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RESISTANCE, RESILIENCE AND SENSITIVITY: QUANTIFICATION IN RIVERINE HABITATS

by

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ABSTRACT

Tuononen, E.I., Hodgson, E.E., Dey, C.J., Drake, D.A.R., Koops, M.A., and Chu, C. 2024. Resistance, Resilience and Sensitivity: Quantification in Riverine Habitats. Can. Data Rep. Fish. Aquat. Sci. 1356: iii + 13 p.

The sensitivity of fish habitat is an important consideration for Fisheries and Oceans Canada's decision making related to regulating works, undertakings, and activities near water. In this report, we first compiled definitions of habitat sensitivity from the literature to understand how other authors have defined the concept. Next, we conducted a review of primary literature articles in which habitat sensitivity (or its components, habitat resistance, and resilience) was quantified in riverine systems to survey the approaches currently used for measuring and assessing habitat sensitivity. This report summarizes the main study designs, response variables, disturbance types, indicators, and duration for studies quantifying habitat sensitivity in riverine systems in a tabular form. We expect these data will be useful for future research and science advice projects relating to habitat sensitivity in aquatic environments.

RÉSUMÉ

Tuononen, E.I., Hodgson, E.E., Dey, C.J., Drake, D.A.R., Koops, M.A., and Chu, C. 2024. Resistance, Resilience and Sensitivity: Quantification in Riverine Habitats. Can. Data Rep. Fish. Aquat. Sci. 1356: iii + 13 p.

La sensibilité de l'habitat du poisson est une considération importante pour la prise de décision de Pêches et Océans Canada concernant la réglementation des ouvrages, des entreprises, et des activités à proximité de l'eau. Dans ce rapport, nous avons d'abord compilé les définitions de la sensibilité de l'habitat tirées de la littérature pour comprendre comment d'autres auteurs ont défini le concept. Ensuite, nous avons effectué une revue des articles de la littérature primaire dans lesquels la sensibilité de l'habitat (ou ses composantes, la résistance, et la résilience de l'habitat) ont été quantifiées dans les systèmes fluviaux, pour étudier les approches actuellement utilisées pour mesurer et évaluer la sensibilité de l'habitat. Ensuite, nous avons effectué une revue des articles de la littérature primaire sur les rivières dans lesquelles la sensibilité de l'habitat (ou ses composantes, la résistance, et la résilience de l'habitat) a été quantifié afin d'étudier les approches actuellement utilisées pour mesurer la sensibilité de l'habitat. Ce rapport résume les principales conceptions d'études, les variables de réponse, les types de perturbations, les indicateurs, et la durée des études quantifiant la sensibilité de l'habitat dans les systèmes fluviaux. Nous prévoyons que ces données seront utiles pour de futurs projets de recherche et d'avis scientifiques liés à la sensibilité de l'habitat dans les milieux aquatiques.

DESCRIPTION

Riverine systems are diverse in both their ecology and geomorphology, providing essential habitats for freshwater and terrestrial biota, and important ecosystem services for Canadians. However, rivers are under threat from a multitude of stresses and stressors (Ouellet Dallaire et al., 2020). For example, climate-induced changes include flooding, drought, thermal stress, and run-off from increased incidences of forest fires (Leigh et al., 2015). Other stresses such as pollution, channelization, and the creation of instream barriers can degrade the quality of riverine habitat and fragment connectivity among river reaches (Bradford, 1994; Minns, 2001).

How riverine habitat and biota respond to pressures (i.e., the natural and human actions that impact aquatic ecosystems) and stressors (i.e., the specific, measurable effects from pressures) can vary substantially (Chu et al., 2018), and is an important consideration in managing risk associated with works, undertakings, and activities near rivers. In some cases, whole riverine systems or river segments can recover after experiencing disturbances whereas others can experience permanent shifts in state (regime changes) in their habitat characteristics (Scheffer et al., 2001; Dakos et al., 2015; van de Leemput et al., 2018). Understanding the diversity in these responses to disturbances may help managers identify important strongholds of fish habitat (e.g., for identifying Ecologically Significant Areas) and systems that are more likely to change in response to further anthropogenic activities.

In this report, we provide two datasets. First, we compiled definitions of ‘habitat sensitivity’ from the primary literature and government research documents (Table 1) to inform development of a single definition to use as the basis for our review (see below). Second, we include data from a review of English language primary literature articles focused on the response of riverine habitats to stressors. Specifically, we reviewed studies that focused on quantifying “resistance”, “resilience”, or “sensitivity” (collectively, ‘RRS’) of riverine habitat, where those terms are defined as:

Habitat Sensitivity: the degree and duration of damage caused by an external factor to the habitat in its current state, where these are measured through assessing the habitat’s resilience and resistance to the external factor.

Habitat Resilience: the rate of recovery of a current habitat following an impact, measured as the time required for a habitat and its constituent biological, chemical, and physical features to recover to their characteristic state after disturbance.

Habitat Resistance: the ability of the current habitat to maintain its characteristic biological, chemical, and physical features in the face of a temporary or prolonged disturbance, where high resistance results in low levels of impact.

Initially, we attempted a systematic literature review of studies that quantified RRS based on a Web of Science database search. The search string was composed of groups of terms categorized as: “habitat terms” related to habitat types and spatial scales, “response terms” which contained the core RRS terms, “stressor terms” related to general terms that identify papers discussing impacts on riverine habitats, and “empirical terms” relating to the measurement or quantification of responses. Different search strings used are listed in Table 2, and the final search string was:

Habitat terms	(river* or stream) AND (river* OR habitat* OR scale OR watershed OR "zone of influence" OR "Functional Process zone" OR macrosystem* OR lotic OR fluvial OR riverscape OR stream* OR "local riverine ecosystem" OR "riverine macrosystems")
	AND
Response terms	(resilien* OR resistan* OR sensitiv*)
	AND
Stressor terms	("disturbance regime" OR perturbations OR threats OR impacts)
	AND
Empirical terms	(quantifi* OR measure* OR empir*)

This string yielded 4481 hits on Web of Science. These papers were sorted by “Relevance” and the top 600 papers had their title and abstract reviewed as an initial screen of whether they were relevant to the study objectives. This yielded 400 papers that had the potential to include relevant information. Of these 400 papers, during a secondary review phase the first 88 were read in more detail, with only two that were found to be relevant to our criteria. At this point, with the low relevancy of papers, this type of search was discontinued.

Instead, we focused on identifying articles for review based on suggestions from the project team and from promising references therein, and by non-systematic literature searches (Table 3). Data collected from the papers included data on the study design, the response variable, or indicator used to measure or infer RRS, the scale of the riverine system used in the study, the study location, the main pressure/stressor(s) causing disturbance, and the length of the data collection period (Table 4). This review and data compilation was undertaken between February 10th and March 25th 2022.

These datasets are part of a larger project aiming to develop a framework and recommend approaches to quantifying RRS in rivers, in support of DFO decision-making. Specific conclusions with regards to the data collected in this review will be available in forthcoming publications.

Table 1. Compilation of definitions of habitat sensitivity from the primary literature and government research documents. Underlining has been added to better emphasize and differentiate the specific components of each definition included in this table. Note that the definition provided by Bax & Williams (2001) is for habitat vulnerability, but it is included here because of its importance in contributing to later definitions of habitat sensitivity.

Authors	Year	Definition
Webb et al.	1994	"we have defined sensitivity indices to be developed in this project as indices of relative concern for particular watersheds… [based on] 1. Levels of human activity… 2. Levels of important environmental variables… 3.The ability of the watershed to resist change… 4. Characteristics of particular habitat types… 5. Characteristics of fish stocks"
Hiscock et al.	1999	"sensitivity is the intolerance of a habitat, community or species to damage, or death, from an external factor"
Laffoley et al.	2000	"A sensitive habitat or species is one that is easily affected by human activity, and is expected to only recover over a long period of time"
Bax and Williams	2001	"We define vulnerability here as the product of a habitat's resistance to modification from a particular source and its resilience, or the time taken for the habitat to resume its original ecosystem functions (or more conservatively its original condition) once the modifier is removed."
Berry et al.	2003	"In order to assess the sensitivity of species to climate change the percentage change in their suitable climate space was calculated, both as a percentage of the land area… and also as a percentage of its simulated current suitable climate space"
Zacharias and Gregr	2005	"We define stress as a deviation of environmental conditions beyond the expected range. Sensitivity is the degree to which marine features respond to such stress… Vulnerability is the probability that a feature will be exposed to a stressor to which it is sensitive."
Hiddink et al.	2007	"Sensitivity is calculated from model estimates of the recovery time of production and biomass following a specified trawling event"
Acreman et al.	2008	"...a curvilinear relationship between physical habitat, expressed as weighted usable area (WUA)... against river flow, for particular life stages of target species... The slope of this curve defines the physical habitat sensitivity to change in flow."
Eno et al.	2013	"The sensitivity of each habitat type to each fishing activity type, at the four fishing intensities was assessed by considering the resistance of the habitat to each fishing activity at each intensity and the resilience (recovery potential) of the habitat... Resistance is considered to represent the ability of the habitat to maintain its characteristic species and physical features in the face of fishing disturbance, where high resistance is associated with low levels of impact"
Rivière et al.	2016	"Sensitivity is defined as the combination of resistance and resilience… Resilience is defined as the time a habitat needs to recover from the effect of a pressure, once that pressure has been alleviated... Resistance is defined as the ability of a habitat to tolerate a pressure without significantly changing its biotic or abiotic characteristics"
Goldsmit et al.	2019	"Certain areas have been identified as biologically important in the Canadian Arctic, and this information was used to develop a proxy for habitat sensitivity"
Hodgson et al.	2021	"Habitat Sensitivity: the degree and duration of damage caused by an external factor to the habitat in its current state, where these are measured through assessing the habitat's resilience and resistance to the external factor".

Table 2. Summary of strings initially used to search Web of Science Core Collection and number of results.

(((TS=((river* OR habitat* OR scale OR watershed OR "zone of influence" OR "Functional Process zone" OR macrosystem* OR lotic OR fluvial OR riverscape OR stream* OR "local riverine ecosystem" OR "riverine macrosystems"))) AND TS=((Resilience OR resistance OR sensitivity OR Risk* OR Threshold OR Recovery OR "Ecological stability" OR "Ecological precariousness" OR impact* OR tele-connection OR "directional connectivity" OR "ecological elasticity"))) AND TS=((effect OR impact OR affect OR "disturbance regime" OR perturbations OR threats OR impacts)))	634,416
(((TS=((river* OR habitat* OR scale OR watershed OR "zone of influence" OR "Functional Process zone" OR macrosystem* OR lotic OR fluvial OR riverscape OR stream* OR "local riverine ecosystem" OR "riverine macrosystems"))) AND TS=((Resilience OR resistance OR sensitivity))) AND TS=((effect OR impact OR affect OR "disturbance regime" OR perturbations OR threats OR impacts)))	110,148
(((TS=(river* or stream) AND TS=((habitat* OR scale OR watershed OR "zone of influence" OR "Functional Process zone" OR macrosystem* OR lotic OR fluvial OR riverscape OR stream* OR "local riverine ecosystem" OR "riverine macrosystems"))) AND TS=((Resilien* OR resistan* OR sensitiv*))) AND TS=(("disturbance regime" OR perturbations OR threats OR impacts)) AND TS=((quantifi* OR measure* OR empir*)))	3051
(((TS=(river* or stream) AND TS=((river* OR habitat* OR scale OR watershed OR "zone of influence" OR "Functional Process zone" OR macrosystem* OR lotic OR fluvial OR riverscape OR stream* OR "local riverine ecosystem" OR "riverine macrosystems"))) AND TS=((Resilien* OR resistan* OR sensitiv* OR recover*))) AND TS= ((Fish* OR "fish habitat" OR feature* OR trait* OR composition)) AND TS=(("disturbance regime" OR perturbations OR threat* OR impact*)) AND TS=((quantifi* OR measure* OR empir*)))	1372
(((TI=(river* or stream*) AND TS=((habitat* OR scale OR watershed OR "zone of influence" OR "Functional Process zone" OR macrosystem* OR lotic OR fluvial OR riverscape OR stream* OR "local riverine ecosystem" OR "riverine macrosystems"))) AND TS=((Resilien* OR resistan* OR sensitiv*))) AND TS=(("disturbance regime" OR perturbations OR threats OR impacts)) AND TS=((quantifi* OR measure* OR empir*)))	942

Table 3. Primary literature articles included in this review related to habitat resistance, resilience, and sensitivity in riverine environments. ID number is a unique label to connect the article meta-data from this Table with the information in Table 4. Year is the publication year for the article.

ID	Year	Authors	Title	Journal Title
1	1983	Tschaplinski and Hartman	Winter distribution of juvenile Coho Salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival	Canadian Journal of Fisheries and Aquatic Sciences
2	1992	Detenbeck et al.	Recovery of temperate-stream fish communities from disturbance: a review of case studies and synthesis of theory	Environmental Management
3	1996	Hartman et al.	Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat	Canadian Journal of Fisheries and Aquatic Sciences
4	1996	Barrat-Segretain and Amoros	Recovery of riverine vegetation after experimental disturbance: a field test of the patch dynamics concept	Hydrobiologia
5	2000	Labbe and Fausch	Dynamics of intermittent stream habitat regulate persistence of a threatened fish at multiple scales	Ecological Applications
6	2008	Lyon and O'Connor	Smoke on the water: can riverine fish populations recover following a catastrophic fire-related sediment slug?	Austral Ecology
7	2010	Nielsen et al.	Riverine habitat heterogeneity: the role of slackwaters in providing hydrologic buffers for benthic microfauna	Hydrobiologia
8	2011	O'Neill and Thorp	Flow refugia for the zoobenthos of a sand-bed river: the role of physical-habitat complexity	Journal of the North American Benthological Society
9	2012	Mayer	Controls of summer stream temperature in the Pacific Northwest.	Journal of Hydrology
10	2013	Milner et al.	Major flood disturbance alters river ecosystem evolution	Nature Climate Change
11	2014	Luce et al.	Sensitivity of summer stream temperatures to climate variability in the Pacific Northwest	Water Resources Research
12	2015	Isaak et al.	The cold-water climate shield: delineating refugia for preserving salmonid fishes through the 21st century	Global Change Biology
13	2015	Lisi et al.	Watershed geomorphology and snowmelt control stream thermal sensitivity to air temperature	Geophysical Research Letters
14	2015	Snyder et al.	Accounting for groundwater in stream fish thermal habitat responses to climate change	Ecological Applications
15	2015	Schulz and Costa	The effects of press and pulse disturbance by long and short-term pollution on the fish community in the Sinos River, RS, Brazil	Brazilian Journal of Biology
16	2015	Katz and Freeman	Evidence of population resistance to extreme low flows in a fluvial-dependent fish species	Canadian Journal of Fisheries and Aquatic Sciences
17	2016	Isaak et al.	Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity	Proceedings of the National Academy of Sciences
18	2017	Tschaplinski and Pike	Carnation Creek watershed experiment—long-term responses of coho salmon populations to historic forest practices	Ecohydrology
19	2018	Milner et al.	River ecosystem resilience to extreme flood events	Ecology and Evolution
20	2019	Troia et al.	Species traits and reduced habitat suitability limit efficacy of climate change refugia in streams	Nature Ecology & Evolution

21	2019	Gido et al.	Pockets of resistance: response of arid-land fish communities to climate, hydrology, and wildfire	Freshwater Biology
22	2020	LeMoine et al.	Landscape resistance mediates native fish species distribution shifts and vulnerability to climate change in riverscapes	Global Change Biology
23	2021	Hare et al.	Continental-scale analysis of shallow and deep groundwater contributions to streams	Nature Communications
24	2021	Gozzi et al.	Are geochemical regime shifts identifiable in river waters? Exploring the compositional dynamics of the Tiber River (Italy)	Science of the Total Environment
25	2021	Rohr et al.	Recovery of riverine fish assemblages after anthropogenic disturbances	Ecosphere
26	2021	Reiber et al.	Long-term effects of a catastrophic insecticide spill on stream invertebrates	Science of the Total Environment

Table 4. Summary of information compiled from a review of English language primary literature articles focusing on the quantification of habitat sensitivity, and its components resistance and resilience, in riverine environments. 'Methods' describes the design of the study, with 'BACI' indicating 'Before-After-Control-Impact', and 'Before-after' including studies comparing responses across a gradient of stressor intensities. The 'Stressor or Pressure' column describes the primary factors causing disturbance to the focal system, which is further described either as a pulse (i.e., temporary) or press (i.e., persistent) disturbance to the system. The 'Study length' is indicated in years.

Response type	Response metric	Stressor or pressure	Disturbance type	Study design	Study length	Scale	Study location	ID
Resistance and Resilience	Benthic invertebrate biomass, richness, abundance	Point source pollution	Pulse	Before-after	2.17	Sub-basin	Germany	26
Resistance and Resilience	Fish abundance	Forest fire	Pulse	BACI	9	Basin	Australia	6
Resistance and Resilience	Fish abundance	Wildfire, drought, climate change	Press and Pulse	Before-after	29	Basin	New Mexico	21
Resistance and Resilience	Fish species richness, fish abundance	Pollution	Press and Pulse	Control-Impact	4.5	Reach	Brazil	15
Resistance and Resilience	Habitat heterogeneity	High discharge events	Pulse	Before-after	0.25	Reach	Kansas	8
Resistance and Resilience	Macroinvertebrate density, macroinvertebrate community structure, fish recruitment	Flooding events	Pulse	Before-after	30	Basin	Alaska	19
Resistance	Fish occupancy	Climate change, road density, forest fires, barriers	Press	Before-after	6	Basin	Montana	22
Resistance	Fish occupancy	Logging	Press	BACI	10	Reach	British Columbia	1
Resistance	Fish production, sediment transport, stream temperature	Logging	Pulse	Before-after	34	Basin	Carnation Creek British Columbia	18
Resistance	Fish recruitment and survival	Low flow events (drought)	Pulse	Before-after	5	Reach	Georgia	16
Resistance	Fish recruitment, bank erosion	Logging	Press	Before-after	20	Basin	British Columbia	3
Resistance	Habitat suitability	Thermal stress	Press	Simulation	0.55	Reach	Southern Appalachia	20
Resistance	Microinvertebrate densities	High discharge events	Pulse	Before-after	0.16	Pool	Australia	7

Resistance	Pool presence, fish presence	Drought	Pulse	Before-after	0.5	Pool, reach	Arkansas	5
Resistance	Refugia presence and abundance	Climate change	Press	Simulation	30	Reach	Pacific Northwest of US	12
Resistance	Stream chemical composition	Multiple	Press and Pulse	Before-after	2	Basin	Umbria and Lazio, Italy	24
Resistance	Stream temperature	Thermal stress (air temperature)	Pulse	Before-after	3	Reach	Alaska	13
Resistance	Stream temperature, fish habitat availability	Thermal stress (air temperature)	Press	Simulation	0.21	Reach	Virginia	14
Resistance	Stream temperature	Thermal stress (air temperature)	Pulse	Before-after	30	Basin	Pacific Northwest of US	9
Resistance	Stream temperature	Thermal stress (air temperature)	Pulse	Before-after	23	Basin	Pacific Northwest of US	11
Resistance	Stream temperature	Thermal stress (air temperature)	Press	Before-after	13	Reach	Pacific Northwest of US	17
Resistance	Stream temperature	Thermal stress (air temperature)	Press	Before-after	14-30	Basin	Continental United States	23
Resilience	Fish abundance, macroinvertebrate abundance and richness, channel morphology	Flooding	Pulse	Before-after	3	Basin	Alaska	10
Resilience	Fish population densities, fish community, total biomass, benthic invertebrate community	Mining, chemical spills, rotenone, logging, channelization	Press and Pulse	Meta-analysis	varied	Basin, sub-basin, reach	United States	2
Resilience	Fish species richness, biotic integrity index, fish density	Point source pollution	Pulse	BACI	3	Reach	Illinois	25
Resilience	Macrophyte richness	Macrophyte uprooting	Pulse	Before-after	0.42	Reach	France	4

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