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Pathways of Effects Literature Review: Temperature and Dissolved Oxygen Endpoints

Examen de la littérature relative aux séquences d'effets – Résultats finaux concernant la température et l'oxygène dissous

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ABSTRACT

The Department of Fisheries and Ocean's Habitat Management Program reviews more than 7000 development proposals annually, to ensure that fish and fish habitat are not harmed. In order to assist the biologists responsible for these reviews, Pathways of Effect diagrams (PoEs) were developed as part of the Risk Management Framework, incorporating the current understanding of the potential effects of development activities on fish and fish habitat.

A DFO Science peer review and advisory process was held 7-8 September 2005 in Toronto, Ontario to consider four endpoints of the PoEs, and associated linkages, which together comprise more than 70% of all the linkages in the full set of PoE diagrams, and cover the majority of impact types on aquatic habitats. The meeting was asked to consider each of the selected linkages and to conclude:

- whether or not there was scientific information to support the linkage,
- whether there was scientific information that would be inconsistent with the linkage,
- or whether there was not sufficient information to arrive at a conclusion.

Research documents were prepared summarizing the evidence contained in the scientific literature, and these documents were subjected to peer review at the meeting.

This report contains the results of a study looking at the linkages in the PoEs involving changes in temperature and oxygen levels. This study was conducted by Golder Associates Ltd, under contract to DFO. The approach of the study was to perform a literature review to provide scientific evidence for the linkages between certain physical activities and the endpoints of temperature and dissolved oxygen. For the most part, this approach involved determining from the literature how the activity (e.g., vegetation clearing) affects the endpoint (e.g., water temperature), and not how changes in the endpoint affect fish. However, if a relevant paper also reported effects on the aquatic biota (i.e., fish), these effects were also noted and summarized. Some papers were also reviewed and summarized to provide an indication of the potential effects on fish, but this was not the focus of the work.

This paper was discussed and peer reviewed at the meeting, and the results of those discussions can be found in the Proceedings document (#2005/031) which was produced after that meeting.

RÉSUMÉ

Les responsables du Programme de gestion de l'habitat du ministère des Pêches et des Océans examinent chaque année plus de 7000 propositions d'aménagement du territoire pour s'assurer que les poissons et son habitat ne sont pas en danger. Afin d'aider les biologistes responsables de ces examens, on a mis au point des diagrammes de séquences d'effets (SdE), dans le contexte du Cadre de gestion des risques, qui incorporent les connaissances actuelles relatives aux effets potentiels des activités d'aménagement sur le poisson et sur son habitat.

Le secteur des Sciences du MPO a mené un examen par des pairs et un processus de consultation les 7 et 8 septembre 2005 à Toronto, en Ontario, pour étudier quatre résultats finaux des SdE et des liens connexes, lesquels représentent, ensemble, plus de 70 % de tous les liens de l'ensemble complet des diagrammes de séquences d'effets et couvraient la majorité des types d'impacts sur les habitats aquatiques. On a demandé aux participants à la réunion d'étudier chacun des liens choisis et de conclure :

- si l'on disposait ou non de l'information scientifique nécessaire pour étayer le lien,
- si l'on disposait d'information scientifique qui ne serait pas cohérente avec le lien,
- ou si l'on ne disposait pas d'information suffisante pour arriver à une conclusion.

On a préparé des documents de recherche pour résumer les preuves énoncées dans les écrits scientifiques, et ces documents ont été soumis à un examen par des pairs au cours de la réunion.

Le présent rapport renferme les résultats d'une étude examinant les liens dans les SdE concernant les changements de température et de teneur en oxygène. Cette étude a été menée par Golder Associates Ltd, en vertu d'un marché passé par le MPO. L'approche adoptée dans le cadre de l'étude consistait à effectuer un examen de la littérature visant à étayer scientifiquement l'existence de liens entre certaines activités physiques et les résultats finaux concernant la température et l'oxygène dissous. La plupart du temps, cette approche consistait à déterminer, à partir des écrits scientifiques, comment l'activité (p. ex. le défrichage) affecte le résultat final (p. ex. la température de l'eau), et non pas comment le changement dans le résultat affecte les poissons. Toutefois, si un article pertinent énonçait également l'existence d'effets sur le biote aquatique (c.-à-d. les poissons), ces effets ont également été pris en note et résumés. On a également examiné et résumé certains articles afin de fournir une indication des effets potentiels sur les poissons, mais cette tâche ne constituait pas le cœur du travail.

L'article a été soumis à des discussions et à un examen par des pairs au cours de la réunion, et les résultats de ces discussions peuvent être consultés dans le compte rendu (2005/031) qui a été produit à la suite de cette réunion.

1. INTRODUCTION

1.1 Background

DFO has developed a methodology termed “Pathways of Effects” (PoE) to standardize aquatic effects assessment and identify regulatory requirements under the *Fisheries Act*. This approach is intended to provide a standard framework for assessing impacts on fish and fish habitat, while allowing flexibility to address ecological variation among the regions and differences in the best management practices used by industry. The PoE builds a biologically-based model that outlines the potential effects on fish habitat as a result of any given activity. These PoE conceptual models can be used to trace the pathways of effect on fish and fish habitat to provide a systematic and reproducible process to facilitate regulatory decision making. The resulting linkage diagrams present a clear picture of how a given work or undertaking affects fish and can then be used to guide the development of mitigation measures. Breaking any one of the links eliminates the source of the potentially adverse effect.

A total of 21 PoE models have been developed to date; however, these are based solely on input from habitat practitioners and habitat scientists. A detailed literature review has not been completed and is required to determine if the linkages presented in the PoE models are scientifically sound and complete. Literature reviews will be conducted at some point to support all cause-and-effect relationships within the 21 PoEs, as the implications of effects must be derived from critical reviews of scientific and technical literature. The interpretation and use of results derived from peer reviewed literature is essential to ensure that the implications of effects are defensible, and to avoid perpetuation of unsupported theories on cause-and-effect linkages between change in habitat and biological effects to fish.

This report summarizes the results of the review the relevant literature as it relates to two endpoints:

- Changes in Dissolved Oxygen Concentration; and
- Changes in Temperature.

1.2 Approach

The approach of the study was to perform a literature review to provide scientific evidence for the linkages between certain physical activities and the endpoints of temperature and dissolved oxygen. For the most part, this approach involved determining from the literature how the activity (e.g., vegetation clearing) affects the endpoint (e.g., water temperature), and not how changes in the endpoint affect fish. However, if a relevant paper also reported effects on the aquatic biota (i.e., fish), these effects were also noted and summarized. Some papers were also reviewed and summarized to provide an indication of the potential effects on fish, but this was not the focus of the work.

The review was primarily focused on the scientific peer-reviewed literature, and not on grey literature. For many of the linkages, expansion to the grey literature would provide additional evidence, where there was limited documentation in the primary literature.

2. METHODS

2.1 Identification of Linkages

From a review of the recent Pathways of Effects diagrams, the following nine linkages were identified:

Change in Water Temperature

- Increase in riparian and bank vegetation → Change in shade → Change in water temperature
- Loss/damage of riparian vegetation → Change in shade → Change in water temperature
- Alteration of groundwater flows to surface waters → Change in water temperature
- Addition or removal of aquatic vegetation → Change in light penetration → Change in water temperature
- Thermal loading → Change in water temperature
- Change in timing, duration and frequency of flow → Change in water temperature

Change in Dissolved Oxygen

- Addition or removal of aquatic vegetation → Change in light penetration → Change in dissolved oxygen
- Thermal loading → Change in dissolved oxygen
- Nutrient loading → Change in dissolved oxygen

2.2 Database Search

Searches for each linkage were carried out by entering key words into the CSA Allumina and DFO's WAVE databases. Multiple searches using various combinations of "keywords" resulted in lists of literature that contained these words in their titles or abstracts. These lists had their titles and abstracts screened to create a "short list" of articles for each linkage. Peer reviewed literature was given priority. Articles that appeared relevant based on the abstract were ordered and reviewed for information.

References were entered into a Procite database. However, to ensure the bulk of the effort was expended on the review rather than the loading of the database, the Procite database only included author and publication references, and did not involve the inclusion of other summary or abstract information.

2.3 Selection of Relevant References

A short list of papers was created for each of the nine linkages. These papers were selected to provide information on each linkage (i.e., physical activity to endpoint). For many references, there was no information on the secondary link to effects on fish. Note that most of the references were local, i.e., from the United States or Canada. This was likely partially from the search databases used, and partially as a result of the selection process.

Note that the references reviewed were not exhaustive for each linkage. For some linkages, an abundance of information is available, and a detailed review of all was beyond the scope of this work. Detailed reviews were conducted on those papers in which: (1) there was a clear indication showing the link; (2) the information was quantitative; (3) the study was fairly recent; and (4) there was an attempt to measure an effect on the aquatic biota (i.e., fish).

2.4 Summarizing References into Table Format

Once a suitable reference was located and reviewed (i.e., the "short list"), it was included and summarized into an Excel table (Appendix I). The papers are listed in alphabetical order under each linkage. The fields in the table included the following:

- Reference Title and Source
- Type of Study (e.g., laboratory study, field study, modelling, study, overview paper)
- Environment (e.g., marine, freshwater, estuarine)
- Location
- Country
- Aquatic Organisms (e.g., fish, macrophytes, benthic invertebrates, plankton, if applicable)
- System Type (e.g., lentic, lotic, marine, estuarine, environments)
- Fish Category (large-bodied, small-bodied fish species, if applicable)
- Fish Families (if effects were linked to fish)
- Fish Species (if effects were linked to fish)
- Overview of Study
- Effect on Endpoint (Water Temperature or Dissolved Oxygen)
- Effect on Biota

The *Fish Category*, *Fish Families*, and *Fish Species* columns were only relevant where there were effects on fish discussed within the paper. For many papers where there was only a discussion between the activity and the endpoint and no effects on fish, then these cells were shown as "NA" (not applicable). Scientific names of fishes referred to in the table and in the report are provided in Appendix II.

The final three columns provide a summary of each of the relevant research papers. A brief description of the study was provided in the *Overview of Study*, with any effects on the endpoint summarized in the following column. Once again, if there was an attempt to measure the effect on fish, then the effects were briefly summarized in the last column.

2.5 Summarizing into Report Format

The table described in Section 2.4 and provided in Appendix I, formed the basis for the report. However, additional references are also included in the report which are not summarized in the table; these references provide additional background information, but do not illustrate the linkage as identified. The report lists the six linkages for the temperature endpoint and the three linkages fore the dissolved oxygen endpoint. Where possible, the references are summarized under the activity. Under some linkages, it was difficult to directly link to an activity and more general information is provided.

3. CHANGE IN WATER TEMPERATURE

3.1 Loss/Damage of Riparian Vegetation → Change in Shade → Change in Water Temperature

Overview of Search

A search was conducted to find literature relevant to the link between changes in water temperature from reduced shading due to riparian vegetation removal, as well as information that associates this link to fish. Peer reviewed literature on this topic was abundant compared to other topics searched for this study, with the majority of information from research on the effects of riparian vegetation removal by logging or livestock grazing on water quality or fish. Effects of riparian vegetation removal on water quality have been reported extensively in literature that considers the impacts of clearcut logging on streams, and effects of clearcut logging on salmonid habitat have been studied in many different geographical areas. While there are some exceptions, most frequently these articles present studies on impacts to lotic systems that contain salmonids. Only a few studies consider effects on non-salmonid communities or non-lotic systems such as lakes.

Summary of Literature Review

General Information

Various studies have shown that streambank vegetation prevents excessively high water temperatures in summer (Rinne 1988) and that removal of vegetation near streams can affect stream temperature (Johnson 2004). In addition to providing large woody debris, a forested riparian zone near a stream also provides bank stability, shade litterfall and nutrients that influence stream temperature, trophic relationships and the sediment transport regime (Liquori and Jackson 2001).

Clearcut Logging - Streams

The physical impacts of clearcut logging in stream systems have been reported to involve increases to water temperatures. The literature from a variety of sources and geographic locations suggests that increases to mean temperatures of 3-6°C, and to maximum temperatures of 3-8°C, have been common (Bartholow 2000). Clearcut logging of 41% of the basin of Carnation Creek, British Columbia, resulted in increased stream temperatures in all months of the year, and in some cases monthly mean stream temperatures were as much as 5°C warmer after the beginning of logging (Holtby 1988). Increases to pre-logging temperatures ranged from 0.7°C in December to 3.2°C in August. Macdonald et al. (2003) also found that five years after the completion of harvesting, temperatures remained 4-6°C warmer and diurnal temperature variation remained higher than in the control streams regardless of treatment. Initially the high retention treatment acted to mitigate the temperature effects of the harvesting, but three years of windthrow subsequently reduced canopy density which affected temperatures. Beschta and Taylor (1988 cited in Bartholow 2000) documented increases of average daily maximum temperatures 6°C at the mouth of the Salmon Creek watershed following the removal of forest cover over a 29 year period. Brown and Krieger (1970 cited in Bartholow 2000) reported an average monthly maximum increase of about 8°C after clearcutting a small Oregon watershed. Johnson and Jones (2000) compiled historic stream temperature data and established study sites in three basins streams in the Western Cascades, Oregon following removal of riparian vegetation from forest harvesting. Maximum stream temperatures increased 7°C and occurred earlier in the summer, with diurnal fluctuations in June increasing from approximately 2 to 8°C. Stream temperatures in the unshaded streams had wider diurnal fluctuations than in the unharvested basins (Johnson and Jones 2000).

Mellina et al. (2002) examined the temperature patterns of two subboreal outlet streams in north-central British Columbia for one year before and three years after clearcut logging. Only modest changes (averaging 0.05-1.1°C) were found with respect to summer maximum and minimum temperatures, diurnal fluctuations and stream cooling. Although this study showed similar temperature responses to streamside timber harvesting as what had been previously reported in the literature, the magnitude of changes was lower. The authors suggest that these relatively modest changes, when compared with other literature values, may reflect the effect of headwater lakes on outlet stream temperature regimes and the subsequent moderating of their responses to harvesting. As well, although logging reduced the canopy cover by ~50%, the treatment streams were still provided with between 40 to 60% shade during the post-logging years. The model showed that lentic waterbodies and groundwater inflows are important determinants of stream temperature patterns in subboreal forests and may moderate their responses to streamside harvesting.

Temperature-related impacts in streams are usually attributed to decreased canopy shading, although other local factors including changes to wind, stream discharge and groundwater inputs can also be important factors affecting water temperature following logging. Bartholow (2000) developed a model to estimate the cumulative effects of large-scale timber harvest on stream temperature. He found that changes in stream shading was the most influential factor influencing increases in maximum daily water temperature, accounting for 40% of the total increase. The model also indicates that even light alterations to stream shading during harvest may result in increases to maximum daily water temperature. Other researchers also attribute temperature increases after clearcutting to the increased exposure of the stream surface to incident solar radiation (Holtby 1988, Brown and Krieger 1970 cited in Bartholow 2000, Johnson and Jones 2000).

Effects on fish populations from increased temperatures following logging have been studied or inferred. Holtby (1988) observed the following: earlier emergence of coho salmon fry; lengthening of the growing season by up to six weeks; fingerlings significantly larger by fall with improved overwinter survival; and earlier seaward migrations of smolts. However, other researchers have found that the impact of elevated stream temperatures following logging to have deleterious effects on salmonids (Brown 1971, Hall and Lantz 1969, Hall et al. 1987 cited in Hartman et al. 1996). Macdonald et al. (2003) suggested that the temperatures impacts in the study remained within the tolerance limits of local biota; however, even modest temperature changes could alter insect production, egg incubation, fish rearing, migration timing, and susceptibility to disease, and the effects of large changes to daily temperature range are not well understood. Johnson and Jones (2000) suggest that the shifts in the timing of summer maxima and greater increases in early summer stream temperatures could affect sensitive stages of aquatic biota; however, this was not studied.

Logging – Lakes
The effect of logging on lake water temperatures has not been as well studied. As water temperature in lakes is influenced by a complex and interacting suite of factors, the link between shoreline clearcutting and decreased shading is less clear than in stream systems. Compared with streams, lakes have a higher thermal mass and smaller edge-area ratio, and in all but the smallest lakes, only a portion of the lake surface may be shaded by shoreline forest (Steedman et al. 2001). Several studies were conducted to determine the effects of experimental clearcut logging of small boreal shield lakes in the Experimental Lakes Area of northwestern Ontario. Steedman and Kushneriuk (2000) found that late-summer thermoclines were about 1 m shallower in two of three study lakes after logging, but it was not possible to exclude weather as a factor. None of the lakes showed significant declines in lake trout habitat volume. Steedman et al. (2001) found that the experimental shoreline logging did not significantly increase average littoral water temperatures. However, over the early summer monitoring period, clearcut shorelines were associated with increases of 1-2°C in maximum littoral water temperature, and increases of 0.3-0.6°C in average diurnal temperature range, compared with undisturbed shorelines or shorelines with a 30-m buffer strip. These temperature increases were found to be caused by daytime heating. Steedman (2003) found that an abundant and diverse littoral fish community, dominated by Cyprinidae (minnows), persisted in the study lakes five years after logging, which was consistent with other postlogging responses of the study lakes. This suggests that effects on the littoral fish community were small, compensatory, or delayed (Steedman 2003).

Other studies with lake deforestation are not linked to shading, but to other factors. France (1997) examined the link between riparian deforestation and exposure of lake surfaces to stronger winds, the deepening of thermoclines and subsequent habitat losses for cold-water fish species, such as lake trout. Lakes where the riparian trees were removed had thermocline depths over 2 m deeper per unit fetch compared with lakes surrounded by mature forests, indicating the dominance of the surrounding riparian forests in modifying the patterns of wind-induced mixing in these small boreal lakes. As a result, riparian tree removal was considered by the author to exacerbate hypolimnion habitat losses for cold-water species that may be already occurring due to factors such as acidification, eutrophication and climate warming (France 1997).

Livestock Grazing
Unmanaged livestock grazing is consistently associated with the degradation of riparian areas and fish habitat. The effects of grazing on stream quality have been extensively studied, especially in Alberta and the western United States. Factors that contribute to increases water temperature includes vegetation losses, especially shrubs and trees, which reduce canopy shade and heighten the potential for increased water temperatures (Kauffman and Krueger 1984, Wohl and Carline 1996). However, the results are less clear than for alterations to riparian vegetation from logging.

Wohl and Carline (1996) assessed conditions in two streams with extensive grazing and in a third stream with no riparian grazing. Temperatures during summer and winter were significantly different among streams; however, this was attributed to several factors, including absence of riparian shading in two of the streams contributing to high summer temperatures, as well as streamflow discharge and groundwater inflow. Sovell et al. (2000) examined the effect of rotationally and continuously grazed pastures and different types of buffer strips on streams. The researchers could not determine whether there were any significant differences in temperature among sites. Fitch and Adams (1998) used three literature reviews (Kauffman and Krueger 1984, Platts 1991, Ohmart 1996) that considered over 100 papers to identify and summarize the impacts of livestock grazing on riparian areas. They identified impaired water quality, including increased water temperature, as a consequence of unmanaged livestock grazing in riparian areas. However, it was suggested that altered stream morphology and flow could also contribute to elevated water temperatures observed in grazing impacted areas (Fitch and Adams 1998).

Effects on fish have been reported, but the results are not consistent across studies. In the review by Fitch and Adams (1988), decreases in fish species and numbers were reported following overgrazing of riparian areas by livestock. Wohl and Carline (1996) found that fish diversity was highest in the stream with the highest summer temperatures; this pattern of increasing diversity with temperature has also been reported in other studies (Decker and Erman 1992 cited in Wohl and Carline 1996). Substrate permeability of potential brown trout spawning sites and densities of benthic invertebrates were significantly higher, and that densities of wild brown trout were 5-23 times higher in the ungrazed stream. However, the authors suggest that other watershed attributes could have had some influence on these streams (Wohl and Carline 1996). Sovell et al. (2000) found that effects on aquatic biota were not linked to the riparian buffers. For example, benthic macroinvertebrate metrics were not consistent among grazing and riparian buffer management types, fish species richness was not related to different grazing practices, and fish density was related to riparian buffer type, rather than grazing practice.

General Riparian Land Use

Barton et al. (1985) examined the relationships between riparian land use and environmental parameters (including temperature) that define the suitability of southern Ontario streams for trout. The results suggest that temperature was the most important variable distinguishing trout form non-trout streams. Streams with weekly maximum temperatures less than 22°C supported self-sustaining trout populations, whereas warmer streams had, at best, only marginal trout populations. Variation in temperature was influenced by the presence of forested (i.e., a complete canopy of deciduous or coniferous vegetation) riparian buffer strips. Fifty-six percent of the observed variation in weekly maximum temperature could be explained by the fraction of bank forested within 2.5 km upstream of a site. The most important cause of high stream temperatures was considered to be direct insolation resulting from the absence of shading by a forest canopy (Barton et al. 1985).

3.2 Increase in Riparian and Bank Vegetation → Change in Shade → Change in Water Temperature

Overview of Search

A search was conducted to find literature relevant to the link between changes in water temperature from increased shading due to increases to riparian vegetation, as well as information that associates this link to fish. While there are many examples of stream restoration projects available, especially in the grey literature, the peer reviewed literature that provides very little on water quality changes (specifically temperature) following riparian zone recovery. Most of the relevant research is from riparian zone recovery following logging or with cattle exclusion. However, there is little information the primary literature that specifically links increases to riparian vegetation from riparian plantings to temperature.

Some relevant information that explores the link between the effects of shade and water temperature is from experiments that simulate shading in the riparian areas of streams. Other relevant studies include those that compare the effects of different types of riparian vegetation on water temperature.

Summary of Literature Review

General Information

Various studies have shown that streambank vegetation prevents excessively high water temperatures in summer (Rinne 1988) and that changes in vegetation near streams can have major affects on stream temperature (Johnson 2004). Shade from leaves on streamside reduces active radiation falling on the streambed significantly (Hill et al. 2001). While several studies have concluded canopy shading is what primarily influences water temperatures in steams (Brown and Krygier 1970), few studies have actually measured the direct effect of streamside shade on water temperature.

Riparian Revegetation

Several studies have measured stream temperatures following riparian recovery. For example, Johnson and Jones (2000) found that stream temperatures returned to preharvest levels approximately 15 years after clearcutting, coinciding with canopy closure in the riparian zone. However, the authors point out that the species composition of the overstory riparian vegetation shifted from primarily conifer to deciduous, and as a result, the timing of vegetation establishment and stream temperature recovery cannot be extrapolated to other locations.

Studies have shown that there is no upstream cumulative temperature effect due to riparian shading, that is, stream temperatures reflect the local heat equilibrium and providing or removing shade from an upstream site has little influence on local water temperature (Zwieniecki and Newton 1999 cited in Liquori and Jackson 2001). Liquori and Jackson (2001) compared stream temperatures between streams with forest and scrub-shrub riparian vegetation. Fire suppression and/or lack of active riparian zone management in the study area have resulted in dense encroachment of the fir forests that create closed forest canopies over the channel, and scrub-shrub vegetation communities are virtually absent near the channel. The authors observed lower summer water temperatures in areas of the stream with scrub-shrub vegetation than in areas with forested vegetation, even when average shade values were very similar. The scrub-shrub streams were 1.5 to 4°C cooler than the upstream forested reaches, demonstrating that there can be variation in cooling effects of different types of riparian vegetation, likely as a result of differences in root density and canopy conditions. The authors suggest that managing streams for dense riparian conifer does not mimic natural conditions, nor provide superior instream habitat; however, further fish and benthic invertebrate studies are required to investigate diversity and productivity within these different riparian settings (Liquori and Jackson 2001).

It has been suggested that riparian recovery through riparian grazing strategies may bring improved habitat for aquatic organisms, more stable channels, improved water quality, and a shift toward perennial streamflow (Elmore and Beschta 1987 cited in Fitch and Adams 1998). However, a four year study of a montane stream from which cattle grazing had been excluded for ten years indicated that stream bank vegetation and stability were markedly improved and that stream substrate fines were somewhat reduced, but that fish populations were unaffected (Rinne

1988). Platts and Nelson (1985) compared responses in the fish habitat and fish population in an area protected from grazing for eleven years and on adjacent, heavily grazed areas of similar structural and riparian character. Prohibiting grazing dramatically improved riparian vegetation, streambanks, and stream channel conditions, but the fish populations did not respond to improving habitat conditions, perhaps because the small size of the livestock enclosure did not reduce influences from upstream.

Experimental Shading

Johnson (2004) examined stream temperature dynamics before, during, and after experimental shading of a 150-m stream reach. Maximum stream temperatures significantly decreased during shading of the water surface of a 150-m bedrock reach, but minimum and mean temperatures were not substantially affected. During the experiment, maximum water temperatures at the lower end of the reach was up to 1°C lower than at the upstream site. However, the author acknowledge that the type of material used for shading may not have functioned in a similar manner to the influence of riparian vegetation on stream temperatures, as riparian vegetation influences stream and stream temperatures through multiple pathways in addition to providing shade, i.e., influencing microclimatic conditions, providing bank stability, contributing large organic matter.

A field study by Ebersole (2003) considered the influence of experimental shading on the thermal characteristics of steams, as the spatial distribution of temperatures within streams is recognized as a factor influencing the distribution of stream fish. The experimental application of shade, which simulated 100% riparian cover, reduced surface temperatures within cold water patches. Experimental shading cooled daily maximum temperatures of surface waters within cold water patches 2 to 4°C, indicating a strong influence of riparian vegetation on the expression of cold water patch thermal characteristics (Ebersole 2003). During the warmest portions of the year, the presence of cool thermally stable habitats (i.e., cold water patches) can provide thermal refugia to allow fish to thermoregulate and avoid stressful temperatures. Ebersole et al. (2003) found that the addition of cold water patch frequency and area was associated with increases of rainbow trout and chinook salmon abundances, and were associated with potential linkages between the occurrence of cold water patches in streams and channel and riparian structure.

3.3 Addition or Removal of Aquatic Vegetation → Change in Light Penetration → Change in Water Temperature

Overview of Search

A search was conducted to find literature relevant to the link between changes in water temperature from the changes in light penetration from the addition or removal of aquatic vegetation. Several comparative studies were reviewed that considered the effects of varying densities of vegetation on water quality; these included changes to water temperature over time (diurnally, seasonally, annually) or space (depths, quadrants). Studies are available on the removal of macrophytes for aquatic vegetation control (e.g., carp grazing, mechanical harvesting); however, the majority do not discuss the potential linkage to changes in water temperature. As well, although a reasonable amount of information was available on associations between macrophytes and water temperatures, a direct link to variations in light penetration and water temperature was not always made in these studies.

Summary of Literature Review

General Information

Large stands of submersed macrophytes greatly influence the diurnal changes in the physical and chemical variables in the vertical water column (Dale and Gillespie 1977). For submersed aquatic plants, the radiant energy heats the surrounding water and the distribution of plant structures determined which part of the water mass is heated. In the middle of the growing season in temperate regions, the warmer surface water may float on the denser underlayer without mixing. During cold, clear nights, the cooler, more dense water sinks, mixing the layers so that the water profile is isothermal in the early morning (Dale and Gillespie 1977).

Aquatic vegetation also provides habitat for macroinvertebrates, stabilizes sediment, produces oxygen, and provides spawning substrate as well as refuge for both prey and predator species. Loss of macrophytes can also reduce fish populations and loss of biodiversity (Lau and Lane 2002).

Comparative Studies

Several studies have measured water temperatures within macrophytes stands. O'Neill Morin and Kimball (1983) measured water quality parameters in the water column within macrophyte stands in a New England Lake. Elevated surface temperatures were observed from June to September when submergent vegetation reached the surface. At this time, surface and bottom water temperatures generally differed by 1 to 3°C in the vegetation stands. Carter et al. (1988) compared water quality parameters between sites with and without submerged macrophytes at very high population densities in the tidal Potomac River. Water temperature increased during the day with the steepest vertical gradients and maximum reading occurring within the macrophyte bed during mid-afternoon at low tide. Rose and Crumpton (1996) found that water temperature was significantly lower and varied less diurnally in areas with emergent vegetation in a natural prairie pothole wetland. For example, in late August, water temperature at vegetated sites varied 3-4% around a mean of 20°C, while open water at the edge of the vegetated sites varied 8-10°C around a mean of 25°C. Large macrophytes can also have a significant role in reducing water column temperature in constructed wetlands for wastewater treatment (Williams et al. 1999); an annual average temperature reduction of 12°C was observed in vegetated wetland cells in 1996 and a reduction of 13°C in 1997.

Changes due to macrophytes in the surrounding water column include a reduction in light availability (Hillbricht-Ilkowska et al. 1972 cited in O'Neill Morin and Kimball 1983). For example, Rose and Crumpton (1996) found that due to canopy cover, water column light availability of ambient light in areas with emergent vegetation zones in a natural prairie pothole wetland was less than 2%. Other factors can also play a role in modifying water temperature. Carter et al. (1988) found that thermal stratification in the Potomac River was the result of thermal insolation combined with very slow movement of water in plant beds near low slack tide. O'Neill Morin and Kimball (1983) indicated that their results were due to the reduction of water circulation in the littoral zone from the dense foliage and the decline in light levels with depth from macrophyte shading. Submerged macrophytes have a major effect on daily temperature variations and depth gradients because of their physical structure. Submerged macrophytes attenuate light rapidly through the stand, and this leads to heating of the upper part of the canopy, whereas the shaded parts at the base have a more constant and lower temperature (Dale and

Gillespie 1977). This gradient is stabilized during the day because the stand density greatly reduced vertical mixing by wind action (Sand-Jensen 1989).

Weed Removal
There are studies regarding the removal of macrophytes for aquatic vegetation control, including water-level manipulation, chemical processes, mechanical devices, manual operations and utilization of biological methods. However, these studies usually discuss the efficacy of the removal method and/or succession of the plant community, and do not discuss the link to changes in temperature. For example, an experimental aquatic plant harvesting program was initiated to remove excessive growths of aquatic vegetation in southern Lake Chemong in Ontario (Wile 1978). The report indicates that temperature differences between the surface and bottom strata in the lake were less than 1°C; however, no comparison was made to pre- and post-harvest temperatures. Sheldon (1986) observed disturbed areas where vegetation had been removed for three years and found that the size, shape and extent of disturbance had an effect on the pattern of plant re-establishment. The data also suggest that disturbance may contribute to high macrophyte diversity. Other researchers have discussed the effects of fish removal during aquatic macrophyte harvesting (Haller et al. 1980, Mikol 1985, Engel 1990; Serafy et al. 1994, Booms 1999), or to effects on benthic macroinvertebrates (Rasmussen 1982, Kaenel et al. 1998).

Mitchell et al. (1984) studied changes in water quality in Parkinsons Lake, New Zealand, following the introduction of Chinese grass carp for aquatic macrophyte control. The researchers found that the elimination of the submerged and emergent aquatic plants did not result in any significant change in water temperature over the successive two years. The effect on the position of the thermocline was also considered to be negligible. Other researchers looked at the effects on other water quality parameters from aquatic vegetation removal by grass carp (e.g., dissolved oxygen, biological oxygen demand, turbidity and alkalinity) (Lembi et al. 1978, Mitzner 1978), but do not evaluate the linkage to temperature.

3.4 Alteration of Groundwater Flows to Surface Waters → Change in Water Temperature

Overview of Search

A search was conducted to find literature linking alterations to groundwater flow on changes to surface water temperature, as well as information that associates this link to fish. The majority of information available on groundwater in the primary aquatic literature was contained in literature that studied associations between fish habitat (thermal refugia, overwintering, spawning) and groundwater seepage in streams. Many papers stated that groundwater reduces surface water temperatures in streams; however, not all papers reviewed provide quantitative information or a reference to support their statement. Studies typically considered the influence of groundwater on water temperature indirectly when reporting other findings.

There was very little direct information on alterations to groundwater in the literature reviewed. Discussions of ground water-surface water interactions are available in the hydrogeological literature or in references such as Jones and Mulholland (2000). Review papers such as (Pringle and Triska 2000, Ward 1985, Poole and Berman 2001, Poff et al. 1997) provide discussions on potential effects of anthropogenic alterations to groundwater, for example, land use activities, groundwater withdrawals, other hydrological modifications, climate change etc., but there are few cause and effect studies in the primary aquatic literature for this linkage and effects on temperature. Many researchers also discuss the implications to resource managers of protecting areas of groundwater upwelling that provide critical habitats (e.g., Garrett et al. 1998, Van den Avyle and Evans 1990, Cunjak 1996). It may be that a separate review of the hydrogeological/hydrological literature may need to be conducted to elucidate this linkage in greater detail.

Summary of Literature Review

General Information
Groundwater influences stream functioning by affecting water temperature, which in turn influences rates of many processes (Ward and Stanford 1982, White 1987 cited in Holmes 2000). Groundwater temperatures tend to be relatively constant at about the mean annual air temperature, whereas surface water temperatures often vary greatly and seasonally (Brunke and Gonser 1997 cited in Holmes 2000). As shown by Mellina et al. (2002) groundwater inflows are important determinants of stream temperature patterns in subboreal forests and may moderate their responses to clearcut harvesting.

Thermal Refugia
Differences in temperature between upwelling ground- and surface waters can affect the thermal regime of rivers and streams, and as such, habitat for aquatic biota. For example, upwelling of cold groundwaters creates cold water refugia for striped bass and other cold water species in a southeastern United States coastal river (Van den Avyle and Evans 1990). Monitored striped bass moved into spring-fed areas when water temperatures warmed to 23-25°C and left the springs when temperatures cooled to 17-23°C in the fall. Movement into spring-fed areas in winter also indicated avoidance of cold water. A similar study by Gibson (1966) found that in the Miramichi River, groundwater created cooled local areas of the stream providing thermal refugia. Salmon parr moved toward the source of spring seepage when water temperatures exceeded 22°C and parr grouped in cooler seepage water and oriented themselves towards the source of seepage. Snuicins and Gunn (1995) found that nearshore groundwater seepage provided refugia for lake trout when naturally elevated summer lake temperatures exceeded their preferred thermal range of 6-13°C. Groundwater emerged from the source at 10°C providing a refuge area located in shallow water that was approximately 30 m^2, with temperatures <15°C. Lake trout moved from the hypolimnion to shallow water in areas of groundwater seepage and remained in the groundwater seepage area at night and left during the day.

Point sources of groundwater discharge which provide “winter-warm” microhabitats may serve as winter refugia from instream problems such as ice and variable streamflow (Cunjak 1996). Cunjak and Power (1986) found large numbers of brook trout and brown trout aggregated near such spring sources, attesting to the importance of groundwater point sources to salmonid productivity and stream ecosystems.

Spawning Habitat
Advantages to spawning in areas of groundwater upwelling include, among other things, a more constant incubation temperature and protection against the potential for freezing in harsh winter conditions (Lorenz and Eiler 1989 cited in Garrett et al. 1998). In a study by Hansen (1975),

brown trout redds had higher and less variable temperatures as the percentage of groundwater to surface water increased. The higher percentage of groundwater led to earlier egg hatching. Garrett et al. (1998) found that intragravel temperatures in groundwater-induced kokanee redds exceeded surface flow water temperatures by 2.4-2.6°C. Pre-emergent survival from sites with groundwater upwelling significantly exceeded that from redds in other areas. Higher incubation temperatures at upwelling sites were considered to accelerate rates of development, protect embryos from freezing and potentially increase survival. Garrett et al. (1998) also indicates the importance of these sites to naturally reproducing populations and the need for managers to identify and protect these habitats.

Anthropogenic Influences

Anthropogenic influences, for example, land use activities, hydrologic modifications and climate change can impact surface-subsurface interactions and thereby affect biological patterns (Pringle and Triska 2000). Land use activities may influence groundwater-stream water interchange rates and temperatures (Ebersole 2003). Riparian zones functions as the immediate source of groundwater, which sustains some baseflows in interstorm periods (Hill 2000). Logging or other vegetation removal can lead to increases in shallow groundwater temperature (Hewlett and Fortson 1982 cited in Ebersole et al. 2003). Although overall water yield may increase with logging, the majority of the literature does not appear to support any change to low summer base flows (Stednick 1996, Harr et al. 1982, Burton 1977, Jones and Grant 1996, Fowler et al. 1987 cited in Bartholow 2000). However, in Brazil, the high water consumption of eucalyptus tress in tree plantations for the pulp and paper industry has lowered groundwater tables on a regional scale accompanied by the disappearance of streams and rivers (Carrere 1996 cited in Pringle and Triska 2000). Urbanization and increases in impervious surfaces in the landscape results in changing patterns in runoff, groundwater recharge, soil loss and hydrologic shift in surface-subsurface flowpaths (Pringle and Triska 2000).

Hydrological modifications (e.g., stream water diversions, wetlands drainage groundwater extraction, channelization and damming) can decouple the surface water - ground water interface (Pringle and Triska 2000). For example, groundwater may be withdrawn for agricultural, industrial or municipal purposes, and these withdrawals may influence flows from springs that provide critical habitats (Van den Avyle and Evans 1990). Groundwater pumping may reduce the level of water in streams and rivers, and the effects depend on the interaction and balance between the surface waters and the groundwater in the system (Glennon 1995). Constructions of dams and impoundments can cause large-scale alterations of the flow regime, leading to significant changes in patterns of surface-subsurface exchange (Galay 1983, Curry et al 1994, Goltz 1994 cited in Dent et al. 2000). Streamflow reductions for hydroelectric developments could also alter winter groundwater flow to brook trout incubation habitat and result in freezing of eggs and alevins (Curry et. al 1992 cited in Cunjak 1996).

A review of the potential effects of climate warming on groundwater suggests that an increase in the temperature of baseflow of 4-5°C in streams at low elevations and latitudes will shrink longitudinal distributions of trout in summer through reductions in preferred thermal habitat (Meisner et al. 1988). The authors hypothesized that low temperature plumes below groundwater discharge sites may shrink reducing coldwater refugia in summer. Meisner (1990) estimated the loss of summer thermal brook trout habitat in two Southern Ontario streams using a climate warming scenario. Elevated air and groundwater temperatures increased maximum summer stream temperatures and moved thermal habitat barriers upstream, which reduced summer thermal habitat for brook trout in these two streams by 42% and 30%. However, the author indicates that because groundwater temperatures will always be lower than summer air temperatures, the cooling function of groundwater in streams will be maintained.

3.5 Thermal Loading → Change in Water Temperature → Alterations of Currents, Thermocline → Change in Migration/Access to Habitat

Overview of Search

A search was conducted to find literature relevant to the link between changes in water temperature and the resulting alterations of currents and thermocline from thermal loading. Abundant research has been conducted that consider the diverse physical and biological effects of thermally modified wastewater. Sources of thermal loading were almost exclusively from power generation cooling water, including coal burning and nuclear power. Studies on the effect of thermal effluent resulting from mining, manufacturing or steel production on fish were not found, probably because of the potential confounding effects of contaminants also created by these industries. Some text books and review papers consider how thermal plumes behave physically, but they rarely address alterations to water currents and thermoclines.

Abundant literature is available that studies the effects of thermal loading on aquatic biota in cooling ponds, estuaries, lakes and streams. The information reviewed studied how fish behaviour, movement, success and physiology are influenced directly by thermal effluents. Most of the studies on fish movement focus on effects on attraction or repulsion from the plume, but do not address effects on migratory timing or access to habitat. However, some studies do discuss how changes to natural migratory patterns may potentially affect predation or harvest.

Many laboratory and field studies have examined species-specific thermal preferences and tolerances, as well as the effects of heated effluent water on fish growth, size, development, metabolism, reproductive success etc. The effects on macrophyte growth and primary production have also been well studied. Summarizing all the effects of thermal loading on fish and other aquatic biota located in the primary literature would be extensive and beyond the scope of this literature review.

Summary of Literature Review

General Information

Sources of thermally altered wastewater include, but are not limited to: sewage treatment plants, nuclear power plants, coal burning facilities and hydroelectric facilities. It is not possible to generalize changes to water temperature, as the effects of the thermal plume differ in each case, depending upon the effluent and the receiving environment, for example, waterbody type (e.g., lake, river, estuary), temperature regime and the current or stream flow. Thermal stratification can also occur. Thermal effluent from wastewater has been found to influence the abundance and distribution of fish, benthic invertebrates, zooplankton, macrophytes as well as influencing primary production. Exposure to thermal wastewater can have developmental and behavioural implications on fish and other organisms. Faster growth rates, due to prolonged growing seasons in thermal effluent, have been reported in several studies.

Macrophyte Growth

In a study of the effects of thermal effluent on aquatic macrophytes in Lake Wabamun (Haag and Groham 1977), heated water from the Wabamun Generating Station was discharged during the winter at 25°C and in the summer at 27-32°C. The heated water formed a thin layer on the surface which averaged 7°C warmer than ambient surface water temperature. The authors found that the discharge of thermal effluent resulted in a major alteration of community growth dynamics, with a greater standing crop of macrophytes present in the thermal mixing zone in the winter, with *Elodea canadensis* dominant in this zone during the winter. Higher light levels, due to the absence of ice cover resulted in earlier spring growth in the effluent zone. The growth of *E. canadensis* continued to increase compared to the control site. Although the study did not discuss any effects of the heated effluent or the changes in the plant community on fish, the authors concluded that the qualitative and quantitative changes in macrophyte growth in the thermal discharge zone are unlikely to have any significant impact on the biology of the lakes as a whole (Haag and Groham 1977).

Lower Trophic Levels

Rasmussen (1982) found that species composition in the benthic macroinvertebrate community was also much different in the heated area of Lake Wabamun with the warmest areas supporting a community dominated by tubificid oligochaetes, and the moderately heated areas supporting a community dominated by large *Chironomus* species. The heated water from a power plant on the White River, Indiana depressed the populations of caddisfly larvae, mayfly nymphs and other invertebrates in the discharge area when temperature ranged from 31 to 39°C, but the populations recovered less than 550 m below the discharge (Benda and Proffit 1973).

Studies have also shown effects on plankton abundance and dynamics, where the thermal effluent eliminated zooplankton from regions where temperature exceeded 45°C (Leeper and Taylor 1995). Many studies have found that fish distribution is affected by the presence of thermal plumes, but that the effects are not consistent. The results are also dependent upon species preferences and tolerances, and can vary seasonally.

Fish Distribution and Movement near the Plume - Rivers

Ross and Winter (1981) monitored winter movements of yellow perch, northern pike, walleye and largemouth bass near the thermal plume of a power plant on the Mississippi River. The researchers found that all species except largemouth bass moved freely between discharge-affected and unaltered waters, where the largemouth bass preferred the warmest locations near the discharge point. Both the northern pike and yellow perch had home ranges larger than the discharge area. A similar study comparing attraction of salmonines and centrarchids near a thermal discharge was conducted by Haynes et al. (1989).

A study on the effect of thermal effluent from a power plant on the White River, Indiana, found that fish (centrarchids) were attracted to the heated discharge in the cold months, but were repelled during hot months, as temperature tolerance levels were reached for each species (Benda and Proffit 1973). The thermal effluent travelling across the river did not create a barrier to migrating fish. Ginot et al. (1996) examined fish catches and the structure of fish populations in relation to thermal loading in the Rhône River. Fish were found to move away from the site as temperatures increased. Above 15°C, fish gradually began to leave the shoreline and a threshold was reached at 25°C when the largest individuals left the area. By 29°C, diversity was non-existent near the outfall. In winter, attraction to the heated water appeared insignificant, except for perch which were attracted. Secondary factors such as discharge ands season also were found to have significant impacts on population structures.

Fish Distribution and Movement near the Plume - Estuary

In a study of an Australian estuary that receives thermal loading from a power generating station, decreasing numbers of species were found at decreasing distances from the thermal outfall (Jones et al. 1996). During the summer/autumn period, thermal effluent only affected water temperature and the species composition in the inner estuary, with some estuary-opportunistic fish species avoiding the area at that time. During the winter/spring months, thermal effluent acted in the opposite way, with species attracted to the warmer waters of the estuary. The extended growth seasons for these species also contributed to significantly higher growth rates.

Fish Distribution and Movement near the Plume – Lakes and Reservoirs

A study by Spigarelli et al. (1982) in Lake Michigan found that fish densities in plume and reference areas varied seasonally, where temperature selection was strongest during the fall and weakest during the summer. The highest plume densities occurred during late spring, as large numbers of alewife congregated near and within the thermal plumes during the spawning period. Temperatures selected by fish in plume areas were 1-3°C higher than maximum ambient temperatures.

Minns et al. (1978) studied the distribution of fish in the vicinity of two thermal generating stations on the Great Lakes. At both sites, fish densities were generally greatest in the shallowest depths and there was a perceptible clustering of fish in the vicinity of the thermal outfalls particularly in the spring and fall. However, there was no significant evidence of altered fish communities in relation to temperature and no apparent response in vertical distribution of fish where as summer thermal stratification occurred. The authors suggest that the lack of a clear temperature response suggest that these fish are responding to currents and perhaps topography (Minns et al. 1978).

Brown bullhead were tracked near a thermal discharge in Lake Ontario to determine the effect of the discharge on their movement (Kelso 1974). All bullhead remained in the influence of the plume during the day of monitoring. Fish in the plume swam at lower speeds, milled more and turned more then fish in the control site, indicating that thermal discharges can interrupt or alter the normal movement patterns of brown bullhead.

Galloway (1991) examined water temperatures and fish movement patterns within the Flint Creek Reservoir. Horizontal and vertical gradients were present, and the thermal effluent was found to affect up to 100% of the reservoir to depths in excess of 4 m. In the study, largemouth bass were highly mobile and made local and intra-reservoir movements consistent with their thermal preferendum. Large adult bass moved less than juveniles, except in summer when the adults abandoned their territories to migrate to the thermal refuge stations. Black bullheads concentrated in summer thermal refuge stations, whereas the channel catfish avoided the thermal refuges and were capture in the main reservoir during summer.

Effects on Reproduction

Shuter et al (1985) reported on a 20-year integrated field, laboratory and modelling study on the impact of thermal effluent on the smallmouth bass population in Baie du Doré, Lake Huron. The study found that there was no significant change in the location of smallmouth bass nesting or nursery areas. There was also no evidence of a major shift in areas frequented by young-of-the-year (YOY) in early summer; however, the discharge area attracted YOY and adults during summer and early fall. Cooke et al. (2003) also conducted a study in a thermal effluent canal at Nanticoke Generating Station in Lake Erie to examine the influence of fluctuating thermal regimes on the reproductive success of smallmouth bass. Spawning in the canal occurred approximately 1 month earlier than in adjacent non-thermally influenced regions. Smallmouth bass nesting in the effluent canal exhibited behavioural alterations, where parental care activity was higher than previously reported and did not follow conventional patterns. However, the reproductive success was high compared to other published values, indicating that the fish are capable of adjusting energetic expenditures in response to high and variable thermal conditions (Cooke et al. 2003).

Predation and Harvesting

Janssen and Giesy (1984) report the movement of fish into less than ideal thermal conditions to obtain access to prey items, where largemouth bass were observed moving into potentially lethal waters to feed on blueblack herring and dead bluegills located in the heated outflow.

The thermal effluent can alter the distribution of adult fish, which in turn can lead to an increase in the effectiveness of a fishery (Shuter et al. 1985). Jones et al. (1996) indicate that these changes to natural distribution patterns may alter the population structures of these species by increasing their vulnerability to heavy localized fishing intensity, aggregation of natural predators and point-source pollution.

3.6 Change in Timing, Duration and Frequency of Flow → Change in Water Temperature

Overview of Search

A search was conducted to find literature relevant to the link between changes in water temperature from alterations of flow. The literature related to this linkage was not abundant in the primary literature. Reviews such as Poole and Berman (2001) and Poff et al. (1997) discuss in general the effects of alterations in flows on river ecosystems, including aquatic biota; however, many of these studies are related to alterations in flow that affect fish habitat, and do not make the linkage to changes in temperature. Studies have investigated the effects of the changes to flows on fish migration (Raymond 1979, Georgi et al. 1997) and spawning habitat (Chapman et al 1986); however these studies once again do not make the linkage to temperature.

The majority of the relevant information considered the effects of dams on water flow, temperature and potentially fish. As well, there are discussions of how alterations to flows (e.g., stream diversions, withdrawals for agricultural, industrial or municipal uses, or presence of dams) affect temperatures in streams contained in the grey literature with respect to Instream Flow Needs. These reports also discuss management of flows to protect temperatures for downstream fish and critical fish habitat.

Summary of Literature Review

General Information

There is evidence showing that highly regulated flows alter stream communities (Petts 1984, Cushman 1985, Irvine 1985 cited in Travnichek et al. 1995). Reductions in flow affect water temperature by reducing the stream's assimilative capacity for heat (Poole and Berman 2001). Because water temperature is partially a function of discharge, extreme flow fluctuations are reflected in the thermal regimes of running waters (Ward 1985). Dams and water withdrawals are mechanisms by which human activities can influence stream temperature by altering the drivers of stream temperature (Poole and Berman 2001).

Streamflow is strongly correlated with many critical physicochemical characteristics of rivers, including water temperature, which in turn limits the distribution and abundance of riverine species (Poff et al 1997). River temperature and flow can affect upstream migratory behaviour and timing (Banks 1969, Jonsson 1991, Trépanier et al. 1996 cited in Quinn et al. 1997).

Dams

In a study of the Platte River downstream of two hydro dams, Sinokrot and Gulliver (2000) found that a clear relationship existed between river water temperatures and river flow rate, and that the occurrence of high water temperatures can be attributed to low river flow rate and can be reduced, but not eliminated, with minimum instream flow requirements. Dams directly affect downstream temperature depending upon their mechanism of release (i.e., top or bottom release). Small surface release dams release warmer epilimnetic water which may in turn affect downstream communities (Lessard and Hayes 2003), whereas deep release dams can provide summer-cool and winter-warm conditions reminiscent of spring-fed lotic habitats (Ward 1985). Therefore, in some cases, effects on temperature and fish distribution are related to the releases as well as the reduction in flows. There are often confounding effects of the reduction in flows affecting fish movement and distribution, as well as temperature.

Management of the of the Columbia River for hydroelectric power production has led to decreasing discharges and warming of the lower river in late spring and early summer over the last five decades (Quinn and Adams 1996). The river's warming (i.e., first date of 15.5°C water) was found to occur about 30 days earlier now than in the past (i.e., 1938-1993). The annual maximum temperatures increased by about 1.8°C from 1949 to 1993, and fall cooling occurred later in the season (Quinn and Adams 1996). These increasing temperatures and flows were correlated with earlier arrivals of American shad and progressively earlier arrivals of sockeye salmon at the Bonneville Dam. Quinn et al. (1997) related the arrival timing of sockeye salmon at a series of dams on the Columbia River and Snake River. The temperatures experienced by sockeye salmon have increased in the lower but not upper reaches of the system, and the flows have reduced. The decreases in flow from flow manipulation caused earlier spring warming, higher June and July temperatures, and later fall cooling. As a result, Bonneville-McNary travel rates for migrating sockeye salmon have increased and the sockeye pass McNary Dam about 11 days earlier than in 1954. The effects are unknown of the shift toward an earlier arrival in the upper Columbia River on survival and reproduction (Quinn et al. 1997).

Graham and Orth (1986) evaluated the influences of water temperature and discharge variables on the timing of duration of smallmouth bass spawning in both streams regulated by dams and unregulated streams. Water temperatures were slightly warmer at the sites with surface water releases. The authors found that mean daily water temperature, and not discharge variables, was the single most important variable in controlling smallmouth bass spawning time, in both regulated and unregulated systems. Lessard and Hayes (2003) examined the effects of elevated summer temperature increases from small surface release dams on fish and macroinvertebrate communities. Mean summer water temperatures varied significantly between upstream and downstream sections across all study streams, with higher mean summer temperatures below the dams. Changes in mean summer temperature downstream of the dam varied from 1°C cooler to greater than 5°C warmer. These increases in temperature were maintained at least 2 to 3 km downstream of the dams. Downstream communities responded to warming below the dams with shifts in the macroinvertebrate community, increased fish species richness and reductions in the population densities of the coldwater species of brown trout, brook trout and slimy sculpin.

Paragamian (1999) studied the effects of variable flows and temperature on burbot spawning migrations in the Kootenai River. During the winter, warmer water and more erratic flow occurred downstream of the dam. The fluctuations in flow were found to affect burbot spawning. Warmer winter temperatures in the Kootenai River may not have affected spawning, but burbot were found to be attracted to the colder water of Goat River (1°C) over the warmer water (4°C) of the Kootenai River.

Farquhar and Gutreuter (1989) studied the seasonal distribution and migration patterns of striped bass in relation to water temperatures and deep water discharges in a large Texas reservoir. In the spring and summer, white striped bass were distributed in areas with temperatures below 26°C and dissolved oxygen levels greater than 4 mg/L. Due to cool water discharge, this area was usually restricted to locations within 15 km of the dam. Edwards (1978) surveyed fish faunas above and below another Texas reservoir to determine the effect of the impoundment on downstream community. A total of 22 fish species were found above the reservoir, but only 18 downstream of the dam, showing decreased diversity below the dam. The seven species were known in the downstream study are prior to impoundment. The author suggested that the absence of these species was due to changes in downstream temperature due to cooler hypolimnetic water releases. The extent to which an upstream reservoir modifies downstream thermal conditions depends on operational variables (release depth, discharge pattern), limnological variables (retention times, stratification pattern and thermal gradients) and position of the dam along the longitudinal profile (Ward and Stanford 1982 cited in Ward 1985).

Water Withdrawals

Water withdrawals reduce instream flow and therefore also reduce the assimilative capacity of streams (Poole and Berman 2001). Water withdrawals can be for industrial, agricultural or municipal needs. As discussed in Section 3.4, hydrological modifications, such as stream water diversions, wetlands drainage, groundwater extraction, channelization and damming can reduce flows and consequently temperatures in streams and rivers. Groundwater withdrawals can also affect flows and subsequently temperatures in surface waters, depending upon the interaction and balance between the surface waters and the groundwater in the system (Pringle and Triska 2000, Van den Avyle and Evans 1990, Glennon 1995).

Winter water withdrawals could severely affect fishes that are poorly adapted for activity at freezing temperatures (Cunjak 1996). Streamflow reductions for hydroelectric developments could also alter winter groundwater flow to brook trout incubation habitat and result in freezing of eggs and alevins (Curry et. al 1992 cited in Cunjak 1996). Poole and Berman (2001) indicate that protecting or re-establishing instream flow is critical for maintaining or restoring thermal regimes in streams.

Land Use

Dams are the most obvious modifiers of river flow, but for many rivers, it is land use activities, including timber harvest, livestock grazing, agriculture and urbanization that are the primary causes of altered flow regimes (Poff et al. 1997). Increases in water flows can occur from disturbance of upland vegetation and the relative amount of surface runoff within the basin. Changes to channel morphology and reduced shading (see Section 3.1) can lead to increases in the temperature of water in the stream (Poole and Berman 2001).

4. CHANGE IN DISSOLVED OXYGEN

4.1 Addition or Removal of Aquatic Vegetation → Change in Light Penetration → Change in Dissolved Oxygen

Overview of Search

A search was conducted to find literature relevant to the link between changes in dissolved oxygen from the changes in light penetration from the addition or removal of aquatic vegetation. Similar to the linkage of the addition or removal of aquatic vegetation on water temperature (Section 3.3), most of the relevant papers were comparative studies that considered the effects of different vegetation densities on water quality, and were not looking at the direct link of vegetation addition or removal on dissolved oxygen. The research generally measured dissolved oxygen over time and space in study sites with and without aquatic vegetation present. A direct link to variations in light penetration and dissolved oxygen was very rarely made in these studies. Very little information was found in the macrophyte removal literature (i.e., carp grazing and mechanical weed harvesting).

Summary of Literature Review

General Information
The literature indicates that the presence of submersed macrophytes can alter the water quality in lakes, rivers and estuaries (Carpenter and Lodge 1986 cited in Carter et al. 1988). Changes associated with the presence of macrophytes include altered light attenuation, water temperature and dissolved oxygen concentrations (Hannan and Anderson 1971, Carter et al. 1988, O'Neill Morin and Kimball 1983). Aquatic vegetation can alter dissolved oxygen dynamics in the water column through a variety of means including directly reducing gas exchange at the water's surface, by root respiration, and indirectly by reducing light available for photosynthesis (Rose and Crumpton 1996). Diurnal variations in dissolved oxygen are attributed to the presence of submerged macrophytes in aquatic water bodies

Comparative Studies
Studies that compare dissolved oxygen between areas with and without macrophytes find diurnal variations occur in macrophyte beds, with high levels occurring during the day due to photosynthesis and low levels occurring at night due to respiration. Effects on dissolved oxygen vary by the species present and their density and biomass within the macrophyte stands.

O'Neill Morin and Kimball (1983) observed decreasing dissolved oxygen with depth in dense macrophyte stands in a New England lake. The maximum dissolved oxygen level from June to September occurred at 0 to 0.6 m in depth (107% saturation) and declined rapidly below 1.3 m (84% saturation at 1.9 m). The dense foliage in the macrophyte stands impeded water circulation in the littoral zone and photosynthesis occurred mainly in the upper water column. A study by Rose and Crumpton (1996) found areas with emergent vegetation in a natural prairie pothole wetland were generally anoxic until the marsh began to freeze in November, whereas open water sites were rarely anoxic. Sites within the emergent stands had extremely low dissolved oxygen and were almost consistently anoxic, while sites on the edges of the stand had higher dissolved oxygen concentrations. Dissolved oxygen concentrations were significantly lower and varied less diurnally in vegetated areas; these results persisted throughout the study.

Carter et al. (1988) compared water quality parameters between sites with and without submerged macrophytes at very high population densities in the tidal Potomac River. Diurnal fluxes in dissolved oxygen and stratification were observed at all stations; however, dissolved oxygen stratification was greatest at the vegetated stations. The extremely large variations in dissolved oxygen observed were considered to be related to the high biomass of vegetation in the system. The effects of macrophytes on dissolved oxygen were greatest in August-October, corresponding with the peak system-wide biomass.

Jorga and Weise (1977) measured the biomass of submerged macrophytes and dissolved oxygen in the Kleine Elster River, a slow-moving stream with dense growths of photosynthetic plants. The authors found that photosynthetic oxygenation was a function of biomass and light intensity up to a certain level (i.e., biomass of 250 g dry wt/m^2), but crops above this level caused a decrease in dissolved oxygen. In autumn, the oxygen balance was adversely affected by dying plants and decreased flow, as well as other factors.

Hannan and Anderson (1971) monitored the oxygen balance on a seasonal basis in two experimental ponds, one with a higher macrophyte growth. Both the dense and sparse growth ponds showed a daily dissolved oxygen pulse and there were similarities in the minimum and maximum dissolved oxygen concentrations. Large macrophytes have also been found to reduce dissolved oxygen in constructed wetlands for wastewater treatment (Williams et al. 1999). The dissolved oxygen levels were found to vary seasonally, with concentrations in the interior locations depressed from the inlet or outlet values. The presence of the large macrophytes obstructed wind and created shade that reduced aeration and algal activity, leading to the decline of dissolved oxygen concentrations in the water column (Williams et al. 1999).

Weed Removal
As discussed in Section 3.4, there are studies on various methods for removal of macrophytes for aquatic vegetation control; however, most of these studies do not discuss the link to changes in dissolved oxygen. In a few cases, however, measurements of dissolved oxygen concentrations were taken during the study. For example, in an experimental aquatic plant harvesting program in southern Lake Chemong (Wile 1978), dissolved oxygen concentrations rarely fell below 80% saturation and changes with depth were minimal. In Parkinsons Lake, New Zealand, Chinese grass carp were introduced for aquatic macrophyte control (Mitchell et al. 1984). The researchers found that the elimination of the submerged and emergent aquatic plants did not result in any significant change in dissolved oxygen over the successive two years. The influence of the rooted vegetation on oxygen budgets was considered to be negligible.

4.2 Thermal Loading → Change in Dissolved Oxygen

Overview of Search

A search was conducted to find literature relevant to the link between changes in dissolved oxygen from thermal loading. As discussed in the linkage of thermal loading on water temperature, alterations to currents and thermoclines (Section 3.5), abundant research has been conducted on the effects of thermal plumes; however, there was very little linking these effects to changes in dissolved oxygen concentrations. Only four studies in the thermal wastewater literature were found which reported dissolved oxygen levels. All other studies reviewed did not measure or report on dissolved oxygen in the thermal plume. In the majority of the studies, the effects from the thermal plume on fish behaviour, distribution, movement, condition, etc. were linked to temperature and not to dissolved oxygen; a summary of these studies are in Section 3.5.

Laboratory and field studies have been conducted on species-specific dissolved oxygen requirements. There is also abundant literature linking temperatures and dissolved oxygen in both streams and lakes, for example, lake stratification and reduction of hyoplimnetic dissolved oxygen; however, these studies are not related to thermal effluents.

Summary of Literature Review

General Information

Effects of thermal effluent include increases in water temperature and changes in circulation conditions, which can lead to a decrease in the solubility of gases (for example, dissolved oxygen) (Eloranta 1983). Waters receiving cooling water discharge have decreased oxygen concentration because the solubility of gases decreases with increasing water temperature. However, the warm water effluent may also increase the exchange of oxygen from air to water by preventing or shortening the period of ice cover (Veltz and Gannon 1960 cited in Eloranta 1983).

Thermal Effluent

Only four studies were found which reported on dissolved oxygen in thermal effluent plumes, as a result, it is difficult to draw any conclusions regarding the results, as one was in a reservoir, one in a marine bay, one in a lake, and one in a pond. McNeely and Pearson (1974) studied the effects of a thermal effluent on the distribution and condition of fish within a reservoir in northeastern Texas. As well as monitoring temperatures within the reservoir, dissolved oxygen concentrations were also measured. These researchers found that the heated effluent entered the reservoir as an overflow, floating on top of the main mass, with the heated plume being 2-3 m deep and 5-15°C warmer than the water beneath. The cooler water beneath the effluent contained an adequate supply of dissolved oxygen for all species of warmwater fish. Surface and bottom dissolved oxygen concentrations ranged from 6.1 to 10.2 mg/L and 4.7 to 10.0 mg/L, respectively. No serious depletion of dissolved oxygen was found at either the surface or the bottom at either station. Of the 30 species of fish, two forage species were absent or rare from the outfall area, and some species (white crappie and river carpsucker) may have been attracted to the effluent area in the summer. The size and condition of fish from the outfall area did not differ significantly from those at other stations (McNeely and Pearson 1974).

Kailasam and Sivakami (2004) also reported low dissolved oxygen (surface mean of 3.70 mg/L) within a thermal plume within Tuticorin Bay, India (surface mean temperature of 38.92°C and bottom mean temperature of 38.86°C). Dissolved oxygen concentrations and temperature improved with distance from the thermal discharge site. Effects were noted in the benthic invertebrate population (density and species diversity); however, these effects were considered by the researchers to be correlated with temperature and not with dissolved oxygen.

Eloranta (1983) examined the physical and chemical properties of the water in a natural closed pond in central Finland receiving warm-water effluent from a thermal power plant over a two year period. The warm water effluent was discharged to the pond's surface, which promoted unusually early thermal and subsequent chemical stratification. During the summer stratified periods, an anaerobic hypolimnion always developed. During the winter months, the surface waters were undersaturated possibly because of the continuous decompositions of organic material, low primary production and incomplete mixing of the pond water (Eloranta 1983).

Rasmussen (1982) found that the thermal effluent affected the benthic invertebrate communities in Lake Wabamun. Aston (1973 cited in Rasmussen 1982) found species in heated effluent benthic invertebrate species to be exceeding tolerant of the reduced dissolved oxygen concentrations that can accompany such high temperatures; however, no dissolved oxygen concentrations were reported.

4.3 Nutrient Loading → Change in Dissolved Oxygen

Overview of Search

A search was conducted to find literature relevant to the link between changes in dissolved oxygen from nutrient loading. General studies on the effects of nutrient loading on lakes, rivers and estuaries were abundant in the literature, related to land use, storm sewers, and industrial/municipal effluents. However, many studies on effects on the aquatic ecosystem and/or fish do not make the link to changes in dissolved oxygen, but instead to various other parameters including phosphorus, nitrogen, biological oxygen demand (BOD) and chlorophyll *a*. Abundant literature exists on lake eutrophication, i.e., effects on primary production, macrophytes, fish populations and communities etc. Many of these studies may also consider the link to dissolved oxygen, but to review all of these was outside the scope of this review.

Summary of Literature Review

General Information
Increased land use, including agricultural activities, urban and industrial development, including wastewater discharges can cause increased nutrient loadings to lakes, streams and estuaries. Nutrient loading in lakes is recognized as a serious threat to water quality (Bekliogu et al. 2003), as lake eutrophication from excessive inputs of phosphorus and nitrogen leads to water quality deterioration, and can also modify water clarity and food web structure, as the lakes may shift from a macrophyte-dominated clearwater state to a phytoplankton-dominated turbid state in response to nutrient loading (Bekliogu et al. 2003). One of the most important consequences of high anthropogenic nutrient loadings is low dissolved oxygen concentrations that reduce the extent and suitability of habitat for a wide range of organisms (Breitburg et al. 2003).

Nutrient Loadings- Rivers
Chambers et al. (1997) examined temporal and spatial patterns in winter dissolved oxygen in the Athabasca River to assess the impact of pulp mill and municipal effluents on under-ice oxygen. Improvements in mill technology since 1977 coincided with increases in late-winter dissolved oxygen at two of three downstream sites and improvements in the magnitude and downstream

extent of the dissolved oxygen sag. However, during the years of 1988-1993, effluent loading resulted in sag and recovery zones over small spatial scales (tens of kilometres) and also contributed to large-scale (hundreds of kilometres) linear declines in dissolved oxygen.

To study the effects of effluents produced by pulp mills and sewage plants on northern rivers on benthic invertebrates, Lowell and Culp (1999) experimentally measured the combined effects of increased toxicants and nutrients and decreased dissolved oxygen on the mayfly, *Baetis tricaudatus*. The mayflies were exposed to two dissolved oxygen levels: low (5 mg/L) versus high (11 mg/L) in the presence and absence of effluent from a mixed-effluent outfall. The low dissolved oxygen clearly stressed the mayflies, as grazing intensity was reduced by 80% and after two weeks, survival by 60-90%. As well, the dissolved oxygen level had a significant effect on microhabitat positioning, with a 250-350% greater proportion of mayflies moving into regions of higher current velocity in the low dissolved oxygen treatment, a behaviour that would likely make them more susceptible to predation in the field. In contrast, the 1% effluent increased mayfly survival, although this effect only partially compensated for the pronounced negative effect of low dissolved oxygen levels. The researchers conclude that the negative effects of pulp mill and sewage effluent on *B. tricaudatus* and possibly other benthic invertebrates is more likely related to reductions in dissolved oxygen levels than toxicant effects, at least over the short term.

Sosiak (2002) found that the biomass of periphyton and aquatic macrophytes declined in the Bow River, Alberta, in response to improved phosphorus and nitrogen removal at Calgary's two municipal wastewater treatment plants. The reduction of sewage loading stress in Toronto area waters has allowed sensitive fish species to occupy locales where they were absent several decades ago. Improvements to sewage treatment have more than offset degradation from continued urbanization (Wichert 1995).

Nutrient Loadings- Lakes

Evans et al. (1996) conducted a modelling study to link land-use activities, phosphorus loading, hypolimnetic oxygen depletion, and loss of cold-water fish habitat in Lake Simcoe, Ontario. Conversion from forested to agricultural land in the Lake Simcoe basin has increased phosphorus loadings to the lake. Recruitment failure of lake trout, lake whitefish and lake herring have occurred, as hypolimnetic water quality deteriorated. There was a downward trend in dissolved oxygen concentration of the hypolimnion over 1975 to 1995. The volume-weighted, temperature-corrected hypolimnetic dissolved oxygen from Aug. 30-Sept. 19 declined from 4.5 to 2 mg/L by 1993. During late summer 1975-1993, 60-98% of the 6-12°C thermal habitat volume had <7 mg/L dissolved oxygen and 10-15% had <3 mg/L, the incipient lethal threshold for lake trout. Management goals included reduction in P loadings to improve deep-water habitat for cold-water fishes.

Nutrient Loadings- Estuaries

Breitburg al. (2003) studied the effects of increased nutrient loadings and oxygen depletion on hypoxia-induced mortality of fishes in the mesohaline Patuxent River. Nutrient loadings have resulted in low dissolved oxygen concentrations in the bottom waters of the river, with much of the river below 50% dissolved oxygen saturation during summer. The system is characterized by high spatial and temporal variations in dissolved oxygen concentrations, and this extent of hypoxia was considered sufficient to alter distributions and trophic interactions in the river. Modelling consistently predicted high mortality of planktonic anchovy eggs under current dissolved oxygen levels and increasing survival of fish eggs with increasing dissolved oxygen.

Increases to dissolved oxygen were predicted to occur under conditions of reduced nutrient loading, for example, with changes in land use that reduce nutrients to the river.

Rydberg et al. (1990) investigated the coupling between increasing nutrient supply and decreasing deep-water oxygen concentrations within the SE Kattegat, a strongly stratified Baltic estuary, with large supply of nitrogen from nearby anthropogenic sources. The oxygen consumption was twice as high as that in the open Kattegat, and was well correlated with the measured nitrogen uptake and the external supply of nitrate to surface water. Isaac (1997) also found that nitrogen loading corresponded with reduced dissolved oxygen in the Mt. Hope Bay, a coastal waterbody on the Massachusetts-Rhode Island border.

Price et al. (1985) analyzed the role of nutrient enrichment in altering the ecological conditions for striped bass in Chesapeake Bay. They found that nutrient enrichment was qualitatively correlated with greater deoxygenation of the deep channel in the mid and upper bay. During the late 1970s, summer dissolved oxygen concentrations as low as 2 mg/L approached to within 7 to 8 m of the surface, causing water stressful to striped bass to intrude on shoal areas of the bay. The volume of bottom waters containing 0.5 mg/L dissolved oxygen or less was about 15 times greater in July 1980 than July 1950. The combination of the expanding hypoxic pool and summer temperatures above preferred levels may contribute to an "oxygen-temperature squeeze" that forces adults onto shoal areas of the bay or out of the upper bay. Webb (1981) also found that nutrients released into the Potomac River with discharge from the secondary sewage-treatment plant caused dissolved oxygen sag for approximately 8 nautical miles from the outflow area. In the remainder of the tidal river and transition zone, the oxygen regime was dominated by biological reactions fed by nutrients exchanged with the bottom of the river.

A study by Eby and Crowder (2002) examined the role of hypoxia in altering fish distributions in the Neuse River Estuary, which drains a watershed receiving substantial nutrient loading from a number of agricultural, industrial and municipal sources. In an examination of ten fish species, all avoided areas with dissolved oxygen concentrations < 2 mg/L. The authors suggest that fish may occupy poorer quality habitat (i.e., areas with lower dissolved oxygen levels), as conditions worsen and the size of the oxygenated refuge shrinks. During hypoxic episodes, fish are restricted to oxygenated, shallow, warmer areas. This may affect on competition and predation in these smaller habitat areas, as well as having bioenergetic costs (Eby and Crowder 2002). Price et al. (1985) suggested that forcing striped bass onto unsuitable shoal areas that lack suitable cover for juvenile striped bass and their prey may increase intraspecific competition within these areas.

5. CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

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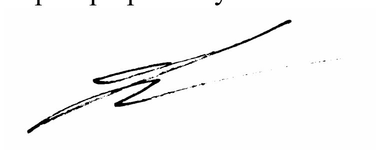

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6. REFERENCES

Bartholow, J.M. 2000. Estimating cumulative effects of clearcutting on stream temperatures. Rivers 7: 284-297.

Barton, D.R., W.D. Taylor and R.M. Biette. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams. N. Am. J. Fish. Manage. 5: 364-378.

Beklioglu, M., O. Ince and I. Tuzan. 2003. Restoration of the eutrophic Lake Eymir, Turkey, by biomanipulation after a major external nutrient control I. Hydrobiologia 489: 93-105.

Benda, R.S. and M.A. Proffitt. 1973. Effects of thermal effluent on fish and invertebrates. In. Conf 370505, Proceedings of a Symposium Held at Augusta, Georgia May 3-5, 1973. pp. 438-447.

Booms, T.L. 1999. Vertebrates removed by mechanical weed harvesting in Lake Keesus, Wisconsin. Journal of Aquatic Plant Management 37:34-36.

Breitburg, D.L., A. Adamack, K.A. Rose, S.E. Kolesar, M.B. Decker, J.E. Purcell, J.E. Keister and J.H. Cowan Jr. 2003. The pattern and influence of low dissolved oxygen in the Patuxent River, a seasonally hypoxic estuary. Estuaries 26: 280-297.

Brown, G.W. and Krygier, J.T. 1970. Effects of clear-cutting on stream temperature. Water Resour. Res. 6:1133-1139.

Carter, V., J.W. Barko, G.L. Godshalk and N.B. Rybicki. 1988. Effects of submersed macrophytes on water quality in the tidal Potomac River, Maryland. J. Freshwat. Ecol. 4: 493-501.

Chambers, P.A., G.J. Scrimgeour and A. Pietroniro. 1997. Winter oxygen conditions in ice-covered rivers: the impact of pulp mill and municipal effluents. Can. J. Fish. Aquat. Sci. 54: 2796-2806.

Chapman, D.W., D.E. Weitkamp, T.L. Welsh, M.B. Dell and T.H. Schadt. 1986. Effects of river flow on the distribution of Chinook salmon redds. Trans. Am. Fish. Soc. 115: 537-547.

Cooke, S.J, J.F. Schreer, D.P. Philipp and P.J. Weatherhead. 2003. Nesting activity, parental care behavior, and reproductive success of smallmouth bass, *Micropterus dolomieu*, in an unstable thermal environment. J. Therm. Biol. 28: 445-456.

Cunjak, R.A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Can. J. Fish. Aquat. Sci. 53(Suppl.1): 267-282

Cunjak, R.A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Can. J. Fish. Aquat. Sci. 43: 1970-1981.

Dale, H.M. and T.J. Gillespie. 1977. The influence of submersed aquatic plants on temperature gradients in shallow water bodies. Can. J. Bot. 55: 2216-2225.

Dent, C.L., J.D. Schade, N.B. Grimm and S.G. Fisher. 2000. Subsurface influences on surface biology. pp. 381-402. In Jones, J.B. and P.J. Mulholland, eds. Streams and Ground Waters. Academic Press: San Diego.

Ebersole, J.L. 2003. Cold water patches in warm streams: Physicochemical characteristics and the influence of shading. Journal of the American Water Resources Association 39: 355-368.

Ebersole, J.L. W.J. Liss and C.A. Frissell. 2003. Thermal heterogeneity, stream channel morphology, and salmonid abundance in northeastern Oregon streams. Can. J. Fish. Aquat. Sci. 60: 1266-1280.

Eby, L.A. and L.B. Crowder. 2002. Hypoxia-based habitat compression in the Neuse River Estuary: context dependent shifts in behavioural avoidance thresholds. Can. J. Fish. Aquat. Sci. 59: 952-965.

Edwards, R.J. 1978. The effect of hypolimnion reservoir releases on fish distribution and species diversity. Trans. Am. Fish. Soc. 107: 71-77.

Eloranta, P.V. 1983. Physical and chemical properties of pond waters receiving warm-water effluent from a thermal power plant. Water Research 17: 133-140.

Engel, S. 1990. Ecological impacts of harvesting macrophytes in Halverson Lake, Wisconsin. Journal of Aquatic Plant Management 28:41-45.

Evans, D.O., K.H. Nicholls, Y.C. Allen and M.J. McMurtry. 1996. Historical land use, phosphorus loading, and loss of fish habitat in Lake Simcoe, Canada. Can J. Fish. Aquat. Sci. 53(Suppl.1): 194-218.

Farquhar, B.W. and S. Gutreuter. 1989. Distribution and migration of adult striped bass in Lake Whitney, Texas. Trans. Am. Fish. Soc. 118: 523-532.

Fitch, L. and B.W. Adams. 1998. Can fish and cows co-exist? Canadian Journal of Plant Science. 78: 191-198.

France, R. 1997. Land-water linkages: influences of riparian deforestation on lake thermocline depth and possible consequences for cold stenotherms. Can. J. Fish Aquat. Sci. 54: 1299-1305.

Galloway, M.L. 1991. Age and growth of largemouth bass and temporal and spatial movements of fishes in thermally enriched Flint Creek Cooling Reservoir. Dissertation Abstracts International Part B: Science and Engineering. 51(11): 140.

Garrett, J.W., D.H. Bennett, F.O. Frost and R.F. Thurow. 1998. Enhanced incubation success for kokanee spawning in groundwater upwelling sites in a small Idaho stream. N. Am. J. Fish. Manag. 18: 925-930.

Georgi, A.E., T.W. Hillman, J.R. Stevenson, S.G. Hays and C.M. Peven. 1997. Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River basin. N. Am. J. Fish. Manag. 17: 268-282.

Gibbons, J.W., R.R. Saritz and I.L. Brisbin Jr. 1980. Thermal ecology research at the Savannah River Plant: A review. Nuclear Safety 21: 367-379.

Gibson, R.J. 1966. Some factors influencing the distribution of brook trout and young Atlantic Salmon. J. Fish. Res. Board Can. 23: 1977-1980.

Ginot, V., Y. Souchon and P. Roger. 1996. Impact of thermal loading induced by the Bugey nuclear power plant (upper Rhône River, France) on fish catches and on fish population structure. Hydroécol. 8(1-2):1-33.

Glennon, R.J. 1995. The threat to river flows from groundwater pumping. Rivers 5: 133-139.

Graham, R.J. and D.J. Orth. 1986. Effects of temperature and streamflow on time and duration of spawning by smallmouth bass. Trans. Am. Fish. Soc. 115: 693-702.

Haag, R.W. and P.R. Gorham. 1977. Effects of thermal effluent on standing crop and net production of *Elodea canadensis* and other submerged macrophytes in lake Wabamun, Alberta. Journal of Applied Ecology 14: 835-851.

Haller, W.T, J.V. Shireman and D.F. DuRant. 1980. Fish harvest from mechanical control of Hydrilla. Transactions of the American Fisheries Society 109: 517-520.

Hannan, H.H. and B.T. Anderson. 1971. Predicting the diel oxygen minimum in ponds containing macrophytes. Progve Fish Cult. 33: 45-47.

Hansen, E. 1975. Some effects of groundwater on brown trout redds. Trans. Amer. Fish. Soc. 1: 100-110.

Hartman, G.F., J.C. Scrivenor and M.J. Miles. 1996. Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat. Can. J. Fish. Aquat. Sci. 53(Suppl. 1): 237-251.

Haynes, J.M., G.P. Gerber and J.K. Buttner. 1989. Response of sport fishes to thermal discharges into the Great Lakes: Is Somerset Station, Lake Ontario, different? J. Great Lakes Res. 15: 709-718.

Hill A.R. 2000. Stream chemistry and riparian zones. pp. 83-110. In Jones, J.B. and P.J. Mulholland, eds. Streams and Ground Waters. Academic Press: San Diego.

Hill, W.R., P.J. Mulholland and E.R. Marzolf. 2001. Stream ecosystem responses to forest leaf emergence in spring. Ecology 82 (8): 2306-2319.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45: 502-515.

Holmes, R.M. 2000. The importance of ground water to stream ecosystem function. pp. 137-148. In Jones, J.B. and P.J. Mulholland, eds. Streams and Ground Waters. Academic Press: San Diego.

Isaac, R.A. 1997. Estimation of nutrient loadings and their impacts on dissolved oxygen demonstrated at Mt. Hope bay. Environment International 23: 151-165.

Janssen, J. and J.P. Giesy. 1984. Thermal effluent as a sporadic cornucopia: Effects on fish and zooplankton. Environmental Biology of Fishes 11: 191-203.

Johnson, S.L. 2004. Factors influencing stream temperatures in small streams and a shading experiment. Can. J. Fish Aquat. Sci. 61: 913-923.

Johnson, S.L. and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris in western Cascades, Oregon. Can. J. Fish. Aquat. Sci. 57(Suppl. 2): 30-39.

Jones, G.K, J.L. Baker, K. Edyvane and G.J. Wright. 1996. Nearshore fish community of the Port River-Barker Inlet Estuary, South Australia. I. Effect of thermal effluent on the fish community structure, and distribution and growth of economically important fish species. Marine and Freshwater Research 47: 785-799.

Jones, J.B. and P.J. Mulholland, eds. Streams and Ground Waters. Academic Press: San Diego.

Jorga, W and G. Weise. 1977. Growth of submerged macrophytes in slow-flowing streams in relation to the oxygen balance. Internationale Revue der Gesamten Hydrobiologie. 62: 209-234.

Kaenel, B.R. and C.D. Matthaei and U. Uehlinger. 1998. Disturbance by aquatic plant management in streams: Effects on benthic invertebrates. Regul. Rivers: Res. Mgmt. 14: 341-356.

Kailasam, M. and S. Sivakami. 2004. Effect of thermal effluent discharge on benthic fauna off Tuticorin Bay, south east coast of India. Indian J. Mar. Sci. 33:194-201.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications: a review. J. Range Manage. 37:430-438.

Kelso, J.R.M. 1974. Influence of a thermal effluent on brown bullhead (*Ictalurus nebulosus*) as determined by ultrasonic tracking. J. Fish. Res. Board Can. 31: 1507-1523.

Lau, S.S.S and S.N. Lane. 2002. Nutrient and grazing factors in relation to phytoplankton level in a eutrophic shallow lake: the effect of low macrophyte abundance. Water Research 3593-3601.

Leeper, D.A. and B.E. Taylor. 1995. Plankton composition, abundance and dynamics in a severely stressed cooling reservoir. J. Plankton Res. 17: 821-843.

Lessard, J.L. and D.B. Hayes. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Research and Applications 19: 721-732.

Lembi, C.A., B.G. Ritenour, E.M. Iverson and E.C. Forss. 1978. The effects of vegetation removal by grass carp on water chemistry and phytoplankton in Indiana ponds. Trans. Am. Fish. Soc. 107:161-171.

Liquori, M. and C.R. Jackson. 2001. Channel response from shrub dominated riparian communities and associated effects on salmonid habitat. Journal of the American Water Resources Association. 37:1639-1652.

Lowell, R.B. and J.M. Culp. 1999. Cumulative effects of multiple effluent and low dissolved oxygen stressors on mayflies at cold temperatures. Can J. Fish. Aquat. Sci. 1624-1630.

Macdonald, J.S., E.A. MacIsaac and H.E. Herunter. 2003. The effect of variable-retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. Can. J. For. Res. 33: 1371-1382.

McNeely, D.L. and W.D. Pearson. 1974. Distribution and condition of fishes in a small reservoir receiving heated waters. Trans. Am. Fish. Soc. 103: 518-530.

Mellina, E., R.D. Moore, S.G. Hinch, J.S. Macdonald, and G. Pearson. 2002. Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. Can. J. Fish. Aquat. Sci. 59: 1886-1900.

Meisner, J.D. 1990. Potential loss of thermal habitat for brook trout, due to climatic warming, in two southern Ontario streams. Trans. Am. Fish. Soc. 119: 282-291.

Meisner, J.D., J.S. Rosenfeld and H.A. Regier. 1988. The role of groundwater in the impact of climate warming on stream salmonines. Fisheries 13: 2-8.

Mikol, G.F. 1985. Effects of harvesting on aquatic vegetation and juvenile fish populations at Saratoga Lake, New York. J. Aquat. Plant Manage. 23: 59-63.

Minns, C.K., J.R.M. Kelso and W. Hyatt. 1978. Spatial distribution of nearshore fish in the vicinity of two thermal generating stations, Nanticoke and Douglas Point, on the Great Lakes. J. Fish. Res. Board Can. 35: 885-892.

Mitchell, CP, G.R. Fish and A.M.R. Burnet. 1984. Limnological changes in a small lake stocked with grass carp. New Zealand Journal of Marine and Freshwater Research 18: 103-114.

Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. Trans. Am. Fish. Soc. 107:135-145.

Ohmart, R.D. 1996. Historical and present impacts of livestock grazing on fish and wildlife resources in western riparian habitats. Pages 245-279 in Paul R. Krausman, ed. Rangeland wildlife. The Society for Range Management, Denver, CO.

O'Neill Morin, J. and K.D. Kimball. 1983. Relationship of macrophyte-mediated changes in the water column to periphyton composition and abundance. Freshwat. Biol. 13: 403-414.

Paragamian, V.L. 1999. The effects of variable flows and temperature on burbot spawning migrations in the Kootenai River, Idaho, USA, and Kootenay Lake, British Columbia, Canada, post Libby Dam. Biology and Management of Burbot. pp. 121-139.

Platts, W.S. 1991. Livestock Grazing. Pages 289-423 in W.R. Meehan, ed. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Bethesda, MD. Spec. Publ. 19.

Platts, W.S. and R.L. Nelson. 1985. Stream habitat and fisheries response to livestock grazing and instream improvement structures, Big Creek, Utah. Journal of Soil and Water Conservation. 40: 374-379.

Poff, N.L. J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47: 769-784.

Poole, G.C. and C.H. Berman. 2001. An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management 27: 787-802.

Price, K.S., D.A. Flemer, J.L. Taft, G.B. Mackiernan, W. Nehlsen, R.B. Biggs, N.H. Burger and D.A Blaylock. 1985. Nutrient enrichment of Chesapeake Bay and its impact on the habitat of striped bass: a speculative hypothesis. Trans. Am. Fish. Soc. 114: 97-106.

Pringle, C.M. and F.J. Triska. 2000. Stream Emergent biological patterns and surface-subsurface interactions at landscape scales. pp. 167-193. In Jones, J.B. and P.J. Mulholland, eds. Streams and Ground Waters. Academic Press: San Diego.

Quinn, T.P. and D.J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology 77: 1151-1162.

Quinn, T.P, S. Hodgson and C. Peven. 1997. Temperature, flow, and the migration of adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River. Can. J. Fish. Aquat. Sci. 54: 1349-1360.

Rasmussen, J.B. 1982. The effect of thermal effluent, before and after macrophyte harvesting, on standing crop and species composition of benthic macrophyte communities in Lake Wabamun, Alberta. Can. J. Zool. 60: 3196-3205.

Raymond, H.L. 1979. Effects of dams and impoundments on migrations of juvenile Chinook salmon and steelhead from the Snake River, 1966 to 1975. Trans. Am. Fish Soc. 108: 505-529.

Rinne, J.N. 1988. Grazing effects on stream habitat and fishes: research design considerations. N. Am. J. Fish. Manage. 8: 240-247.

Rose, C. and W.G. Crumpton. 1996. Effects of emergent macrophytes on dissolved oxygen dynamics in a prairie pothole wetland. Wetlands 16: 495-502.

Ross, M.J. and J.D. Winter. 1981. Winter movements of four fish species near a thermal plume in Northern Minnesota. Trans. Am. Fish. Soc. 110: 14-18.

Rydberg, L, L. Elder, S. Floderus and W. Granéli. 1990. Interaction between supply of nutrients, primary production, sedimentation and oxygen consumption in SE Kattegat. Ambio 19: 134-141.

Sand-Jensen, K. 1989. Environmental variables and their effect on photosynthesis of aquatic plants communities. Aquatic Botany 34: 5-25.

Serafy, J.E., R.M. Harrell, and L.M. Hurley. 1994. Mechanical removal of *Hydrilla* in the Potomac River, Maryland: Local impacts on vegetation and associated fishes. Journal of Freshwater Ecology 9: 135-143.

Sheldon, S.S. 1986. The effects of short-term disturbance on a freshwater macrophyte community. J. Freshwater Ecol. 3: 309-317.

Shuter, B.J., D.A. Wismer, H.A. Regier and J.E. Matuszek. 1985. An application of ecological modelling: Impact of thermal effluent on a smallmouth bass population. Trans. Am. Fish. Soc. 114: 631-651.

Sinokrot, B.A. and J.S. Gulliver. 2000. In-stream flow impact on river water temperatures. Journal of Hydraulic Research 38:339-350.

Snucins, E.J. and J.M. Gunn. 1995. Coping with a warm environment: Behavioral thermoregulation by lake trout. Trans. Am. Fish. Soc. 124: 118-123.

Sosiak, A. 2002. Long-term response of periphyton and macrophytes to reduced municipal nutrient loading to the Bow River (Alberta, Canada). Can. J. Fish. Aquat. Sci. 59: 987-1001.

Sovell, L.A., B. Vondracek, J.A. Frost, K.G. Mumford. 2000. Impacts of rotational grazing and riparian buffers on physicochemical and biological characteristics of Southeastern Minnesota, USA, streams. Environ. Manage. 26: 629-641.

Spigarelli, S.A. R.M. Goldstein, W. Prepejchal and M.M. Thommes. 1982. Fish abundance and distribution near three heated effluents to Lake Michigan. Can. J. Fish. Aquat. Sci. 39: 305-315.

Steedman, R.J. 2003. Littoral fish response to experimental logging around small boreal shield lakes. N. Am. J. Fish. Manage. 23: 392-403.

Steedman, R.J. and R.S Kushneriuk. 2000. Effects of experimental clearcut logging on thermal stratification, dissolved oxygen, and lake trout (*Salvelinus namaycush*) habitat volume in three small boreal forest lakes. Can. J. Fish Aquat. Sci. 57(Suppl. 2): 82-91.

Steedman, R.J., R.S. Kushneriuk and R.L. France. 2001. Littoral water temperature response to experimental shoreline logging around small boreal forest lakes. Can. J. Fish. Aquat. Sci. 58: 1638-1647.

Travnichek, V.H, M.B. Bain and M.J. Maceina. 1995. Recovery of a warmwater fish assemblage after the initiation of a minimum-flow release downstream from a hydroelectric dam. Trans. Am. Fish. Soc. 124: 836-844.

Van den Avyle, M.J. and J.W. Evans. 1990. Temperature selection by striped bass in a Gulf of Mexico coastal river system. N. Am. J. Fish. Manag. 10: 58-66.

Ward, J.V. 1985. Thermal characteristics of running waters. Hydrobiologia 125: 31-46.

Webb, W.E. 1981. The relative importance of annual upland and sewage treatment plant point source nutrient loading on the summer oxygen regime of the tidal Potomac River, Maryland. Estuaries 4: 297.

Wichert, G.A. 1995. Effects of improved sewage effluent management and urbanization on fish associations of Toronto streams. N. Am. J Fish. Manage. 15:440-456.

Wile, I. 1978. Environmental effects of mechanical harvesting. J. Aquat. Plant Manage. 16: 14-20.

Williams, C., M.W. Perry, R. Post and G. Dombeck. 1999. Plant talk. Water Environment and Technology 11: 55-66.

Wohl, N.E. and R.F. Carline. 1996. Relations among riparian grazing, sediment loads, macroinvertebrates, and fishes in three central Pennsylvania streams. Can. J. Fish. Aquat. Sci. 53: 260-266.

APPENDIX I

COMMON AND SCIENTIFIC NAMES OF FISH

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Water Temperature	Effect on Biota
Loss/Damage of Riparian Vegetation → Change in Shade → Change in Water Temperature												
Bartholow, J.M. 2000. Estimating cumulative effects of clearcutting on stream temperatures. Rivers 7: 284-297.	Model	Freshwater	General	United States	NA	Lotic (stream)	NA	NA	NA	A model was developed using information on streams to determine the relative contribution of factors (including riparian vegetation removal) on water temperatures in streams.	The model indicated that riparian vegetation removal was the most influential factor affecting maximum daily water temperature, accounting for 40% of the total increase.	NA
Barton, D.R., W.D. Taylor and R.M. Biette. 1985. Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams. N. Am. J. Fish. Manage. 5: 364-378.	Field	Freshwater	Southern Ontario streams	Canada	Fish	Lotic (stream)	Large-bodied	Salmonidae	Various trout species	Examined relationships between riparian land use and environmental parameters (including temperature) that define suitability of streams for trout.	56% of the observed variation in weekly maximum water temperature could be explained by the presence of buffers upstream of sample sites.	Streams with a weekly maximum water temperature of less than 22°C supported trout. Higher temperature streams supported marginal trout populations at best.
France, R. 1997. Land-water linkages: influences of riparian deforestation on lake thermocline depth and possible consequences for cold stenotherms. Can. J. Fish Aquat. Sci. 54: 1299-1305.	Model	Freshwater	Northwestern Ontario lakes	Canada	Fish	Lentic (lake)	Large-bodied	Salmonidae	Cold stenotherms such as lake trout	Examined link between riparian deforestation and exposure of lake surfaces to stronger winds, and deepening of thermoclines and resulting habitat losses.	Thermal stratification patterns in 63 lakes showed that lakes where riparian tress had been removed had thermocline depths over 2 m deeper per unit fetch compared with lakes surrounded by mature forests.	Riparian tree removal considered to exacerbate hypolimnion habitat losses for cold stenotherms that are already occurring as a result of acidification, eutrophication and climate warming.
Fitch, L. and B.W. Adams. 1998. Can fish and cows co-exist? Canadian Journal of Plant Science. 78: 191-198.	Literature Review	Freshwater	Alberta streams	Canada	Fish	Lotic (stream)	Both	Community	NA	Comprehensive review paper that summarizes the results of many studies that considered the effects of livestock grazing on fish and fish habitat.	Review indicated that inappropriate livestock management results in overuse and subsequent degradation of riparian and stream ecosystems through increasing water temperatures in the water column (among other things).	Decreases in fish species and numbers consistently reported following overgrazing of riparian areas by livestock.
Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 45: 502-515.	Field	Freshwater	Carnation Creek, British Columbia	Canada	Fish	Lotic (stream)	Large-bodied	Salmonidae	Coho salmon	Water quality and fish populations were monitored prior to and following the clearcut logging of 41% of the watershed	Increases in stream temperatures were apparent in all months, but particularly high during the summer, when monthly stream temperatures were as much as 5°C warmer after logging.	Temperature increases were related to the earlier emergence of coho fry. The growth and recruitment was greater in fingerlings and yearling smolts migrated sooner.
Johnson, S.L. and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris in western Cascades, Oregon. Can. J. Fish. Aquat. Sci. 57(Suppl. 2): 30-39.	Field	Freshwater	streams in Western Cascades, Oregon	USA	NA	Lotic (stream)	NA	NA	NA	Historical stream temperature data was used to determine the effects of removal of riparian vegetation by logging on water temperatures.	Maximum stream temperatures increased 7°C after clear-cut and burning in one basin. Diurnal fluctuations in June increased from approximately 2 - 8°C.	NA
Macdonald, J.S., E.A. MacIsaac and H.E. Herunter. 2003. The effect of variable-retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. Can. J. For. Res. 33: 1371-1382.	Field	Freshwater	Streams in northern British Columbia	Canada	NA	Lotic (stream)	NA	NA	NA	Water temperatures were measured in streams that had riparian vegetation removed by three variable-retention harvesting treatments.	Five years after the completion of harvesting, temperatures remained 4-6°C warmer and diurnal temperature variation remained higher than in the control streams regardless of treatment.	NA
Mellina, E., R.D. Moore, S.G. Hinch, J.S. Macdonald, and G. Pearson. 2002. Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. Can. J. Fish. Aquat. Sci. 59: 1886-1900.	Field	Freshwater	streams in North-central British Columbia	Canada	NA	Lotic (stream)	NA	NA	NA	Temperature patterns of two subboreal outlet streams were examined before and after clearcut logging.	Modest changes (averaging 0.05-1.1°C) found in summer maximum and minimum temperatures, diurnal fluctuations and stream cooling.	NA
Sovell, L.A., B. Vondracek, J.A. Frost, K.G. Mumford. 2000. Impacts of rotational grazing and riparian buffers on physicochemical and biological characteristics of Southeastern Minnesota, USA, streams. Environ. Manage. 26: 629-641.	Field	Freshwater	Streams in southeastern Minnesota	United States	Macroinvertebrates and fish	Lotic (stream)	Both	NA	NA	The effect of rotational and continuous grazing and different types of riparian buffers was studied on water chemistry, physical habitat, benthic macroinvertebrates and fish, as indicators of stream quality.	It could not be determined whether there were any significant differences in temperature among sites.	Benthic macroinvertebrate metrics were not consistent among buffer types. Fish species richness was not related to different grazing practices and fish density was related to riparian buffer type, rather than grazing practice.
Steedman, R.J. 2003. Littoral fish response to experimental logging around small boreal shield lakes. N. Am. J. Fish. Manage. 23: 392-403.	Field	Freshwater	Boreal shield lakes, Northwestern Ontario	Canada	Fish	Lentic (lake)	Small-bodied	Cyprinidae	Various	The littoral fish community was studied to determine effects on fish biodiversity, abundance and average size prior to and following the experimental logging of 3 small lakes.	NA	An abundant and diverse littoral fish community persisted in the study lakes 5 years after logging. Changes to catch and average fish size were not linked with logging impacts.
Steedman, R.J. and R.S Kushneriuk. 2000. Effects of experimental clearcut logging on thermal stratification, dissolved oxygen, and lake trout (*Salvelinus namaycush*) habitat volume in three small boreal forest lakes. Can. J. Fish Aquat. Sci. 57(Suppl. 2): 82-91.	Field	Freshwater	Boreal shield lakes, Northwestern Ontario	Canada	NA	Lentic (lake)	NA	NA	NA	Examined the effects of experimental catchment deforestation on thermal stratification in 3 small lake trout lakes.	Late-summer thermoclines were about 1 m shallower in 2 lakes after logging, but it was not possible to exclude weather as a factor. None of the lakes showed significant declines in lake trout habitat volume.	
Steedman, R.J., R.S. Kushneriuk and R.L. France. 2001. Littoral water temperature response to experimental shoreline logging around small boreal forest lakes. Can. J. Fish. Aquat. Sci. 58: 1638-1647.	Field	Freshwater	Boreal shield lakes, Northwestern Ontario	Canada	NA	Lentic (lake)	NA	NA	NA	Water quality was studied prior to and following the complete removal of riparian vegetation around a lake using experimental logging practices.	Logging did not significantly increase average littoral water temperature. However, clear-cut shorelines were associated with 1 -2°C in maximum water temperature and increases of 0.3 - 0.6°C in average diurnal temperature range compared to buffered shorelines.	NA
Wohl, N.E., R.F. Carline. 1996. Relations among riparian grazing, sediment loads, macroinvertebrates, and fishes in three central Pennsylvania streams. Can. J. Fish. Aquat. Sci. 53: 260-266.	Field	Freshwater	Streams in central Pennsylvania	United States	Macroinvertebrates and fish	Lotic (stream)	Both	Community	10 species	The fish community and water temperatures were compared between sites with and without riparian vegetation impacted by livestock grazing	Absence of riparian shading contributed to high summer temperatures (no data provided).	In one stream, the variation in trout density was not related to grazing. In the another stream, the highest density was found in an ungrazed reach .

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Water Temperature	Effect on Biota
Increase in Riparian and Bank Vegetation → Change in Shade → Change in Water Temperature												
Ebersole, J.L. 2003. Cold water patches in warm streams: Physicochemical characteristics and the influence of shading. Journal of the American Water Resources Association. 39:355-368.	Field	Freshwater	Streams in northeastern Oregon	United States	Na	Lotic (stream)	NA	NA	NA	A shading experiment was conducted to determine how shade, simulating riparian cover, influenced temperatures in existing coldwater patches in seasonally warmed streams.	Experimental shading cooled daily maximum temperatures of surface waters 2 - 4°C within cold patches.	NA
Johnson, S.L. 2004. Factors influencing stream temperatures in small streams and a shading experiment. Can. J. Fish Aquat. Sci. 61: 913-923.	Field	Freshwater	Stream in Oregon Cascades	United States	NA	Lotic (stream)	NA	NA	NA	A shading experiment was conducted to determine how water temperatures varied in shaded areas and non-shaded areas. Shading was used to simulate riparian cover.	Maximum stream temperatures significantly decreased during experimental shading of the water surface of a 150-m reach. Maximum water temperature at the lower end of the reach was up to 1°C lower than at the upstream site.	NA
Johnson, S.L. and J.A. Jones. 2000. Stream temperature responses to forest harvest and debris in western Cascades, Oregon. Can. J. Fish. Aquat. Sci. 57(Suppl. 2): 30-39.	Field	Freshwater	Oregon	USA	NA	Lotic (stream)	NA	NA	NA	Historical stream temperature data and re-established study sites were used to determine the recovery of stream temperatures following removal of riparian vegetation by logging.	Stream temperatures returned to preharvest levels approximately 15 years after clearcutting, coinciding with canopy closure in the riparian zone.	NA
Liquori, M. and C.R. Jackson. 2001. Channel response from shrub dominated riparian communities and associated effects on salmonid habitat. Journal of the American Water Resources Association. 37:1639-1652.	Field	Freshwater	Streams in the Cascades, Washington	United States	NA	Lotic (stream)	NA	NA	NA	Stream water temperatures were compared between sections of a stream with different types of riparian cover present (forested canopy and scrub-shrub).	Summer water temperatures were lower in areas of the stream with scrub-shrub vegetation than in areas with forested vegetation (1.5-4°C cooler), even when average shade values were similar. This demonstrated variation in cooling effects of different types of riparian vegetation.	NA
Platts, W.S. and R.L. Nelson. 1985. Stream habitat and fisheries response to livestock grazing and instream improvement structures, Big Creek, Utah. Journal of Soil and Water Conservation. 40: 374-379.	Field	Freshwater	Big Creek, Northeastern Utah	United States	Fish	Lotic (stream)	Both	Salmonidae, Cottidae and Catostomidae	Rainbow trout, Yellowstone cutthroat trout, brook trout, mottled sculpin and sucker	A study was conducted to determine how decreased livestock grazing and stream improvement structures would influence riparian vegetation and fish communities in the nearby stream.	Water quality was not measured in this study.	Decreased grazing resulted in increases to riparian vegetation, but no effect on fish was detected.
Rinne, J.N., 1988. Grazing effects on stream habitat and fishes: research design considerations. N. Am. J. Fish. Manage. 8: 240-247.	Field	Freshwater	Rio de las Vacas, New Mexico	United States	Fish	Lotic (stream)	Both	Salmonidae, Cyprinidae and Catostomidae	Brown trout, Rio Grande chub, Rio Grande sucker	Water quality and fish communities were measured and compared at locations where riparian areas were impacted by cattle grazing and in areas where cattle exclusion had permitted riparian vegetation recovery.	Lower water temperatures were measured in ungrazed areas (0 -14°C) than in grazed areas (2 -22°C).	Fish populations were unaffected by changes to riparian cover.
Addition or Removal of Aquatic Vegetation → Change in Light Penetration → Change in Water Temperature												
Carter, V., J.W. Barko, G.L. Godshalk and N.B. Rybicki. 1988. Effects of submersed macrophytes on water quality in the tidal Potomac River, Maryland. J. Freshwat. Ecol. 4: 493-501.	Field	Freshwater	Potomac River, Maryland	United States	Macrophyte	Tidal river	NA	NA	NA	Water quality parameters were measured and compared between sites with and without submerged macrophytes at very high population densities in the tidal Potomac River.	Water temperature increased during the day with the steepest vertical gradients and maximum reading occurring within the macrophyte bed during midafternoon at low tide. Thermal stratification occurred in vegetated sites when water was slow moving.	NA
Mitchell, CP, G.R. Fish and A.M.R. Burnet. 1984. Limnological changes in a small lake stocked with grass carp. New Zealand Journal of Marine and Freshwater Research. 18: 103-114.	Field	Freshwater	Parkinson's Lake, North Island	New Zealand	Macrophyte	Lentic (lake)	NA	NA	NA	Monitored water quality in Parkinson's Lake, New Zealand following the introduction of grass carp and subsequent removal of macrophytes.	Over 2 years of monitoring, no significant changes in temperature were found as a result of the elimination of aquatic plants by grass carp.	NA
O'Neill Morin, J. and K.D. Kimball. 1983. Relationship of macrophyte-mediated changes in the water column to periphyton composition and abundance. Freshwat. Biol. 13: 403-414.	Field	Freshwater	Lake Winnipesaukee, New Hampshire	United States	Macrophyte	Lentic (lake)	NA	NA	NA	Temperature in the water column was measured and considered as a function of seasonal changes to aquatic vegetation density.	Elevated surface temperatures were observed from June to September when submergent vegetation reached the surface. At this time surface and bottom water temperatures generally differed by 1-3°C in the vegetation stands.	NA
Rose, C. and W.G. Crumpton. 1996. Effects of emergent macrophytes on dissolved oxygen dynamics in a prairie pothole wetland. Wetlands. 16: 495-502.	Field	Freshwater	Goose Lake Marsh, Central Iowa	United States	Macrophyte	Wetland	NA	NA	NA	Surveys examined patterns of light availability, temperature and dissolved oxygen concentrations within and outside emergent vegetation zones in a natural prairie pothole wetland.	Water column light availability was less than 2% of ambient light in vegetated areas due to canopy cover. Water temperature was significantly lower and varied less diurnally in vegetated areas.	NA
Williams, C., M.W. Perry, R. Post and G. Dombeck. 1999. Plant talk. Water Environment and Technology. 11: 55-66.	Laboratory	Freshwater	Construction wetland in California	United States	Macrophyte	Wetland	NA	NA	NA	Water quality (including temperature) parameters were compared between plots in a constructed wetland to determine how the parameters varied with vegetation biomass.	An annual average temperature reduction of -12°C was observed in the vegetated wetland cells in 1996 and a reduction of -13°C in 1997.	NA

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Water Temperature	Effect on Biota
Wile, I. 1978. Environmental effects of mechanical harvesting. J. Aquat. Plant Manage. 16: 14-20.	Field	Freshwater	Southern Chemong Lake, Ontario	Canada	Macrophyte	Lentic (lake)	NA	NA	NA	An experimental aquatic plant harvesting program was initiated to remove excessive growths of aquatic vegetation in a southern Ontario lake.	Temperature differences between the surface and bottom strata in the lake were less than 1°C. No comparison was made to pre- and post-harvest temperatures.	NA
Alterations of Groundwater Flows to Surface Waters → Change in Water Temperature												
Cunjak, R.A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Can. J. Fish. Aquat. Sci. 43: 1970-1981.	Field	Freshwater	Credit River, Southern Ontario	Canada	Fish	Lotic (stream)	Large-bodied	Salmonidae	Brook trout and brown trout	Observational study describes winter habitat and behaviour of brook trout and brown trout.	Groundwater created "winter-warm" microhabitats in streams during the colder months of the year.	Large numbers of brook trout and brown trout ("aggregations") were found at locations with groundwater seepage during the winter.
Garrett, J.W., D.H. Bennett, F.O. Frost and R.F. Thurow. 1998. Enhanced incubation success for kokanee spawning in groundwater upwelling sites in a small Idaho stream. N. Am. J. Fish. Manag. 18: 925-930.	Field	Freshwater	North Fork of the Payette River, Idaho	United States	Fish	Lotic (stream)	Large-bodied	Salmonidae	Kokanee	Compared preemergent survival and physical parameters of kokanee redds in upwelling areas with redds without groundwater inflow.	Water temperatures at the water-substrate interface ranged from 0.2-0.4°C for all sites. Intragravel temperatures were 2.6 and 2.8°C at sites with groundwater upwelling.	Preemergent survival from sites with groundwater upwelling significantly exceeded that from redds in other areas. Higher incubation temperatures at upwelling sites accelerated rates of development, protected embryos from freezing and may increase survival.
Gibson, R.J. 1966. Some factors influencing the distribution of brook trout and young Atlantic Salmon. J. Fish. Res. Board Can. 23: 1977-1980.	Field	Freshwater	Northwest Miramichi River, New Brunswick	Canada	Fish	Lotic (stream)	Large-bodied	Salmonidae	Brook trout and Atlantic Salmon	Comparison of habitat preferences were made between juvenile Atlantic salmon and brook trout. Habitat characteristics included the presence of groundwater seepage which had a cooling effect on surface water.	Areas with spring seepage had water temperatures of 17°C compared to >22°C temperatures of surface water, demonstrating the local cooling influence of groundwater.	Salmon parr moved toward the source of spring seepage when water temperatures exceeded 22°C. Parr grouped in cooler seepage water and oriented themselves towards the source of seepage. Groundwater created cooled local areas of the stream providing thermal refugia.
Hansen, E. 1975. Some effects of groundwater on brown trout redds. Trans. Amer. Fish. Soc. 1: 100-110.	Field	Freshwater	Poplar Creek, lower Michigan	United States	Fish	Lotic (stream)	Large-bodied	Salmonidae	Brown trout	Measured habitat parameters associated with areas of groundwater seepage and tracked the movement of brown trout and their redds relative to seepage areas in the stream. Egg hatching times were measured as a function of percentage groundwater seepage in the redds.	Groundwater temperatures were between 8.5 - 10°C. In the winter when surface water temperature was 0°C, redd temperatures were measured at 0°C and warmer due to groundwater flow. Water temperature ranged from 1 - 7°C where surface water-groundwater mixing occurred in the stream bed.	Brown trout redds had higher and less variable temperatures as the percentage of groundwater to surface water increased. The higher percentage of groundwater led to earlier egg hatching.
Snucins, E.J. and J.M. Gunn. 1995. Coping with a warm environment: Behavioral thermoregulation by lake trout. Trans. Am. Fish. Soc. 124: 118-123.	Field	Freshwater	Pedro and Whitepine lakes near Sudbury, Ontario	Canada	Fish	Lentic (lake)	Large-bodied	Salmonidae	Lake trout	Monitored the behavioural response of lake trout to naturally elevated summer water temperatures in two small lakes. Observations were made of their use of nearshore groundwater discharge as refugia in the summer.	Groundwater emerged from the source at 10°C providing a refuge area located in shallow water that was approximately 30 m^2 with temperatures <15°C. This was cooler than the hypolimnion which had temperatures exceeding 16°C during the summer.	Nearshore groundwater seepage provided refugia for lake trout when ambient lake temperatures exceeded the preferred thermal range of 6-13°C. Lake trout remained in the groundwater seepage area at night and left during the day.
Van den Avyle, M.J. and J.W. Evans. 1990. Temperature selection by striped bass in a Gulf of Mexico coastal river system. N. Am. J. Fish. Manag. 10: 58-66.	Field	Freshwater	Apalachicola River system, Gulf of Mexico	United States	Fish	Lotic (stream)	Large-bodied	Moronidae	Striped bass	Determined behavioural responses and temperature preferences of adult striped bass in the Apalachicola River system.	When surface waters warmed to ~24°C in May, water in five spring discharges was 19-20°C. In January when ambient temperatures declined to 5-8°, temperature at a spring-fed site was ~15.4°C.	Striped bass moved into spring-fed areas when temperatures warmed to 23-25°C and left when temperatures cooled to 17-23°C in the fall. Movement into spring-fed areas in winter may indicate avoidance of cold water. Springs considered critical habitats that should be protected.
Thermal Loading → Change in Water Temperatures → Alterations of Currents, Thermocline → Change in Migration/Access to Habitat												
Cooke, S.J, J.F. Schreer, D.P. Philipp and P.J. Weatherhead. 2003. Nesting activity, parental care behavior, and reproductive success of smallmouth bass, *Micropterus dolomieu* , in an unstable thermal environment. J. Therm. Biol. 28: 445-456.	Field	Freshwater	Lake Erie, southern Ontario	Canada	Fish	Lentic (lake)	Large-bodied	Centrarchidae	Smallmouth bass	A study was conducted in a thermal effluent canal at Nanticoke Generating Station to examine the influence of fluctuating thermal regimes on the reproductive success of smallmouth bass.	Mean daily water temperature fluctuation in the effluent was 5.4°C, compared to 1.7°C in the lake.	Smallmouth bass nesting in the effluent canal exhibited behavioural alterations, but had high reproductive success compared to other published values for bass.
Galloway, M.L. 1991. Age and growth of largemouth bass and temporal and spatial movements of fishes in thermally enriched Flint Creek Cooling Reservoir. Dissertation Abstracts International Part B: Science and Engineering. 51(11): 140.	Laboratory & field	Freshwater	Flint Creek Reservoir, Arkansas	United States	Fish	Reservoir	Large-bodied	Centrarchidae, Ictaluridae	Largemouth bass, black bullhead, channel catfish	Examined the relationship between the ratio of power output to reservoir surface area and growth of fish. Water temperatures and patterns within the reservoir are presented.	The one year water temperature mean (upper 4 m), of Flint Creek Reservoir was 29°C, indicating that thermal effluent can affect up to 100% of the reservoir to depths in excess of 4 m. The average horizontal thermal gradient, from the hot water outlet to the make-up water outlet by the dam, was 8°C. Vertical thermal gradients were observed with a maximum of 20°C in 1 m.	Largemouth bass were highly mobile and made local and intra-reservoir movements consistent with their thermal preferendum. Large adult bass moved less than juveniles, except in summer when the adults abandoned their territories to migrate to thermal refuge stations. Black bullheads concentrated in summer thermal refuges but channel catfish did not.

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Water Temperature	Effect on Biota
Ginot, V., Y. Souchon and P. Roger. 1996. Impact of thermal loading induced by the Bugey nuclear power plant (upper Rhône River, France) on fish catches and on fish population structure. Hydroécol. 8(1-2):1-33.	Field	Freshwater	Rhône River	France	Fish	Lotic (stream)	Both	Community	All	Examined fish catches and structure of fish populations in relation to thermal loading due to the operation of the Bugey nuclear power plant.	Water was warmed by approximately 10°C.	Fish moved away as temperatures increased and that by 29°C diversity was non-existent near the outfall. Several thermal groups of fish were defined, i.e. below 6°C, 7-24°C, and >25°C.
Haag, R.W. and P.R. Gorham. 1977. Effects of thermal effluent on standing crop and net production of *Elodea canadensis* and other submerged macrophytes in lake Wabamun, Alberta. Journal of Applied Ecology. 14: 835-851.	Field	Freshwater	Lake Wabamun, Alberta	Canada	Macrophytes	Lentic (lake)	NA	NA	NA	The effects of thermal effluent were studied on submerged macrophytes in Lake Wabamun, Alberta.	During the winter, water was discharged at 25°C; in the summer, water is discharged at 27-32°C. Heated water forms a thin layer on the surface which averages 7°C warmer then ambient surface water temperature.	Changes in species composition and earlier spring growth of macrophytes occurred in the heated area of the lake. Information on water temperatures associated with effluent discharge are presented.
Jones, G.K, J.L. Baker, K. Edyvane and G.J. Wright. 1996. Nearshore fish community of the Port River-Barker Inlet Estuary, South Australia. I. Effect of thermal effluent on the fish community structure, and distribution and growth of economically important fish species. Marine and Freshwater Research. 47: 785-799.	Field	Marine	Port-River Barker Inlet Estuary, South Australia	Australia	Fish	Estuary	Both	Community	41 species	The nearshore fish community af an estuary was sampled to determine the effect of thermal effluent on the community structure and nursery function of estuary.	Water temperatures were increased within the vicinity of the outflow source.	Effects included decreasing numbers of species with decreasing distance from the thermal outfall, and increased growth rates of some species. During the summer/autumn period, certain species avoided the warmed estuary. In the winter/spring period, thermal effluent had the opposite effect and attracted these species.
Kelso, J.R.M. 1974. Influence of a thermal effluent on brown bullhead (*Ictalurus nebulosus*) as determined by ultrasonic tracking. J. Fish. Res. Board Can. 31: 1507-1523.	Field	Freshwater	Lake Ontario, southern Ontario	Canada	Fish	Lentic (lake)	Large-bodied	Ictaluridae	Brown bullhead	Brown bullhead were tracked to determine the effect of thermal discharge on their movement	Within 200 m of shore, temperature was generally homogeneous over depth and varied between 16 and 26°C.The thermal plume was stretched along the shoreline or located in the southern area of the tracked area.	Fish in the plume swam at lower speeds, milled more and turned more then fish in the control site, indicating that thermal discharges can interrupt or alter the normal movement patterns of brown bullhead.
Luksiene, D., O. Sandstroem, L. Lounasheimo and J. Andersson. 2000. The effects of thermal effluent exposure on the gametogenesis of female fish. J. Fish Biol. 56: 37-50.	Field	Freshwater	Thermal effluent areas	Sweden and Lithuania	Fish	Lentic (lake)	Both	Esocidae, Percidae and Rutilus	Northern pike, perch and roach	A study was conducted to determine the effect of thermal effluent exposure on gametogenesis in several species of fish.	High temperature thermal effluent at source of outflow.	Negative effects were found on gametogenesis of female perch, roach and northern pike, indicating a trade-off between temperature preference and reproductive success.
Minns, C.K., J.R.M. Kelso and W. Hyatt. 1978. Spatial distribution of nearshore fish in the vicinity of two thermal generating stations, Nanticoke and Douglas Point, on the Great Lakes. J. Fish. Res. Board Can. 35: 885-892.	Field	Freshwater	Lake Erie and Huron, Ontario	Canada	Fish	Lentic (lake)	Both	Community	All	Used digital acoustic fish enumeration to study the distribution of fish in the vicinity of two thermal generating stations on the Great Lakes.	At Nanticoke, temperature increase averaged between 0.4 and 3.9°C. At Douglas Point, daily temperature rise was 7.1-13.6°C.	No evidence of altered fish communities in relation to temperature. At Douglas Point, there was thermal stratification present in the summer, but no apparent response in vertical distribution.
Rasmussen, J.B. 1982. The effect of thermal effluent, before and after macrophyte harvesting, on standing crop and species composition of benthic macrophyte communities in Lake Wabamun, Alberta. Can. J. Zool. 60: 3196-3205.	Field	Freshwater	Lake Wabamun, Alberta	Canada	Macrophytes	Lentic (lake)	NA	NA	NA	Benthic macroinvertebrate communities were compared between heated and unheated stations in Lake Wabamun.	Temperatures at heated stations exceeded control stations.	Benthic macroinvertebrate community composition different in the heated areas of Lake Wabamun, compared to the moderately heated and unheated parts of the lake.
Ross, M.J. and J.D. Winter. 1981. Winter movements of four fish species near a thermal plume in Northern Minnesota. Trans. Am. Fish. Soc. 110: 14-18.	Field	Freshwater	Upper Mississippi River, Minnesota	United States	Fish	Lotic (stream)	Large-bodied	Percidae, Esocidae and Centrarchidae	Yellow perch, northern pike, walleye and largemouth bass	Winter movements of fish were monitored near the thermal plume of a power plant.	Designed 15°C elevation of temperature between intake and temperature. Actual discharge temperatures ranged from 6-18°C during the study.	All species except largemouth bass moved freely between discharge-affected and unaltered waters. Northern pike and yellow perch had home ranges larger than the discharge area. Largemouth bass preferred warmest locations near the discharge point.
Shuter, B.J., D.A. Wismer, H.A. Regier and J.E. Matuszek. 1985. An application of ecological modelling: Impact of thermal effluent on a smallmouth bass population. Trans. Am. Fish. Soc. 114: 631-651.	Field and modelling	Freshwater	Baie du Doré, Lake Huron, Ontario	Canada	Fish	Lentic (lake)	Large-bodied	Centrarchidae	Smallmouth bass	Reported on a 20-year integrated field, laboratory and simulation study on the impact of thermal effluent on the smallmouth bass population.	Different thermal regimes and plume dynamics in the model from preoperational and postoperational recorded temperatures.	The discharge area attracts YOY and adults during summer and early fall, but no evidence of major shift in areas frequented by YOY in early summer. There was no significant change in the location of nesting or nursery areas.
Spigarelli, S.A. R.M. Goldstein, W. Prepejchal and M.M. Thommes. 1982. Fish abundance and distribution near three heated effluents to Lake Michigan. Can. J. Fish. Aquat. Sci. 39: 305-315.	Field	Freshwater	Lake Michigan	United States	Fish	Lentic (lake)	Both	Community	All	Combined echo location-temperature mapping technique was used to determine the abundance and distribution of fish with depth and temperature in locally heated and unheated areas.	The temperature increases at the three power plants were ~10.7°C (Point Beach), ~11°C (Zion) and ~7°C (Waukegan).	Temperatures selected by fish in plume areas were 1-3°C higher than maximum ambient temperatures. Fish densities varied seasonally and distribution was similar with depth.
Change in Timing, Duration and Frequency of Flow → Change in Water Temperature												
Edwards, R.J. 1978. The effect of hypolimnion reservoir releases on fish distribution and species diversity. Trans. Am. Fish. Soc. 107: 71-77.	Field	Freshwater	Canyon Reservoir, Texas	United States	Fish	Lotic (stream)	Both	Various	22 species	Fish faunas were surveyed above and below the reservoir to determine the effect of the impoundment on downstream community.	Average maximum stream temperatures above the reservoir were 29.6° and 19.7°C below.	22 species were found above the reservoir, but only 18 downstream of the dam, showing decreased diversity. Changes in downstream temperature due to hypolimnetic water releases were considered to be the causal factor.

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Water Temperature	Effect on Biota
Farquhar, B.W. and S. Gutreuter. 1989. Distribution and migration of adult striped bass in Lake Whitney, Texas. Trans. Am. Fish. Soc. 118: 523-532.	Field	Freshwater	Lae Whitney, Texas	United States	Fish	Reservoir	Large-bodied	Moronidae	Striped bass	Considered seasonal distribution and migration patterns of striped bass in relation to water temperatures in the reservoir.	Deepwater discharge from the dam added cooler water into the reservoir.	In spring and summer, white striped bass were distributed in areas with temperatures <26°C and dissolved oxygen levels >4 mg/L. Due to cool water discharge, this area was usually restricted to locations within 15 km of the dam.
Graham, R.J. and D.J. Orth. 1986. Effects of temperature and streamflow on time and duration of spawning by smallmouth bass. Trans. Am. Fish. Soc. 115: 693-702.	Field	Freshwater	New River, Virginia and West Virginia	United States	Fish	Lotic (stream)	Large-bodied	Centrarchidae	Smallmouth bass	Influences of water temperature and discharge variables were evaluated on the timing of duration of smallmouth bass spawning, in regulated and unregulated streams.	Man daily water temperatures when spawning occurred were 12.5-23.5°C. Water temperatures were slightly warmer at the sites with surface water releases.	Mean daily water temperature, and not discharge variables, was the single most important variable in controlling smallmouth bass spawning time, in both regulated and unregulated systems.
Lessard, J.L. and D.B. Hayes. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Research and Applications 19: 721-732.	Field	Freshwater	Streams in lower Michigan	United States	Macroinvertebrates and fish	Lotic (stream)	Both	Salmonidae and Cottidae	Brown trout, slimy sculpin, mottled sculpin	Examined the effects of elevated summer temperature increases from small dams on fish and macroinvertebrate communities.	Changes in mean summer temperature downstream of the dam varied from 1°C cooler to >5°C warmer.	Increased temperatures below the dam coincided with lower densities of several coldwater fish species, while fish richness improved downstream. Macroinvertebrates showed shifts in community composition.
Paragamian, V.L. 1999. The effects of variable flows and temperature on burbot spawning migrations in the Kootenai River, Idaho, USA, and Kootenay Lake, British Columbia, Canada, post Libby Dam. Biology and Management of Burbot. pp. 121-139.	Field	Freshwater	Kootenai River, Idaho, Kootenay Lake, BC	United States/ Canada	Fish	Lotic (stream)	Large-bodied	Gadidae	Burbot	This study considers the effects of variable flows and temperature on burbot spawning migrations in the Kootenai River, Idaho.	Warmer winter water and more erratic flow occurred downstream of the dam. The Kootenai River was found to be 4°C in the winter (1994-1995) compared to the nearby Goat River (1°C).	Fluctuations in flow were found to affect burbot spawning. Warmer winter temperatures in the Kootenai River may not have affected spawning, but burbot were attracted to the colder water of Goat River over the warmer water of the Kootenai River.
Quinn, T.P. and D.J. Adams. 1996. Environmental changes affecting the migratory timing of American shad and sockeye salmon. Ecology. 77: 1151-1162.	Field	Freshwater	Columbia River	United States	Fish	Lotic (stream)	Large-bodied	Clupeidae, Salmonidae	American shad, sockeye salmon	Compared environmental changes in the Columbia River with adaptation of an introduced population and the response of established populations.	The river's spring warming has occurred progressively earlier since ~1950, coinciding with a reduction in spring discharge.	Shad ascend the river ~38 days earlier than 1938 and progressively earlier arrivals of sockeye salmon occur at Bonneville Dam.
Quinn, T.P, S. Hodgson and C. Peven. 1997. Temperature, flow, and the migration of adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River. Can. J. Fish. Aquat. Sci. 54: 1349-1360.	Field	Freshwater	Columbia River, Snake River	United States	Fish	Lotic (stream)	Large-bodied	Salmonidae	Sockeye salmon	Related arrival timing of adult sockeye salmon at a series of dams in the Columbia and Snake rivers to the changing flows and temperature regimes over the last several decades.	The decreases in flow caused earlier spring warming to (>15.5°C, 15 days earlier), higher June and July temperatures (mean 1.5°C and maximum 1.2°C), and later fall cooling (<15.5°C, 12 days later).	Progressively earlier arrivals occurred of sockeye salmon at dams to spawn and increased travel rates.

Pathways of Effects Literature Review - Changes in Dissolved Oxygen Endpoint

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Dissolved Oxygen	Effect on Biota
Addition or Removal of Aquatic Vegetation → Change in Light Penetration → Change in Dissolved oxygen												
Carter, V., J.W. Barko, G.L. Godshalk and N.B. Rybicki. 1988. Effects of submersed macrophytes on water quality in the tidal Potomac River, Maryland. J. Freshwat. Ecol. 4: 493-501.	Field	Freshwater	Potomac River, Maryland	United States	Macrophyte	Tidal river	NA	NA	NA	Water quality parameters were measured and compared between sites with and without submerged macrophytes at very high population densities in the tidal Potomac River.	Diurnal fluxes in dissolved oxygen and stratification observed at all stations. DO stratification was greatest at vegetated stations. Extremely large variations in DO were observed and likely related to the high biomass of vegetation in the system.	NA
Hannan, H.H. and B.T. Anderson. 1971. Predicting the diel oxygen minimum in ponds containing macrophytes. Progve Fish Cult. 33: 45-47.	Field	Freshwater	Experimental ponds at Southwest Texas State University	Texas	Macrophyte	Ponds	NA	NA	NA	The oxygen balance in two ponds, one with a higher macrophyte growth, was studied on a seasonal basis.	Both ponds showed a daily dissolved oxygen pulse and similarities in their minimal and maximal DO content.	NA
Jorga, W and G. Weise. 1977. Growth of submerged macrophytes in slow-flowing streams in relation to the oxygen balance. Internationale Revue der Gesamten Hydrobiologie. 62: 209-234.	Field	Freshwater	Kleine Elster River	Germany	Macrophyte	Lotic (stream)	NA	NA	NA	Biomass of submerged macrophytes and dissolved oxygen were measured in a slow-moving stream with dense growths of photosynthetic plants.	Photosynthetic oxygenation was a function of biomass and light intensity up to a biomass of 250 g (dry wt)/m^2, but crops above this level caused a decrease in DO. In autumn, the oxygen balance was adversely affected by dying plants, decreased flow and other factors.	NA
Mitchell, CP, G.R. Fish and A.M.R. Burnet. 1984. Limnological changes in a small lake stocked with grass carp. New Zealand Journal of Marine and Freshwater Research. 18: 103-114.	Field	Freshwater	Parkinson's Lake, North Island	New Zealand	Macrophyte	Lentic (lake)	NA	NA	NA	Monitored water quality in Parkinson's Lake, New Zealand following the introduction of grass carp and subsequent removal of macrophytes.	Over 2 years of monitoring, no significant changes in dissolved oxygen were found as a result of the elimination of aquatic plants by grass carp.	NA
O'Neill Morin, J. and K.D. Kimball. 1983. Relationship of macrophyte-mediated changes in the water column to periphyton composition and abundance. Freshwat. Biol. 13: 403-414.	Field	Freshwater	Lake Winnipesaukee, New Hampshire	United States	Macrophyte	Lentic (lake)	NA	NA	NA	Dissolved oxygen in the water column was measured and considered as a function of seasonal changes to aquatic vegetation density.	In the macrophyte stands, DO decreased with depth. Maximum DO levels from June -Sept. occurred at 0-0.6 m depth (107%) and declined rapidly below 1.3 m (84% at 1.9 m).	NA
Rose, C. and W.G. Crumpton. 1996. Effects of emergent macrophytes on dissolved oxygen dynamics in a prairie pothole wetland. Wetlands. 16: 495-502.	Field	Freshwater	Goose Lake Marsh, Central Iowa	United States	Macrophyte	Wetland	NA	NA	NA	Examined spatial and temporal dynamics of water column dissolved oxygen within and outside emergent vegetation zones in a natural prairie pothole wetland.	Sites with emergent macrophytes were generally anoxic until the marsh began to freeze in November, whereas open water sites were rarely anoxic, even at night. DO concentrations were significantly lower and varied less diurnally in vegetated areas..	NA
Williams, C., M.W. Perry, R. Post and G. Dombeck. 1999. Plant talk. Water Environment and Technology. 19: 55-66.	Laboratory	Freshwater	Construction wetland in California	United States	Macrophyte	Wetland	NA	NA	NA	Water quality (including dissolved oxygen) parameters were compared between plots in a constructed wetland to determine how the parameters varied with vegetation biomass.	The presence of large macrophytes reduced water-column dissolved oxygen in the wetlands.	NA
Wile, I. 1978. Environmental effects of mechanical harvesting. J. Aquat. Plant Manage. 16: 14-20.	Field	Freshwater	Southern Chemong Lake, Ontario	Canada	Macrophyte	Lentic (lake)	NA	NA	NA	An experimental aquatic plant harvesting program was initiated to remove excessive growths of aquatic vegetation in a southern Ontario lake.	Oxygen concentrations rarely fell below 80% saturation and changes with depth were minimal.	`
Thermal Loading → Change in Dissolved Oxygen Concentration												
Eloranta, P.V. 1983. Physical and chemical properties of pond waters receiving warm-water effluent from a thermal power plant. Water Research 17: 133-140.	Field	Freshwater	Vasikkalampi Pond	Finland	NA	Lentic (lake)	NA	NA	NA	The physical and chemical properties of pond waters receiving warm-water effluent from a thermal power plant were studied over a 2 year period.	The oxygen concentration in the water layers near the bottom appeared to be closely related to the thermal stratification. Early and prolonged chemical and thermal stratification occurred (April-October).	Increased phytoplankton growth was evident in February.
Kailasam, M. and S. Sivakami. 2004. Effect of thermal effluent discharge on benthic fauna off Tuticorin Bay, south east coast of India. Indian J. Mar. Sci. 33: 194-201.	Field	Marine	Tuticorin Bay	India	Benthic invertebrates	Bay	NA	NA	NA	Studied the effects of thermal effluent discharge on water quality and benthic fauna over a period of two years.	The thermal effluent was characterized by low dissolved oxygen (surface mean 3.79 mg/L)	The closest site showed the lowest benthic population density and species diversity; some benthic species eliminated at this site, and survival of fewer organisms.

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Dissolved Oxygen	Effect on Biota
Lessard, J.L. and D.B. Hayes. 2003. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Research and Applications 19: 1535-1459.	Field	Freshwater	Michigan	United States	Macroinvertebrates and fish	Lotic (stream)	Both	Salmonidae and Cottidae	brown trout, slimy sculpin, mottled sculpin	Measured water quality above and below dams.	Dissolved oxygen concentrations were always >80% saturation and did not significantly differ below the dams.	Increased temperatures below the dam coincided with lower densities of coldwater fish.
McNeely, D.L. and W.D. Pearson. 1974. Distribution and condition of fishes in a small reservoir receiving heated waters. Trans. Am. Fish. Soc. 103: 518-530.	Field	Freshwater	North Lake, Texas	United States	Fish	Reservoir	Both	Community	NA	Determined effects of a thermal effluent on the distribution and condition of fish within a reservoir.	DO concentrations were adequate for fish throughout the study. Surface DO ranged from 6.1-10.2 mg/L and bottom DO from 4.7-10.0 mg/L. No serious depletion of DO was found at either the surface or the bottom at either station.	Of the 30 species of fish, none were positively influenced by the effluent, although 2 forage species were absent or rare from the outfall area. Some species may have been attracted to the effluent area in the summer. The size and condition of fish from the outfall area did not differ significantly from those at other stations.
Nutrient Loading → Change in Dissolved Oxygen Concentration												
Breitburg, D.L., A. Adamack, K.A. Rose, S.E. Kolesar, M.B. Decker, J.E. Purcell, J.E. Keister and J.H. Cowan Jr. 2003. The pattern and influence of low dissolved oxygen in the Patuxent River, a seasonally hypoxic estuary. Estuaries 26: 280-297.	Field and modelling	Estuarine	Patuxent River, Chesapeake Bay, Maryland	United States	Fish	Stream and estuary	Both	Engraulididae	Anchovy eggs	The effect of increased nutrient loadings and oxygen depletion on hypoxia-induced mortality of fishes in the Patuxent River was studied.	Nutrient loadings have resulted in low dissolved oxygen concentrations in the bottom waters, with bottom waters in much of the river below 50% DO saturation during summer (e.g., 1-2.9 mg/L). The system is characterized by high spatial and temporal variations in DO concentrations.	Modelling predicted high mortality of anchovy eggs under current dissolved oxygen levels and increasing survival of fish eggs with increasing DO. Increases to DO were predicted to occur under conditions of reduced nutrient loading.
Chambers, P.A., G.J. Scrimgeour and A. Pietroniro. 1997. Winter oxygen conditions in ice-covered rivers: the impact of pulp mill and municipal effluents. Can. J. Fish. Aquat. Sci. 54: 2796-2806.	Field	Freshwater	Athabasca River, Alberta	Canada	NA	Lotic (stream)	NA	NA	NA	To assess the impact of pulp mill and municipal effluents on under-ice oxygen, temporal and spatial patterns in DO were examined in the Athabasca River.	Improvements in mill technology coincided with increases in late-winter DO at 2 of 3 downstream sites and improvements in the magnitude and downstream extent of the DO sag.	NA
Eby, L.A. and L.B. Crowder. 2002. Hypoxia-based habitat compression in the Neuse River Estuary: context dependent shifts in behavioural avoidance thresholds. Can. J. Fish. Aquat. Sci. 59: 952-965.	Field	Estuarine	Neuse River Estuary, North Carolina	United States	Fish and shellfish	Estuary	Both	Community	NA	Examined fish behavioural avoidance thresholds over a range of DO concentrations.	DO concentrations were spatially and temporally dynamic. Hypoxia formed most often in the deeper upstream portion of the estuary, but at times extended throughout the estuary. Hypoxic bottom waters were intermittently present.	In an examination of 10 fish species, all avoided areas with DO < 2 mg/L. Fish may occupy poorer quality habitat, as conditions worsen and the size of the oxygenated refuge shrinks.
Evans, D.O. K.H. Nicholls, Y.C. Allen and M.J. McMurtry. 1996. Historical land use, phosphorus loading, and loss of fish habitat in Lake Simcoe, Canada. Can J. Fish. Aquat. Sci 53(Suppl.1): 194-218.	Modelling	Freshwater	Lake Simcoe, Ontario	Canada	Fish	Lentic (lake)	Large-bodied	Salmonidae	Lake trout	Linked land-use activities, P loading, hypolimnetic oxygen depletion, and loss of cold-water fish habitat.	There was a downward trend in DO concentration of the hypolimnion over 1975-1995. The volume-weighted, temperature-corrected hypolimnetic DO from Aug. 30-Sept. 19 declined from 4.5 - 2 mg/L by 1993. During late summer 1975-1993, 60-98% of the 6-12°C thermal habitat volume had <7mg/L DO and 10-15% had <3mg/L, the incipient lethal threshold for lake trout.	Recruitment failure of lake trout (1960s), lake whitefish (1970s) and lake herring (1980s) followed peaks in P loading, potentially due to oxygen depletion and associated loss of cold-water habitat.
Isaac, R.A. 1997. Estimation of nutrient loadings and their impacts on dissolved oxygen demonstrated at Mt. Hope bay. Environment International 23: 151-165.	Field	Estuarine	Mt. Hope Bay, Massachusetts	United States	NA	Coastal Waterbody	NA	NA	NA	Annual nitrogen and phosphorous loadings to Mt. Hope Bay and relationships between nutrients and dissolved oxygen were made.	Nitrogen loading corresponded with reduced dissolved oxygen in the bay.	NA
Lowell, R.B. and J.M. Culp. 1999. Cumulative effects of multiple effluent and low dissolved oxygen stressors on mayflies at cold temperatures. Can J. Fish. Aquat. Sci. 1624-1630.	Laboratory	Freshwater	Artificial streams, Saskatoon	Canada	Benthic invertebrates	Lotic (stream)	NA	NA	NA	Experimentally measured the combined effects of increased toxicants and nutrients and decreased DO on a mayfly.	Exposed to 2 DO levels: low (5 mg/L) vs. high (11 mg/L).	In the low DO treatment, grazing intensity was reduced by 80% and after 2 weeks survival by 60-90%; 250-3505 more mayflies moved to the surface of the low DO streams.
Price, K.S., D.A. Flemer, J.L. Taft, G.B. Mackiernan, W. Nehlsen, R.B. Biggs, N.H. Burger and D.A Blaylock. 1985. Nutrient enrichment of Chesapeake Bay and its impact on the habitat of striped bass: a speculative hypothesis. Trans. Am. Fish. Soc. 114: 97-106.	Modelling	Estuarine	Chesapeake Bay	United States	Fish	Estuary	Large-bodied	Moronidae	Striped bass	Analyzed the role of nutrient enrichment in altering the ecological conditions for striped bass in Chesapeake Bay.	Nutrient enrichment was qualitatively correlated with greater deoxygenation of the deep channel in the mid and upper bay. During the late 1970s, summer DO concentrations as low as 2 mg/L approached to within 7-8 m of the surface. The volume of bottom waters containing 0.5 mg/L DO or less was ~15 times greater in July 1980 than July 1950.	Water stressful to striped bass intruded on shoal areas of the bay. The combination of the expanding hypoxic pool and summer temperatures above preferred levels may contribute to an "oxygen-temperature squeeze" that forces adults onto shoal areas of the bay or out of the upper bay.
Rydberg, L, L. Elder, S. Floderus and W. Granéli. 1990. Interaction between supply of nutrients, primary production, sedimentation and oxygen consumption in SE Kattegat. Ambio 19: 134-141.	Field	Marine	Baltic Sea	Sweden	NA	Estuary	NA	NA	NA	The chemical relationship between nutrient loading and decreasing deep water oxygen concentrations in the Baltic estuary was studied.	The oxygen consumption was twice as high as that in the open Kattegat, and was well correlated with the measured nitrogen uptake and the external supply of nitrate to surface water, especially in in the deep waters.	NA

Title & Source	Type of Study	Environment	Location	Country	Organisms	System Type	Fish Category	Fish Families	Fish Species	Overview of Study	Effect on Dissolved Oxygen	Effect on Biota
Webb. W.E. 1981. The relative importance of annual upland and sewage treatment plant point source nutrient loading on the summer oxygen regime of the tidal Potomac River, Maryland. Estuaries 4: 297.	Field	Estuarine	Potomac River, Maryland	United States	NA	Estuary	NA	NA	NA	The impact of sewage treatment outflow on the summer oxygen regime of a river was studied.	Nutrients released with discharge from the secondary sewage-treatment plant caused dissolved oxygen sag for approximately 8 nautical miles from the outflow area. In the remainder of the tidal river and transition zone, the oxygen regime is dominated by biological reactions fed by nutrients exchanged with the bottom of the river.	NA

APPENDIX II

COMMON AND SCIENTIFIC NAMES OF FISH

Table II-1
Common and Scientific Names of Fish

Common Name	Scientific Name
American shad	*Alosa sapidissima*
Atlantic Salmon	*Salmo salar*
bay anchovy	*Anchoa mitchilli*
black bullhead	*Ameiurus melas*
blueblack herring	*Alosa aestivalis*
bluegill	*Lepomis macrochirus*
brook trout	*Salvelinus fontinalis*
brown bullhead	*Ictalurus nebulosus*
brown trout	*Salmo trutta*
burbot	*Lota lota*
channel catfish	*Ictalurus punctatus*
chinook salmon	*Oncorhynchus tshawytscha*
coho salmon	*Oncorhynchus kisutch*
European perch	*Perca fluviatilis*
grass carp	*Ctenopharyngodon idella*
kokanee	*Oncorhynchus nerka*
lake herring	*Coregonus artedi*
lake trout	*Salvelinus namaycush*
lake whitefish	*Coregonus clupeaformis*
largemouth bass	*Micropterus salmoides*
mottled sculpin	*Cottus bairdi*
northern pike	*Esox lucius*
rainbow trout	*Oncorhynchus mykiss*
Rio Grande chub	*Gila pandora*
Rio Grande sucker	*Catostomus plebeius*
river carpsucker	*Carpiodes carpio*
roach	*Rutilus rutilus*
slimy sculpin	*Cottus cognatus*
smallmouth bass	*Micropterus dolomieu*
sockeye salmon	*Oncorhynchus nerka*
striped bass	*Morone saxatilis*
walleye	*Sander vitreus*
white crappie	*Pomoxis annularis*
yellow perch	*Perca flavescens*
Yellowstone cutthroat trout	*Oncorhynchus clarki bouvieri*