Space, time, and scale: new perspectives in fish ecology and management

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Abstract: This supplement is the product of a special symposium organized on “Space, time, and scale: new perspectives in fish ecology and management” held during the 127th annual meeting of the American Fisheries Society in Monterey, California, August 1997. The purpose of this supplement is to illustrate the breadth and diversity of ideas and applications being explored for integrating space, time, and scaling issues and to highlight future directions. Topics cover a variety of studies, techniques, and applications from salt water to freshwater, from lotic to lentic habitats, and across various scales that can be used as background for integrating space, time, and scale in ongoing and future fish research and management.

Résumé : Le présent supplément est le fruit du symposium spécial <<Espace, temps, échelle : nouvelles perspectives pour l’écologie et la gestion des pêches>>, qui s’est déroulé durant la 127e réunion annuelle de l’American Fisheries Society à Monterey, en Californie, en août 1997. Ce supplément veut refléter l’étendue et la diversité des nouvelles idées et applications en matière d’intégration des questions d’espace, de temps et d’échelle, et indiquer les orientations futures en cette matière. Les thèmes abordés couvrent diverses études, techniques et applications relatives au milieu marin et aux eaux douces, aux habitats lotiques et lénitiques sur des échelles diverses qui peuvent servir de base pour l’intégration de l’espace, du temps et de l’échelle dans les activités présentes et futures de recherche et de gestion concernant le poisson.

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Fish ecologists and managers realize that all ecological systems exhibit heterogeneity and patchiness on a broad range of spatial and temporal scales (Haury et al. 1978). We all recognize that these patterns have fundamental effects on biological processes (Brandt et al. 1992; Mason and Brandt 1996), dynamics of populations and ecosystems (Walters and Juanes 1993), our perception of the environment (Levin 1992), and, ultimately, how we sample and manage natural resources (Steele 1978; Loehle 1991). Incorporation of space, time, and scale (and their interactions) in theories, modeling, and sampling has improved our understanding of how population dynamics and species interactions respond to the physical (e.g., temperature) and biological (e.g., prey density) spatial structure in the environment. Multiscale analysis has shown the existence of scale-dependent patterns (Weins 1989; Rastetter et al. 1992) that can be of biological or physical origin and that can have significant effects on biological processes (Turner and Gardner 1991). Recent advances in hardware and software technologies and analytical techniques have contributed to our abilities to acquire and analyze complex spatial data sets, and to model ecological processes, over a wide range of spatial and temporal scales. Despite these advances and our growing appreciation for the importance of space, time, and scale, it is still often ignored in field sampling and modeling programs that attempt to evaluate predator–prey interactions, fish growth and production, and sustainability of a fishery. The purpose of this supplement is to highlight how explicit considerations of space, time, and scale and use of various analysis tools can improve our understanding of species interactions and linkages between biological and physical processes, as well as provide critical data and information for the management of fisheries resources in complex ecosystems.

This supplement is a product of a special symposium organized on “Space, time, and scale: new perspectives in fish ecology and management” held during the 127th annual meeting of the American Fisheries Society in Monterey, California, during 24–28 August 1997. Many of the invited papers presented in the symposium, now peer-reviewed, are published in this supplement of the *Canadian Journal of Fisheries and Aquatic Sciences*. Contributions to the symposium were by invitation. We were particularly looking for a diverse array of research and approaches that represent a gradient from measures to quantify pattern and scale to models that explore the consequences of pattern. We did not intend for the symposium to cover all aspects of space and scaling issues or to be a comprehensive summary of the state of the art. Other reviews on space, time, and scaling issues in ecology and resource management can be found in Wiens (1989), Levin (1992), Kolasa and Pickett (1991), Levin et al. (1993), Schneider (1994), Hanski and Gilpin (1997), and Tilman and Kareiva (1997). Moreover, the symposium does not include all of the innovative technologies being used in aquatic ecosystems (e.g., LIDAR). Rather, our purpose was

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Table 1. Papers in the symposium "Space, time, and scale: new perspectives in fish ecology and management."

	System			Scale		Analysis		
Authors of papers	River	Lake	Ocean*	Spatial	Temporal	Models	Data	General topic
Ault et al.			✓	10–100 m	Days–months	✓		Predator–prey/spatial distribution/recruitment
Beauchamp et al.		✓		1–100 m	Hours	✓		Foraging
Essington and Kitchell		✓		10–100 m	Hours–months	✓	✓	Spatial distribution/horizontal migration
Horne et al.			✓	10^{-4}–10^{11} m^2	Milliseconds–centuries		✓	Critical scales
Hrabik and Magnuson		✓		1–1000 m	Years–decades	✓		Species dispersal/invasion
Kline			✓	100 km	Months–years		✓	Food web/stable isotopes
Lamon and Stow		✓		1–100 m	Years	✓	✓	Contaminants/trend detection
Luecke et al.		✓		1–100 m	Days–years	✓		Foraging/bioenergetics/growth
Nøttestad et al.			✓	1–1000 km	Days–months	✓		Spatial distribution/horizontal migration
Rahel and Nibbelink	✓			1 km	Years		✓	Habitat gradients/species occurrence
Rose and Kulka			✓	1–1000 km	Years		✓	Commercial fisheries
Schindler		✓		1 m	Hours–months	✓		Habitat selection/overwinter mortality
Schneider et al.			✓	1 m – 100 km	Hours–years		✓	Critical scales
Steinhart and Wurtsbaugh		✓		1 m	Hours		✓	Vertical migration
Stockwell and Johnson		✓		1–10 m	Hours–months	✓		Foraging/bioenergetics/growth
Swartzman et al.			✓	1–1000 m	Days		✓	Predator–prey/spatial distribution/tools
Zlokovitz and Secor	✓		✓	10 km	Years		✓	Contaminants/otolith analysis

*Includes estuaries.

to illustrate the breadth and diversity of ideas and applications being explored and to highlight future directions.

The papers presented in this volume cover a variety of studies, techniques, and applications from salt water to freshwater, from lotic to lentic habitats, and across various scales ranging from milliseconds to centuries and millimetres to thousands of kilometres (Table 1). Topics covered in this supplement include the following.

(1) Schindler, Essington and Kitchell, Ault et al., Nøttestad et al., and Hrabik and Mangnuson use contrasting modeling techniques to explore the potential mechanisms for small- and large-scale horizontal migration/dispersal patterns and the corresponding patterns in spatial distribution at scales ranging from metres to thousands of kilometers and from hours to decades. The consequences of these migrations are evaluated in the context of foraging, predator–prey interactions, survival, recruitment, and exotic species invasions. In contrast, Rahel and Nibbelink use Geographic Information System (GIS) technology to predict the landscape-level spatial distribution of brown trout (*Salmo trutta*) and explore the role of smaller-scale regional processes when predictions fail.

(2) Lamon and Stow, and a paper by Zlokovitz and Secor, highlight the advantages of reducing variance in estimates of contaminant concentrations in fish tissue by considering spatial location of samples and identify distinct "hot spots" that may be responsible for contributing to high contaminant levels. In addition, both papers highlight two very different, yet innovative approaches (classification and regression trees and electron microanalysis of otolith strontium) for understanding spatial complexity in contaminant body burden. Both papers emphasize the need to understand better the life stage dependent migratory behavior of fishes in space and time to predict changes in polychlorinated biphenyl levels.

(3) Kline uses stable-isotope ratios of carbon and nitrogen from zooplankton and fish samples to identify seasonal and spatial trends in the source of energy (Prince William Sound versus the Gulf of Alaska) for juvenile Pacific herring (*Clupea pallasi*) and juvenile walleye pollock (*Theragra chalcogramma*) in Prince William Sound, Alaska. Based on his results, he conjectures that recruitment and nutritional processes in fishes residing in Prince William Sound are closely linked to cross-shelf transport of zooplankton, from Gulf of Alaska to Prince William Sound.

(4) Rose and Kulka explore the role of spatial processes in fisheries-dependent data on our ability to interpret overexploitation in a fishery. They provide an important lesson on how ignoring spatial issues in a fishery may have devastating consequences to fish populations.

(5) Beauchamp et al., Luecke et al., Steinhart and Wurtsbaugh, and Stockwell and Johnson explore how fine-scale processes affect the vertical spatial distribution of fishes and highlight the implications for foraging and growth. These contributions demonstrate the behavioral plasticity of fishes to changes in their local environment over diel and seasonal time steps, demonstrate the interactive effect of prey abundance and environmental conditions in mediating predator–prey interactions, provide

insight into the spatial scale at which visual predators experience patchiness of prey, and provide relevance for the use of spatially explicit models of growth rate potential (Brandt et al. 1992) for quantifying pelagic habitat and changes in quantity and quality of habitat.

(6) Horne et al. and Schneider et al. provide insight into the identification of key processes controlling populations over various spatial and temporal scales. Horne et al. use dimensionless ratios of rates to determine the relative importance of biological and physical processes across scales and demonstrate that dominant processes differ across various scales, life history stages, and species. Schneider et al. use a recently developed graphical technique to quantify how critical scales change with fish ontogeny. The two papers combine to demonstrate that critical time and space scales are linked and cannot be taken as constants.

(7) Swartzman et al. develop computer-based tools for the analysis and exploratory comparisons of spatial data sets, patch identification, and quantifying spatial and scale-dependent proximity between predators and prey. These tools may be used for scale-robust hypothesis formulation and testing of spatial patterns of predators and prey.

We hope that the papers in this supplement of the *Canadian Journal of Fisheries and Aquatic Sciences* will provide the motivation to incorporate space, time, and scaling issues in research and management. We expect that our understanding and appreciation of spatial and temporal processes occurring at various scales (dictated by relevant fluid and ecological dynamics) in aquatic ecosystems will dramatically improve in concert with continued development of three-dimensional spatial and temporal modeling and expanded coupling of physical and biological processes.

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