation challenges. Biol. Rev. 81, 163–182. https://doi.org/10.1017/S1464793105006950.

EC, 2015. In-depth report. Ecosystem Services and Biodiversity. European Commission. P. 32. https://nucif.net/wp-content/uploads/2020/02/Ecosystem_Services_Biodiversity_en.pdf. Accessed on [10 May 2022].

FAO, 2020a. The State of Food Security and Nutrition in the World 2020. Transforming Food Systems for Affordable Healthy Diets. FAO, Rome.

FAO, 2022. The State of World Fisheries and Aquaculture 2022. Towards blue transformation, Rome https://www.fao.org/3/cc0461en/cc0461en.pdf.

FAO, 2020b. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. 10.4060/ca9229en.

Fricke, R., Eschmeyer, W.N., Van der Laan, R. (eds), 2022. Eschmeyer's catalog of fishes: genera, species references. http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp). Accessed on [01 August 2022].

Froese, R., Pauly, D. (eds), 2022. FishBase. World Wide Web electronic publication. www.fishbase.org. Accessed on [10 February 2022].

GSO, 2021. Result of the Vietnam household living standards survey 2020. General Statistics Office. Statistical Publishing House. p. 848. h ttps://www.gso.gov.vn/wp-content/uploads/2022/06/Khao-sat-muc-song-2020.pdf. Accessed on [05 October 2022].

Hanna, D.E.L., Tomscha, S.A., Dallaire, C.O., Bennett, E.M., 2018. A review of riverine ecosystem service quantification: Research gaps and recommendations. J. Appl. Ecol. 55, 1299–1311. https://doi.org/10.1111/1365-2664.13045.

Hortle, K.G., Bamrungrach, P., 2015. Fisheries Habitat and Yield in the Lower Mekong Basin. MRC Technical Paper No. 47, 80pp.

IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Bonn. Germany. 39 pp.

IUCN, 2021. The IUCN Red List of Threatened Species. Version 2021-3. https://www.iucnredlist.org. Accessed on [10 February 2022].

Kaval, P., 2019. Integrated catchment management and ecosystem services: A twenty-five-year overview. Ecosyst. Serv. 37 https://doi.org/10.1016/j.ecoser.2019.100912.

Kottelat, M., 2001. Freshwater Fishes of Northern Vietnam: A Preliminary Check-list of the Fishes Known or Expected to Occur in Northern Vietnam with Comments on Systematics and Nomenclature. The World Bank, Washington, p. 184.

Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129, 271–280.

Legendre, P., Legendre, L.F.J., 2012. Numerical Ecology. Elsevier Science.

Lynch, A.J., Cooke, S.J., Deines, A.M., Bower, S.D., Bunnell, D.B., Cowx, I.G., Nguyen, V. M., Nohner, J., Phouthavong, K., Riley, B., Rogers, M.W., Taylor, W.W., Woelmer, W., Youn, S.J., Beard, T.D., 2016. The social economic and environmental importance of inland fish and fisheries. Environ. Rev. 24, 115–121. https://doi.org/10.1139/er-2015-0064.

Lynch, A.J., Cowx, I.G., Fluet-Chouinard, E., Glaser, S.M., Phang, S.C., Beard, T.D., Bower, S.D., Brooks, J.L., Bunnell, D.B., Claussen, J.E., Cooke, S.J., Kao, Y.C., Lorenzen, K., Myers, B.J.E., Reid, A.J., Taylor, J.J., Youn, S.J., 2017. Inland fisheries—invisible but integral to the UN Sustainable Development Agenda for ending poverty by 2030. Glob. Environ. Chang. 47, 167–173. https://doi.org/10.1016/j.gloenvcha.2017.10.005.

MA, 2005. Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Synthesis. Press. Island.

Mai, D.Y., 1978. Identification of freshwater fishes in northern Vietnam. Science and Technology Publisher (Nha Xuat Ban Khoa Hoc Va Ky Thuant), Hanoi. (in Vietnamese).

MARD, 2009. Planning on inland aquatic resources conservation system to 2020. MARD. p. 95 *(in Vietnamese)*.

McIntyre, P.B., Lierman, C.A.R., Revenga, C., 2016. Linking freshwater fishery management to global food security and biodiversity conservation. Proc. Natl. Acad. Sci. 113 (45), 12880–12885. https://doi.org/10.1073/pnas.1521540113.

Miao W., Silva S.D., Davy B., 2010. Inland Fisheries Enhancement and Conservation in Asia. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2010/22, 189 pp.

MoF, 1996. Aquatic resources of Vietnam. Agricultural Publishing House. Ministry of Fisheries, Hanoi, p. 240 in Vietnamese.

Ngo, V.S., Pham, T.A., 2005. Status and solutions for development of natural fish resources in some provinces in Northern Vietnam Paper presented in National Workshop on Environmental Aquatic Resources Conservation Research Institute for Marine Science.Vietnam. *(in Vietnamese)*.

Nguyen, V.H., 2005. The freshwater fishes of Vietnam, Vol. 3. MARD Informatic Center, Agriculture Publisher, Hanoi.

Nguyen, T.H.T., Thinh, D.V., Sugden, F., Smith, K., Bunting, S.W., 2012. HighARCS Integrated Action Planning for the Phu Yen District study site, Son La Province, Vietnam. Highland Aquatic Resources Conservation and Sustainable Development Project. 45 pp. https://rucforsk.ruc.dk/ws/files/54013034/IAP_Son_La_Final.pdf.

Petrtýl, M., Bohlen, J., Kalous, L., Bui, T.A., Chaloupková, P., 2011. Loaches and the environment in two provinces in Northern Vietnam. Folia Zool. – 60 (4), 368–374. 10.25225/fozo.v60.i4.a1.2011.

Phang, S.C., Cooperman, M., Lynch, A.J., Steel, E.A., Elliott, V., Murchie, K.J., Cowx, I.G., 2019. Fishing for conservation of freshwater tropical fishes in the Anthropocene. Aquat. Conserv. Mar. Freshwat. Ecosyst. 29, 1039–1051. https://doi.org/10.1002/aqc.3080.

R Core Team, 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria http://www.R-project.org/.

Sodhi, N.S., Brook, B.W., 2006. Southeast Asian Biodiversity in Crisis. Cambridge University Press, Cambridge, p. 204.

Sodhi, N.S., Koh, L.P., Brook, B.W., Ng, P.K.L., 2004. Southeast Asian biodiversity: an impending disaster. Trends Ecol. Evol. 19 (12), 654–660. https://doi.org/10.1016/j.tree.2004.09.006.

Stamatopoulos, C., 2002. Sample-based fishery surveys: A technical handbook. FAO Fisheries Technical Ppaer 425. Rome, FAO, 132 pp.

TEEB, 2010. London and Washington. The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations, 10.4324/9781849775489.

Teh, L.C., Pauly, D., 2018. Who brings in the fish? The relative contribution of small-scale and industrial fisheries to food security in Southeast Asia. Front. Mar. Sci. 5, 44. https://doi.org/10.3389/fmars.2018.00044.

Vári, Á., Podschun, S.A., Erős, T., Hein, T., Pataki, B., Iojă, I.C., Adamescu, C.M., Gerhardt, A., Gruber, T., Dedić, A., Ćirić, M., Gavrilović, B., Báldi, A., 2021. Freshwater systems and ecosystem services: Challenges and chances for cross-fertilization of disciplines. Ambio 51, 135–151. https://doi.org/10.1007/s13280-021-01556-4.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature 467, 555–561. https://doi.org/10.1038/nature09440.

Young, J.C., Marzano, M., White, R.M., McCracken, D.I., Redpath, S.M., Carss, D.N., Quine, C.P., Watt, A.D., 2010. The emergence of biodiversity conflicts from biodiversity impacts: Characteristics and management strategies. Biodivers. Conserv. 19, 3973–3990. https://doi.org/10.1007/s10531-010-9941-7.

Zuur, A.F., Ieno, E.N., Saveliev, A.A., 2017. Beginner's Guide to Spatial. Temporal. and Spatial-Temporal Ecological Data Analysis with R-INLA. Highland Statistics Ltd. ISBN: 978-0-9571741-9-1.