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REVIEWS

Past, present and future of fishery management on one of the world's last remaining pristine great lakes: Great Bear Lake, Northwest Territories, Canada

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Abstract Great Bear Lake, Northwest Territories, Canada supports important sport and aboriginal-subsistence fisheries and is among the last remaining pristine great lakes of the world. The lake's unique ecology is characterized by a harsh subarctic climate, low productivity and species diversity, and high intraspecific diversity of lake trout. These aspects in combination with geographical remoteness present special challenges to the management of two exceptionally different fisheries. The history of its management has not been well documented or reviewed; therefore, our objectives in this paper were to summarize the history and status of Great Bear Lake's fisheries and their management, and to identify gaps in knowledge, future challenges, and actions required to meet those challenges. Prior to 1970, management goals for the lake had not been established formally, and harvest numbers and biological characteristics of fish were unknown. To reduce data gaps, creel surveys, gillnet assessments, fish tagging, and subsistence monitoring were implemented. During the 1980s, Canada established the management goal of conserving a high quality sport fishery, while protecting aboriginal access to the subsistence fishery. On the basis of assessment data, lodge harvest quotas, lodge guest capacity limits, individual angler harvest limits, and angler licensing were among the management actions taken to achieve that goal. Since 2005, decision making has been guided by the "water heart," a management plan for Great Bear Lake. Management has since evolved into a complex co-management system among aboriginal, territorial, and federal governments. Changes in regulations, sport trophy and tourism industries, subsistence resource use, and social and cultural norms and practices contributed to changes in the Great Bear Lake fishery and its management. In the future, anthropogenic and climate change are the two main challenges facing co-management of the lake's resources. We recommend the adoption of an ecosystem approach to management, establishment of a fishery technical committee, reformulation of the current plan, explicit commitment to evaluation, conducting community-based monitoring, and development and use of a joint strategic plan among co-managers to describe how to interact and implement the Great Bear Lake management plan.

Keywords Sahtudene · Aboriginal · Recreational fishery · Sport fishery · Subsistence fishery · Catch-and-release · Co-management · Lake trout

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Introduction

> Close to the end of time, lots of People will come to Déline and Ayah said, "Great Bear Lake is huge, but it will be full with boats, that's how much people will come."…The very last disaster or plague will be "Famine" it will come from the east and it will affect every living thing. Not even one blade of grass will stand up, every living thing will go… Déline where my people will be the very last ones to have fish…Words of Ayah, a Dene prophet (Déline 2012).

Great Bear Lake, Northwest Territories is the fourth largest and northern-most of the North American great lakes. Great Bear Lake (*Sahtu* in North Slavey language) is home to the Sahtudene, or Sahtugot'ine—the people of the Sahtu. Traditionally, the Sahtudene travelled the land to hunt and fish, but during the 1950s, the community of Déline (formerly Fort Franklin) was established; it is the only permanent settlement on the lake. Déline means *where the river flows*, referring to the headwaters of the Bear River (*Sahtu De*; 65°11 N; 123°25 W; Fig. 1). The Sahtudene harvest lake trout *Salvelinus namaycush*, Arctic grayling *Thymallus arcticus*, lake whitefish *Coregonus clupeaformis*, and cisco *Coregonus* spp. for subsistence. During the 1950s, a fly-in sport fishery was established targeting the unusually large (>15 kg) trophy lake trout. At one time, as many as six lodges hosted up to 230 guests per week during the 3-month, open-ice period (Levy and MacDonald 2003). During the 1970s, harvest by anglers was high, and the requirement for fishery management was brought to the forefront.

Great Bear Lake presents many unique fishery management challenges. First, the lake is among the last remaining pristine great lakes of the world (Evans 2000). Second, the lake straddles several management jurisdictions. The Sahtu aboriginal land claim resulted in co-management of the lakes resources among aboriginal, territorial, and federal governments (Fig. 1b). Third, subsistence and sport fishery users usually have large differences in priorities and place different values on the resource; therefore, their interests can naturally conflict and must be balanced through management. Fourth, the lake's remoteness—located 500 km NW of Yellowknife, Northwest Territories with no permanent road access—and a harsh subarctic climate limits access to the ice-free period between July and September. For these reasons, fishery assessments have been rare, yielding discontinuous, spatially patchy, and temporally limited data sets. Finally, the lake's limnology and ecology differ from lakes further south, so existing knowledge from elsewhere cannot easily be applied. For example, Great Bear Lake is cold, monomictic (meaning the surface and bottom waters do not mix on a seasonal cycle), and it is nearly isothermal year round (meaning water temperatures are similar from the lake bed to the surface, due to the short open–water season). These conditions limit the biological productivity of the lake. The fish community in the main body of the lake consists of only four common species (Table 1); however, the lake trout populations show a high degree of morphological and ecological variation with multiple morphs (i.e., types) occurring (Blackie et al. 2003; Alfonso 2004).

Contemporary co-management of the Great Bear Lake fishery has evolved over the last three decades (Great Bear Lake Working Group 2003, 2005). The Sahtudene hold considerable traditional ecological knowledge (TEK), and some of this information has been incorporated into the lake's management plan (Great Bear Lake Working Group 2003, 2005; Woo et al. 2007). Western science has also contributed to understanding the lake's ecology, and although some of that information has been incorporated in the lake's management plan, many reports are not readily available to managers and scientists outside of the Northwest Territories because they have not been published in the primary literature.

Our goal was to document the past and present fishery management on Great Bear Lake and to discuss its future management. Our specific objectives were as follows: (1) conduct a historical review of Great Bear Lake fisheries and their management; (2) summarize the current status of the fisheries and their management; and (3) identify gaps in knowledge, future management challenges, and actions required to meet those challenges. This paper provides an accessible synthesis of the challenges and successes associated with managing two distinct fisheries, spanning multiple jurisdictions, in one of the last remote, pristine freshwater environments in the world. We intend this contribution to aid in advancing Great Bear Lake fishery management consistent with the current

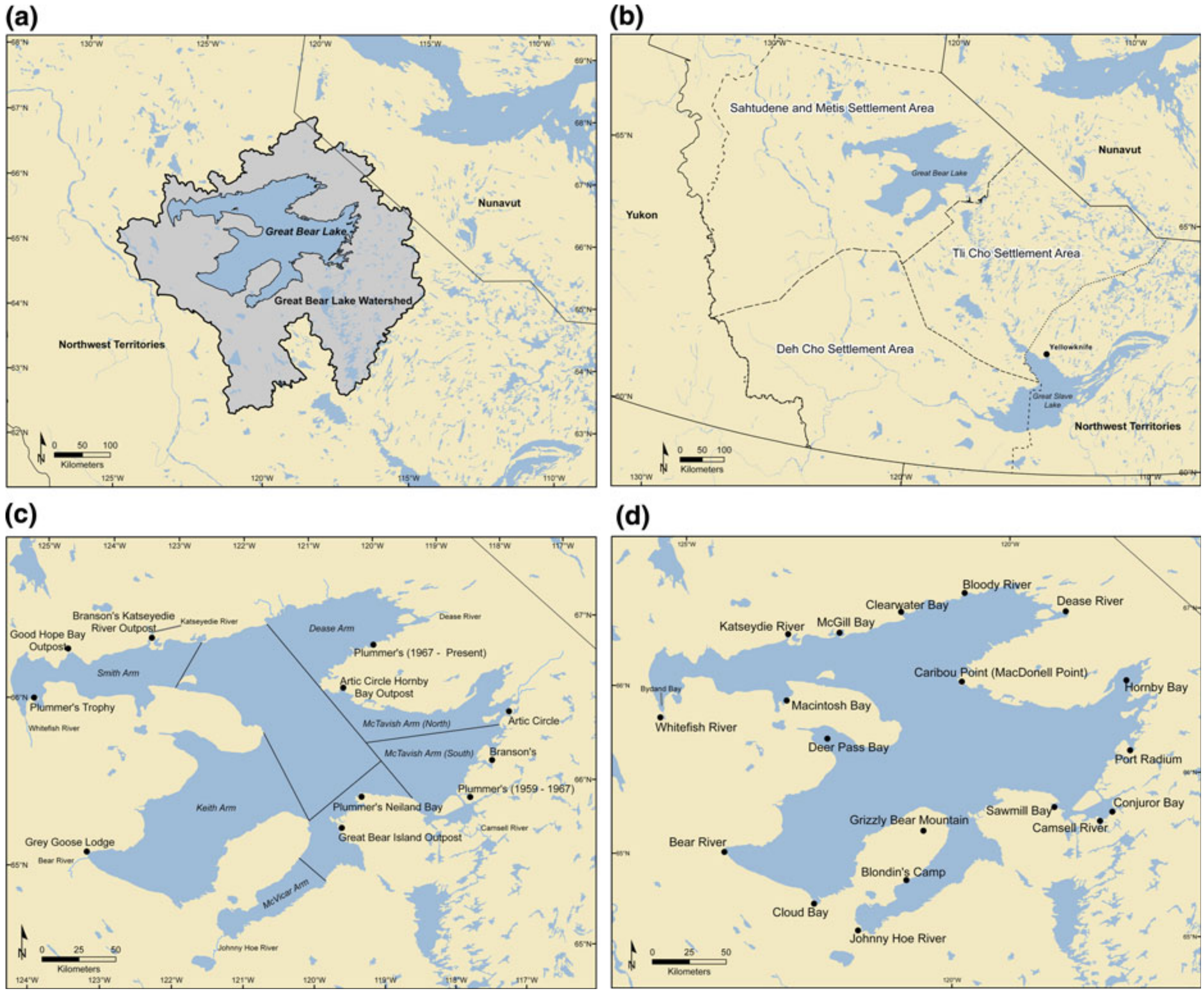

Fig. 1 **a** Great Bear Lake watershed; **b** aboriginal settlement areas within the Sahtu; the Deh Cho area is still under negotiation; therefore, we estimated boundaries for this area on the basis of Deh Cho First Nations and Government of Canada and Government of the Northwest Territories (2012); **c** Sport lodges and camps; *lines* represent Fisheries and Oceans Canada fishery management zones; **d** traditional fishing areas of the Sahtudene (based on Osgood 1931; Johnson 1976). Map datum NAD 1983 CSRS Northwest Territories Lambert

management vision: *Great Bear Lake must be kept clean and bountiful for all time* (Great Bear Lake Working Group 2005). In addition, this paper may highlight challenges and provide potential solutions relevant to fishery management in other large, remote ecosystems supporting multiple fisheries.

Scope of review—Much of the literature cited in this review represents the available western science including lesser-known government publications often not listed within citation indices. We also included aboriginal traditional knowledge if published and, to our knowledge, approved by the community of origin. The ecology of Great Bear Lake is influenced by the entire watershed (Fig. 1a) and, as previously mentioned, management issues span multiple jurisdictions (Fig. 1b); however, the current review is restricted in geographical scope to the lake itself to be consistent with the management plan (Great Bear Lake Working Group 2005). We attempted to verify dates and information by cross-referencing material, consulting authorities and lodge owners, and identifying reviewers most familiar with Great Bear Lake and its management. Despite our best efforts to minimize errors, the nature of the source material prevented reconciliation of all records; therefore inaccuracies may still occur.

Table 1 Summary of aquatic biological diversity in Great Bear Lake, Northwest Territories

Zooplankton		Macroinvertebrates		Fishes	
Bays	Main Lake	Bays	Main Lake	Bays	Main Lake
Daphnia middendorfiana[4,6]	*Daphnia middendorfiana*[5]	Trichoptera[2,4]	*Mysis relicta*[2,4]	Northern pike *Esox lucius*[4]	Lake trout *Salvelinus namaycush*
Daphnia longispina hyalina[4]	*Cyclops scutifer*[5]	Ephemeroptera[2,4]	*Diporeia spp.*[2,4]	Arctic grayling *Thymallus arcticus*[4]	Lake whitefish *Coregonus clupeaformis*
Bosmina longirostris[4]	*Senecella calanoides*[5]	Coleoptera[2,4]		Round whitefish *Prosopium cylindraceum*[4]	Cisco *Coregonus artedi*
Bosmina coregoni[6]	*Limnocalanus macrurus* Sars[5]	Corixidae[2,4]		Walleye *Sander vitreus*[4]	Deepwater sculpin *Myoxocephalus thompsonii*
Holopedium gibberum[6]	*Diaptomus sicilis*[5]	Plecoptera[2,4]		Burbot *Lota lota*[4]	Inconnu *Stenodus leucichthys*[4,a,c]
Cyclops scutifer[4,6]	Hydra spp.[4]	*Diporeia spp.*[2,4]		Slimy sculpin *Cottus cognatus*[4]	Chum salmon *Oncorhynchus keta*[4,b,c]
Cyclops vernalis[4]		*Mysis relicta*[2,4]		Ninespine stickleback *Pungitius pungitius*[4]	
Senecella calanoides[4,6]		Oligochaetae spp.[2,4]		Longnose sucker *Catostomus catostomus*[4]	
Limnocalanus macrurus[4,6]		Chironomidae spp.[2,4]		Trout-perch *Percopsis omiscomaucus*[1]	
Diaptomus sicilis[4,6]		*Sphaerium nitidum*[3]			
Diaptomus ashlandi[6]		*Pisidium idahoenis*[3]			
Diaptomus pribilofensis[6]		*Pisidium casertanum*[3]			
Heterocope septentrionalis[6]		*Pisidium lilljeborgi*[3]			
Leptodora kindtii[4]		*Sphaerium nitidum*[3]			
Epischura nevadensis[4]		*Hyalella azteca*[4]			
		Gammarus lacustris[4]			
		Valvata cincera heliocoidea[4]			
		Gyraylus deflectus[4]			
		Lymnaea elodes[4]			

Diversity is greater in the warmer, nearshore, shallow-water bays that are isolated from the main parts of the lake and in river mouths, than in offshore deep waters. Note that many of the species that occur in the main lake also occur in the bays, but most species that occur in the bays are restricted in distribution to those areas

[1] Miller (1947); [2]Larkin (1948); [3]Clarke (1973); [4]Johnson (1975a); [5]Patalas (1975); [6]Moore (1981)

[a] Recorded by Simpson (1843) from the north end of the Dease Arm and cited by Johnson (1975b)

[b] Recorded from the Bear River outlet, personal communication cited by Johnson 1975b

[c] Species are rare and likely strays from the Mackenzie River; Moore (1981) also reported seven Rotifers and two protozoa occurred in nearshore areas of McTavish Arm

Great Bear Lake—Great Bear Lake was formed by Pleistocene glacial scour. Its geology is characterized by sedimentary Paleozoic deposits to the west and metamorphic Precambrian shield to the east. The region is thought to have become ice-free about 9000 ybp (Johnson 1975a; Herdendorf 1982; Johnson 1994; Evans 2000). The lake straddles the Arctic Circle between 65 and 67°N and 118 and 125°W. It is the fourth largest lake in North America and the ninth largest in the world, having a surface area of 31,326 km^2, and a drainage basin area of 145,870 km^2 (Johnson 1975b; Herdendorf 1982). Great Bear Lake is deep, with a mean depth of 90 m and maximum depth of 446 m, and cold (mean August surface temperature ~4 °C; Johnson 1975a). The lake is oligotrophic, with low dissolved solids (82 mg l^{-1}), low total phosphorous (< 10 μg l^{-1}), and high water clarity (i.e., low chlorophyll concentration; high Secchi depth ~30 m; Johnson 1975b; Moore 1980). These characteristics collectively limit the biological productivity of the lake; therefore, the food web throughout the main basin is relatively simple. On the basis of limited sampling, the main basin food web consists of a sparse phytoplankton community (Moore 1980), three zooplankters (*Diaptomus sicilis*, *Limnocalanus macrurus*, and *Senecella calanoides*; Johnson 1975a), three macroinvertebrates (i.e., *Diporeia* spp. *Mysis relicta*, and Chironomidae spp; Johnson 1975a), lake trout *Salvelinus namaycush*, cisco *Coregonus artedi*, and deepwater sculpin *Myoxocephalus thompsonii* (Johnson 1975a) (formerly considered fourhorn sculpin *Myoxocephalus quadracornis* [Scott and Crossman 1973]). This food web is more diverse in the nearshore, shallow bays (Table 1).

History of human settlement

Sahtudene—The patterns of human habitation of Great Bear Lake are unclear, but estimates of occupation range from 7500 to 2894 ybp (Johnson 1976). Three historical aboriginal occupation locations were identified on Great Bear Lake by Macneish (1955). The Franklin Tanks complex was located on the southern side of the Bear River, close to the lake's outlet; the Northern Transportation Docks complex was superimposed on it, and the Bear River complex was located at another site a few hundred meters downstream of the other two sites (Johnson 1976). Occupation of these sites was dated to 7500–6500 ybp by Macneish (1955), but were considered slightly younger (~5000 ybp) by Clark (1970, 1991). Subsequent ethnographic studies by Déline Band Council (Testo 1991 cited by Hanks 1997; Hanks 1996; Toews 1996) identified another 80 previously unidentified occupations on the western shore of the lake. Projectile points from Grizzly Bear Mountain and Deerpass Bay were dated to between 1000 and 2600 ybp (Hanks 1996; Fig. 1d).

Historically, the Sahtudene, were quasi-nomadic; their movements were typically confined to hunting and fishing around the shores of Great Bear Lake (Morris 1973b; Gillespie 1981). The Sahtudene likely were split from four parent tribes—the Hare in the northwest, Slave in the southwest, Dogrib in the southeast, Copper in the east, and Inuit in the northeast—each originally used the Great Bear Lake watershed on a seasonal basis. The timing of this split is unknown (Osgood 1931; Morris 1973b; Hall 1978); however, interactions with Europeans, and trade wars among aboriginal groups during the 1820s gradually contributed to the evolution of the Sahtudene as a distinct group with its own dialect—North Slavey (Hanks 1997). Aside from the journal entries of early European explorers, such as Mackenzie (1801) and Richardson (1852), and the French missionary, Emile Petitot (1893), little about the Sahtudene prior to European contact has been documented.

Europeans—The first European settlement on Great Bear Lake was established by Alexander Mackenzie in 1799 for the North-West Fur Company (Morris 1973a; Johnson 1976). The North-West Fur Company was taken over by the Hudson's Bay Company in 1821, and a station was established at the outlet of the lake, the headwaters of the Bear River. Permanent headquarters "Fort Franklin" were built on the site in 1825 by John Franklin's second expedition (Fig. 1c; Johnson 1976). In 1836, Peter Warran Dease and Thomas Simpson established Fort Confidence at the mouth of the Dease River on the north shore of the lake. The post marked the route north to the Arctic Ocean through the Dease River, across the Dismal Lakes portage to the Kendall River, which flowed northeast into the Coppermine River and north to the Dolphin and Union Strait. Fort Confidence was inhabited until 1852. After Franklin's third expedition was lost (1845), a mission and a school were erected at Fort Franklin and the Sahtudene began to use the site as a permanent residence, now called Déline (Morris 1973a; Johnson 1976).

In 1930, Gilbert LaBine staked silver and cobalt claims at Port Radium, on the MacTavish Arm in eastern end of the lake (Fig. 1d; Mcdonald 1932; Watt 1980). The site was rich with pitchblende, the source of radium and uranium. Eldorado Mining and Refining Limited (Port Hope, Ontario) extracted these resources from 1932 to 1962, the chief export being uranium oxide. During the 1940s, the Mackenzie River barge service extended its route to Great Bear Lake and the 35-m vessel *Radium Gilbert* was brought up the Mackenzie, through the Bear River, and assembled at Port Radium where it serviced the mine (Johnson 1975a). During the mid-1960s, Echo Bay Mines Limited staked silver claims in the vicinity of Port Radium and much of the Eldorado equipment was returned to service until 1975, when the mine closed permanently. As a result of the mining activities and enhanced transportation, a small community temporarily emerged near Port Radium. However, no permanent non-native communities currently exist on the lake. Two sport fishing lodges are open during July and August to fly-in a seasonal influx of anglers to Great Bear Lake.

History of fisheries

Subsistence fishery—The Sahtudene fished for subsistence with hook-and-line, spruce or willow-bark nets, and stone weirs (Osgood 1931; Johnson 1976), and more recently, with cotton, nylon, or monofilament gillnets (Miller 1947; Johnson 1976; Rushforth 1976). Fishing occurred year round, but when compared to caribou *Rangifer tarandus*, fish were considered a secondary staple of the Sahtudene (Morris 1973b). Miller (1947) estimated that 181,500 kg of cisco and lake trout were harvested from the Keith Arm during summer 1944 (see Fig. 1c, d for locations). The cisco and some lake trout were used as food for about 600 sled dogs and some of the lake trout was consumed by the Sahtudene (Miller 1947). Ciscoes were caught using 76.2- and 88.9-mm stretch-mesh gillnets. Lake trout were also targeted during spring using set lines of hooks constructed of bone, and baited with cisco strips (Miller 1947; Morris 1973b). A second fishery occurred in the Johnny Hoe River (McVicar Arm) between mid-August and mid-September to exclusively catch lake whitefish that moved into the river for spawning. Historically, whitefish were caught in stone or brush weirs built in the river, but during the 1940s were caught in 101.6- and 114.3-mm gillnets (Miller 1947). Miller (1947) estimated that approximately 408,223 kg of lake whitefish were frozen and used to feed dogs through the long winter and an additional 321,687 kg were used as food by the Sahtudene during 1944. A third fishery occurred in the Whitefish River (Smith Arm), where an unknown quantity of lake whitefish was harvested (Miller 1947).

Stewart (1996) provided the most thorough account of the status and harvests of fish stocks supporting the Sahtudene subsistence fishery—the proceeding summary is based primarily on Stewart's summary of data collected between 1961 and 1993 (see Fig. 1c, d for locations). In the Dease Arm, Sahtudene fished for subsistence in Clearwater Bay and other sheltered bays near Caribou Point (Cape MacDonnel), and at the mouth of the Bloody River, but harvests were not recorded. The annual Sahtudene subsistence harvest of fish from the Keith Arm was estimated to be 117,360 kg in 1961 and 22,650 kg in 1973, which was much lower than the 181,437 kg reported by Miller (1947). In 1977, the total subsistence fish harvest for the whole lake was estimated at between 60,000 and 84,300 kg, with lake trout comprising 37 % of this harvest, cisco 31 %, whitefish 26 %, and Arctic grayling 6 %. In the northern part of McTavish Arm, the Sahtudene fished in Hornby Bay, but harvests were not recorded. In the southern part of the McTavish Arm, the Sahtudene fished during autumn in the Conjuror Bay area, where an unknown quantity of Arctic grayling were taken as food for dogs and humans, but harvest was not recorded. Subsistence fishermen caught approximately 4,536 kg of fish from the southern McTavish Arm during autumn 1973. In the autumn and early winter of 1977, an estimated 13,608 kg of fish were harvested from Bydand Bay, and 3,636 kg of whitefish from McGill Bay. Fish were also caught by the Sahtudene in many other areas of the lake, including the Bear River and other tributaries (see Osgood 1931; Morris 1973a, b; Hall 1978; Johnson 1976; Stewart 1996 for details).

Between 2002 and 2004, the Sahtudene recorded the number of fish taken by subsistence harvesters to provide information for co-management of the lakes' resources (Bayha and Snortland 2002; 2003; 2004). During 2003, for example, the community of Déline reported harvesting 620 Arctic grayling, 651 lake whitefish, 1,027 cisco and 4,765 lake trout (Bayha and Snortland 2004). The number of fish caught during

2003 is much less than that taken during the 1940s. Declining subsistence harvest can be attributed to a reduced reliance on dogs for transportation due to the use of snow machines (Rawson Academy of Aquatic Science 1990), a greater reliance on other food sources, including prepared foods (Hall 1978), and a declining population of Sahtudene at Déline (Statistics Canada 2012).

Sport fishery—The Great Bear Lake sport fishery for trophy lake trout is world class, having produced the North American rod and reel record of 32.8 kg (72¼ lb) in 1995. Descriptions of the sport fishery are given by Falk et al. (1973a, b, c), Falk and Dahlke (1974), Falk et al. (1974a, b, 1975, 1982), Moshenko and Gillman (1978a, b), Gillman and Roberge (1982), Moshenko and Gillman (1983), Anderson and Thompson (1991), and Stewart (1996). The earliest sport fishing records are from Port Radium's Eldorado mine, where an estimated 1,360 kg of lake trout were caught and retained annually (1940s) by mine staff (Miller 1947); for management purposes, DFO accounts for these fish as sport harvest.

The sport fishing lodge industry began in 1959 with the establishment of Plummer's Great Bear Lake Lodge in Conjuror Bay, McTavish Arm (Fig. 1c). Plummer's relocated in 1967 to its present location on the southern shore of the Dease Arm (C. Plummer, personal communication, 15 February 2012). By 1970, five lodges (Arctic Circle, Branson's, Plummer's Great Bear Lake, Great Bear [Neiland Bay], and Trophy) were operating and a sixth (Saw-Tew) had operated intermittently out of Déline. Déline opened the Grey Goose Lodge in 1999, which hosts limited sport fishing in the Keith Arm. Plummer's Great Bear Lake Lodge, Neiland Bay Lodge, and Trophy Lodge are the only lodges to have regularly operated since 1990 (Stewart 1996). Presently, Arctic Circle (closed in 1991) and Branson's (closed in 1991) lodges are jointly owned by the Metis Development Corporation and Plummer's, and are managed as outpost camps (Stewart 1996).

The sport fishery has generally been concentrated in nearshore shallow-water areas adjacent to the lodges (Yaremchuk 1986), but has expanded into new areas over the past decade in search of trophy lake trout. Sport harvest records are incomplete, but on the basis of creel surveys, an average of 25,000 kg (range = 6,520–90,751 kg) were harvested per year between 1971 and 1979 (Table 2). Angler effort (i.e., number of sport fishing licenses sold), increased from 968 anglers in 1971 to a peak of 1758 anglers in 1977 and then declined thereafter. Angler catch-per-unit-effort (CPUE) nearly doubled between 1976 and 1980 at Trophy Lodge, but stayed the same at Great Bear Lodge, Branson's Lodge, and decreased at Plummer's lodge over the same time period (Yaremchuk 1986). The sport harvest was not monitored during the 1990s, but an angler diary program was implemented by DFO through a contract with Plummer's Lodge between 2004 and 2008.

Commercial fishery—Distance from markets and low biological productivity has restricted commercial fishery development on Great Bear Lake. Miller (1947) concluded that the lake's "open waters constitute almost a biological desert" and noted that even the meager harvest by the Sahtudene and mine staff at Port Radium had resulted in rapid and obvious changes to the structure of fish populations in the vicinity of these communities.

Despite the limited productivity, some commercial activity has occurred in Great Bear Lake. During the early 1940s, fish were harvested by the Sahtudene and sold to the Hudson's Bay Post at Cameron Bay, McTavish Arm. Lake trout fillets were also sold by the Sahtudene to the Eldorado Mine at Port Radium for \$CAN 0.33 kg^{-1} (Miller 1947). An estimated 2,720 kg $year^{-1}$ were sold to the mine between 1942 and 1945 (Miller 1947). Experimental commercial licenses were held by Déline residents during the 1970s, but no harvest or sales were recorded (Yaremchuk 1986; Stewart 1996). Experimental fisheries in the Great Bear Lake tributaries were deemed unviable due to the scarcity of fish (Chang-Kue 1974; Sutherland and Golke 1978; Stewart 1996). Under the current co-management regime, Déline and DFO do not consider commercial fishery development an objective for Great Bear Lake.

History of management (1940–2005)

Management authority—The Government of Canada became interested in the Great Bear Lake fishery during the 1940s when it launched an experimental gillnet investigation to assess its suitability for commercial development (Fig. 2; Miller 1947). On the basis of this program, DFO concluded that Great Bear Lake was not productive enough to support a

Table 2 Angler creel survey estimates of lake trout *Salvelinus namaycush* harvested (kg) by the Great Bear Lake, Northwest Territories sport fishery and the number of angler licenses sold (in parentheses)

Year	Plummer's	Great Bear	Branson's	Arctic Circle	Trophy	TOTAL
1971	–	8,448[1]	11,885[4]	–	–	20,333
	–	–	–	–	–	
1972	27,410[4]	6520[4]	10,490[4]	3,912[1]	7,210[4]	90,751
	–	–	–	–	–	
1973	18,780[4]	11,210[4]	8,760[4]	–	13,070[4]	51,820
	(413)[1]	(315)[1]	–		(240)[1]	968
1974	–	4,976[1]	12,890[4]	–	–	17,866
	(369)[1]	(278)[1]	–	–	(225)[1]	872
1975	–	–	–	6,520[4]	–	6,520
	(302)[1]	(234)[1]	–	(170)[1]	(306)[1]	1,012
1976	–	–	–	–	9,130[4]	9,130
	(370)[1]	(174)[1]	–	(189)[1]	(315)[1]	1,048
1977	13,070[4]	–	–	–	–	13,070
	(407)[3]	(313)[3]	(377)[2]	(340)[3]	(321)[3]	1,758
1978	–	–	7,210[4]	–	–	7,210
	(425)[1]	(261)[3]	(262)[3]	(289)[1]	(329)[3]	1,566
1979	–	10,890[4]	–	–	–	10,890
	(496)[2]	(225)[2]	(367)[2]	(321)[2]	–	1,409

Sources: [1]Hall (1978); [2]Falk et al. (1982); [3]Moshenko and Gillman (1983); [4]Yaremchuk (1986)

– No data

commercial fishery. Concerns about the potential for overharvest and for conflict between the subsistence and sport fisheries prompted Canada to take a more active role in the lake's management during the 1970s (Hall 1978). In 1986, Canada and the Sahtudene formed the Great Bear Lake Management Committee to assess the health of the fishery and to establish total allowable harvests and allocations for users.

In 1993, Canada (represented by the Department of Indian Affairs and Northern Development, Fisheries and Oceans Canada, and the Department of the Environment), the Northwest Territories (represented by the Department of Environment and Natural Resources), and the Dene and Métis of the Sahtu settlement area ratified the Sahtudene and Métis Land Claim Agreement (hereafter "land claim"; Canada 1993). The land claim is a modern treaty between the First Nation and Canada, which recognizes and affirms the rights of the Sahtudene under Canada's Constitution (Sahtu Land Use Planning Board 2010). Canada also passed into law, in 1998, the Mackenzie Valley Resource Management Act (MVRMA), which was intended to support the land claim by providing *an integrated system of land and water management in the Mackenzie Valley, to establish certain boards for that purpose and to make consequential amendments to other Acts* (Canada 1998). Under these new laws, a complex management structure for Great Bear Lake evolved (Fig. 3). Prior to the land claim, DFO was the sole manager of Great Bear Lake fishery; after the land claim was ratified, DFO entered into co-management with the Sahtudene. Co-management can be defined as "a partnership between the community of local resource users, other primary stakeholders, governments, and NGO's who together share responsibility and authority for resource management (Murray 2007)."

After ratification of the land claim and the MVRMA, several joint regional management boards were established. The Land and Water Board was tasked with regulating, through permits and water licenses, land and water use and waste disposal within the Sahtu. The Sahtu Renewable Resources Board is the main instrument of fishery and wildlife management in the Sahtu settlement area. The Land Use Planning Board, which consists of equal numbers of Sahtu First Nation and federal government nominees,

Fig. 2 Timeline of key fishery management events for Great Bear Lake, Northwest Territories (1960–2005)

was mandated with developing and adopting a land-use plan and for assuring compliance of land-use activities with the plan (Great Bear Lake Working Group 2005). The Mackenzie Valley Environmental Impact Review Board is the primary body overseeing environmental assessment and reviews associated with natural resource development in the Mackenzie valley. Déline also established a number of community-based management support teams. The Déline Land Corporation, Renewable Resource Council, Self Government Team, and the Uranium Team currently play important roles in land, water, and wildlife management in the region. In 2002, representatives of the four boards, six community groups, three federal

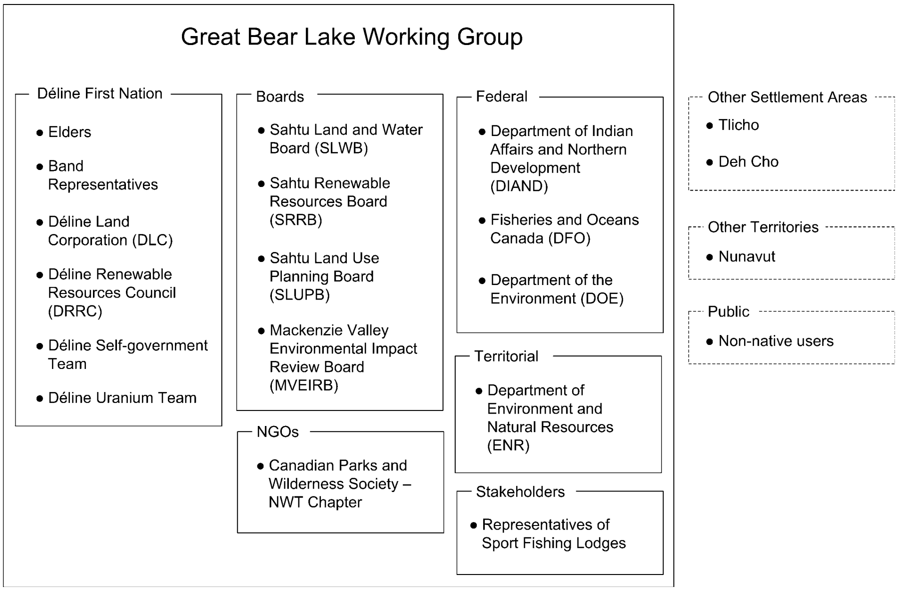

Fig. 3 Parties involved in management of the Great Bear Lake, Northwest Territories watershed. Relationships and direction of information flow among party members of the group are not depicted because they have been dynamic and are currently in a state of flux. *Dashed boxes* indicate parties involved in fishery management within the Great Bear Lake watershed, but were not formally represented in the Great Bear Lake Working Group

governmental bodies, one territorial government, one non-governmental agency, and the stakeholders formed an *ad hoc* coalition called the *Great Bear Lake Working Group* (Fig. 2). The working group developed the Great Bear Lake management plan (Great Bear Lake Working Group 2005).

In terms of geographic scope, the land claim was limited to the Sahtu portion of the watershed (Fig. 1b). The Sahtudene claimed 90,267 km^2 or 63 % of the Great Bear Lake watershed; 37 % of the watershed falls outside of the Sahtu settlement area, with Nunavut comprising 2 % (2,876 km^2), Deh Cho 4 % (6,401 km^2), and Tli Cho 31 % (44,525 km^2; Fig. 1b). Historically, the Great Bear Lake Working Group did not coordinate with these other governments. The Tli Cho Land Claim Agreement was established in 2003 (Tli Cho and Government of the Northwest Territories 2003; Canada 2005), and the Deh Cho settlement area is currently under negotiation (Deh Cho First Nations and Government of Canada and Government of the Northwest Territories 2012). If management at the watershed-level is a goal, then authorities from the Tli Cho and the Deh Cho will have to be included in management decision making.

Gaps in knowledge—When DFO began managing the Great Bear Lake fishery during the 1970s, no specific management goals for the lake had been established; although the Canadian federal government had a general goal of conserving northern fish populations. The trophy sport fishery was essentially unregulated from its inception in 1959 until 1970. Biological data characterizing fish populations were lacking, and nothing was known about harvest numbers or the biological characteristics of fish taken in the sport or subsistence fisheries. To address these gaps, creel surveys, experimental gillnet assessments, fish tagging studies, and subsistence monitoring were implemented to collect harvest and biological data to support management decision making (Table 3).

Creel programs—The Department of Fisheries and Oceans surveyed angler creels from 1972 to 1980 (Falk et al. 1974a, 1975; Moshenko and Gillman 1978b; Falk et al. 1982; Gillman and Roberge 1982; Moshenko and Gillman 1983; Dunn and Roberge 1989), and obtained catch data from angler diaries between 1987 and 1990 (Anderson and Thompson 1991) and 2004–2008 (D. Leonard, unpublished data). Only partial surveys were conducted in some years, and angler response to the diary program was variable, yielding incomplete data series. On the basis of Yaremchuk's (1986) analysis, a follow-up "intensive" creel survey that used fishing guides to collect biological data from the catch, was initiated in 1984–1985 to better resolve the status of lake trout exploited by the sport fishery (Roberge and Dunn 1988). Data from the intensive survey were combined with experimental gillnet data (described below) to assess the status of lake trout populations and to develop a rationale for their management (Yaremchuk 1986).

Table 3 Summary of biological, ecological, and limnological data for Great Bear Lake, NT

Data	1940s	1960s	1970s	1980s	1990s	2000s
Lake trout						
Subsistence harvest	2		27	27	27, 29	30, 34
Commercial harvest	2					
Sport harvest	2		8, 10, 12, 17, 21, 23, 24, 27	26, 27, 25	27	
Experimental fisheries	2		21, 23, 24, 27	22, 26, 27	27	
Morphology						31, 33, 35
Relative abundance		14	8, 10, 24	26		
Distribution	4	14	23			
Movement		14	21, 23	23		
Maturity	1, 2, 4		8, 9, 10, 12, 16, 17, 21, 23	22, 26		
Length/weight			8, 9, 10, 12, 16, 17, 21, 23, 24	22, 26		37
Age	1, 2, 4		8, 9, 10, 12, 16, 17, 21, 23, 24	22, 26		37
Growth	1, 4		8, 9, 10, 12, 16, 17, 21, 23	22, 26		35, 37
Body condition			16, 17, 23			
Mortality			8, 11, 16, 17, 23			
Diet	1, 2,3	14	23			31, 37
Parasitism	1, 2					
Contaminants				20		
Isotopes						37
Zooplankton and mysis						
Spp. composition	3	6, 14, 15		19		
Abundance	2	14, 15		19		
Distribution	3	6, 14		19		
Benthos						
Spp. composition	3	14				
Abundance	3	14	7			
Distribution	3					
Phytoplankton						
Spp. composition	2			18		
Abundance	2			18		
Distribution				18		
Limnology						
Water levels		13, 36	28, 36	28, 36	28, 36	36
Temperature	2	5, 13	21	22		32
Water chemistry	2	5, 6, 13				
Transparency	2	5, 13				

[1] Miller (1946); [2]Miller (1947); [3]Larkin (1948); [4]Miller and Kennedy (1948); [5]Canadian Oceanographic Data Center (1964); [6]Johnson (1964); [7]Clarke (1973); [8]Falk et al. (1973a); [9]Falk et al. (1974a); [10]Falk et al. (1974b); [11]Falk et al. (1974c); [12]Falk et al. (1975); [13]Johnson (1975b); [14]Johnson (1975a); [15]Patalas (1975); [16]Moshenko and Gillman (1978b); [17]Moshenko and Gillman (1978a); [18]Moore (1980); [19]Moore (1981); [20]Moore and Sutherland (1981); [21]Falk et al. (1982); [22]Gillman and Roberge (1982); [23]Moshenko and Gillman (1983); [24]Roberge and Dunn (1988); [25]Thompson et al.(1988); [26]Dunn and Roberge (1989); [27]Stewart (1996); [28]Kerr (1997); [29]Bayha and Snortland (2002); [30]Bayha and Snortland (2003); [31]Blackie et al. (2003); [32]Bussieres and Schertzer (2003); [33]Alfonso (2004); [34]Bayha and Snortland (2004); [35]Howland et al. (2004); [36]Woo et al. (2007); [37]Howland et al. (2008)

Fish data summarized are limited to lake trout *Salvelinus namaycush*, but data for other food-fishes from Great Bear Lake are as follow: coho salmon *Oncorhynchus nerka* (Babaluk et al. 2000); lake whitefish *Coregonus clupeaformis* (Miller 1947; Falk and Dahlke 1974; Stewart 1996), round whitefish *Prosopium cylindraceum* (Miller 1947; Falk and Dahlke 1974; Stewart 1996), cisco (*Coregonus* spp.) (Kennedy 1947; Miller 1947; Kennedy 1949, 1953; Falk and Dahlke 1974; Stewart 1996), northern pike *Esox lucius* (Miller 1947; Miller and Kennedy 1948; Falk and Dahlke 1974; Stewart 1996) and Arctic grayling *Thymallus arcticus* (Miller 1946, 1947; Falk and Dahlke 1974; Stewart 1996). A summary of DFO creel survey data was also given by Yaremchuk (1986)

Experimental gillnet programs—Experimental gillnet programs were initiated to obtain fishery-independent data on lake trout catch, length, weight, age, sex, maturity, diet, and mortality (Table 3). The first experimental gillnetting program on Great Bear Lake began in 1945 (Miller 1947). Multi-mesh gillnet gangs composed of 45-m panels of 64-, 76-, 102-, 127-, 139-mm stretch mesh were fished in the McTavish, Smith, and McVicar arms (Miller 1947). A second experimental gillnetting program was initiated during the 1970s, to provide fishery-independent data on the lake trout populations supporting the sport harvest and to live-capture and release fish for movement studies by tagging. From 1977 to 1979, areas surrounding each of the lodges (except Plummer's main lodge; Fig. 2c) were sampled with 38-mm stretch-mesh gillnets (Falk et al. 1982; Moshenko and Gillman 1983). The small mesh minimized fish mortality to facilitate tagging and release. The areas around Neiland Bay and Trophy Lodge were also sampled with the 38-mm stretch mesh gillnets in 1980 (Gillman and Roberge 1982). In 1984 and 1985, multi-mesh gillnets composed of 50-m panels of 38-, 64-, 89-, 114-, and 139-mm stretch mesh were used to survey fish populations in each arm of the lake except the Keith Arm (Roberge and Dunn 1988; Dunn and Roberge 1989). More recently, DFO in partnership with the Sahtu Renewable Resources Board, sampled the Keith and McTavish arms between 2000 and 2005, but results of these surveys have not yet been released.

Experimental gillnet and creel data showed lake trout populations were affected by overharvest during the 1970s. Mean length and age of lake trout in the Dease Arm declined between 1970 and 1980 (Yaremchuk 1986). Reduced availability of trout >30 year of age and an increase in the instantaneous total mortality rate were also indicative of the effect of the sport fishery (Stewart 1996). Similarly, in both north and south McTavish Arm, lake trout CPUE declined by 40 %, mean size and age of the catch declined, and the number of trophy lake trout (i.e., > 15 kg) caught was greatly reduced (Yaremchuk 1986). Instantaneous total mortality of lake trout increased between 1973 and 1984 (Stewart 1996). In the McVicar Arm, trophy lake trout became rare during the 1970s, due to large harvests, but on the basis of the 1984 experimental fishery, DFO concluded that these populations were no longer in decline and had stabilized. Modal age of lake trout in the Smith Arm declined and the instantaneous total mortality rate remained high; however, trophy-size trout were still available in 1985.

For the whole lake, the available data reaffirmed Miller's (1947) conclusion that lake trout in Great Bear Lake were highly susceptible to exploitation. For example, between 1972 and 1980, mean total mortality (Z = fishing + natural mortality), calculated from catch curves, ranged from 0.17 at Branson's Lodge to 0.50 at Plummer's Great Bear Lodge (Yaremchuk 1986). Considering that natural mortality (i.e., without the fishery) is probably between 0.08 and 0.12 for these populations, even modest exploitation has a substantial effect on lake trout population dynamics (Yaremchuk 1986). Mean age in the sport harvest was 21 years (range = 18–48 years) and mean age-at-first-maturity was 15 years (range = 10–23 years; Yaremchuk 1986), but tended to advance over the time series. Overall, historical yields, especially of trophy lake trout, exceeded equilibrium yield predictions generated by a Ricker yield-per-recruit model (Yaremchuk 1986), providing further evidence that the level of exploitation observed during the 1970s was too high to maintain a trophy lake trout sport fishery.

Tagging programs—Tagging programs, whereby fish are implanted with a visible, unique identification code and released for recapture, can provide information on fish movement and home range that can be used to establish area-based management regulations. Between mid-June and the end of July 1965, 914 lake trout in the east end of McTavish Arm were tagged with Peterson discs (i.e., a tag composed of two plastic discs fastened by a pin through the back muscles of a fish). From 1965 to 1974, 57 (6.24 %) of the fish tagged in 1965 were recovered (Johnson 1975a). On the basis of tag recoveries, Johnson (1975b) concluded that fish movement was localized; the mean distance travelled from the site of tagging by a lake trout was 8.77 km (0–71.6 km) and no trends in movement were apparent. Fisheries and Oceans Canada also marked 203 lake trout with spaghetti tags (i.e., a vinyl t-bar anchor tag inserted into the dorsal fin musculature) near Branson's Lodge during 1978 (Moshenko and Gillman 1983). Four of the 203 (1.97 %) fish were recaptured within 10 km of the lodge during 1979 (Falk et al. 1982; Stewart 1996). In 1979, an additional 256 lake trout were spaghetti-tagged near Neiland Bay (Fig. 1c; Falk et al. 1982), and in 1980, 405 lake trout were tagged near Trophy Lodge, Smith Arm (Fig. 1c;

Gillman and Roberge 1982), but no recoveries from the 1979–1980 tagging events have been reported. The tag-recapture data were interpreted as evidence that lake trout populations are localized, which led DFO to establish lake management zones (Fig. 1c) and establish total allowable harvests (TAHs) for lodges within those zones. The validity of the management zones was questioned by Yaremchuk (1986), who reported that the number of tag returns was insufficient for robust statistical analysis; therefore, previous conclusions about lake trout movement and abundance are tenuous.

Subsistence monitoring program—Pursuant to Sect. 13.5.8 of the Sahtudene and Metis Land Claim (Canada 1993), an aboriginal harvest survey was conducted between 1998 and 2003 to assess the minimum needs level for the community (Bayha and Snortland 2002, 2003, 2004). Conservation may dictate that TAHs be implemented for the lake trout subsistence fishery. The land claim stipulates that the TAH cannot be lower than the minimum needs level, which is defined as one half of the sum of the average annual harvest over the first 5 years of the study and the greatest amount taken in any one of those 5 years (Canada 1993). The minimum needs level protects aboriginal subsistence while providing a tool to minimize fishery exploitation, should such conservative measures be required by the co-managers. In shared fisheries, the minimum needs level for subsistence is the first priority before any harvest for other purposes can occur.

Management actions—The management goal for Great Bear Lake is to conserve a high quality sport fishery, while protecting aboriginal access to a subsistence fishery (Department of Fisheries and Oceans Canada 1985). On the basis of assessment data, lodge quotas, lodge guest capacity limits, angler harvest and possession limits, and angler licensing were among the management actions taken to achieve that management goal.

Lodge regulations—Regulating lodge guest capacity has been used to control angler effort on Great Bear Lake since the 1960s (Fig. 2; Yaremchuk 1986). Under a recommendation from DFO, lodges were licensed by the Government of the Northwest Territories (GNWT) for the number of guests they could host per week. In 2002, 236 guests week^{-1} were permitted on the lake among all lodges combined (Levy and MacDonald 2003). Currently, GNWT does not require lodges to report guest capacity, in part, because the fishery adopted a catch-and-release policy (described below). The lodge licensing program for Great Bear Lake was insufficiently documented and institutional memory of the program has been lost (personal communication, Robert Redshaw, Government of the Northwest Territories, 22 March 2012). Guest-bed capacities are an important management mechanism for controlling fishing effort on remote lakes and may need to be reinstituted, should fishing effort begin to increase, and enforcement of the legislated catch and possession limits be required. On the basis of creel and experimental gillnet data, voluntary TAHs for lodges were implemented in 1988, and were accepted by lodge owners (Roberge and Dunn 1988). The 1988 lake trout TAH for each arm of the lake was as follows: Dease Arm (2,000 lake trout), north McTavish Arm (1,500), south McTavish Arm (1,500), north McVicar Arm (1,500), and Smith Arm (2,500; see Fig. 1C for management areas). The TAHs were never exceeded, in part due to reduced angling effort during the 1990s and 2000s, and in part because lodge owners voluntarily adopted catch-and-release policy as a means of further conserving the trophy fishery.

Angler regulations—Prior to 1974, the daily catch and possession limits at Great Bear Lake, were 5 and 10 lake trout, respectively (Fig. 2; Yaremchuk 1986). These limits were reduced in 1974 to 3 and 5 lake trout, and in 1979 to 2 and 3 lake trout, with the additional limitation that not more than one lake trout may be kept in excess of 700 mm fork length (i.e., tip of the snout to the fork in the tail fin). The fork length limit was implemented to reflect the trophy conservation goal of the sport fishery. In 1991, Great Bear Lake and its tributaries was designated a Special Management Area (Canada 2011). Anglers currently require both a Sport Fishing License and a Special Management Area License, which stipulates a daily catch limit of one lake trout and a possession limit of two lake trout. Daily catch and possession limits for Arctic grayling and northern pike *Esox lucius* were also reduced in 1991 from 5 and 10 fish to 2 and 3 fish, respectively. The strict regulations associated with the special management area were a proactive measure and were as much a reflection of the conservative values held by the sport lodge owners and the community of Déline as they were in response to a management concern by DFO.

As previously mentioned, lodge owners voluntarily established a catch-and-release policy, which was more restrictive than the federal regulations. Although this policy was partly driven by economics and public perception, it was partly facilitated by changes in the sport trophy industry. Historically, large lake trout were retained by anglers because their skin was required for trophy taxidermy mounts. Since the 1980s, fiberglass or graphite replicas of trophy fish have been more popular than traditional skin mounts because they look better, last longer, and the fish can be returned live to the wild. Fiberglass or graphite reproduction artists use reference photos of the live fish, and length and weight measurements to recreate the trophy; therefore, fish can be released live. Between 1972 and 1985, 68 % of lake trout were released live by anglers (range = 35–93 % across all lodges), but by 1988, nearly 91 % of all lake trout were released live (Anderson and Thompson 1991). Today, only small fish are retained for shore lunches and fishing guides require guests to release all other fish live.

Current fisheries and their management (2005-present)

Below we review the contemporary Great Bear Lake fisheries and their management. The conceptual framework we used to evaluate management was described by Krueger and Decker (1999). The framework has five steps; (1) choosing goals; (2) selecting objectives; (3) identifying problems; (4) implementing actions to overcome problems; and (5) evaluating actions to revise management. Each of these steps is to be guided by a fishery and ecology information base. Goals provide long-term statements about what fishery programs are to achieve. Objectives specify measurable, expected outcomes that indicate progress toward attainment of goals and specify a timeline for achieving those outcomes. Problem identification determines what variables and processes impede achievement of goals and objectives. Actions are activities chosen to overcome the problems, and evaluation determines whether the actions implemented helped to solve the problems and help to achieve the goals and objectives. Using this process, management can then benefit from the feedback information and redefine goals and objectives, identify new problems, and implement new actions. This process is an integral part of adaptive management (Walters and Martell 2004). In the proceeding section, we describe current management of the Great Bear Lake fishery using the context of the framework described above.

Management goals and objectives—Since 2005, management of the Great Bear Lake fishery has been guided by a management plan called the "water heart" (Great Bear Lake Working Group 2005). The plan was developed by the Great Bear Lake Working Group (Fig. 3) under the guidance of the Déline elders who provided teachings that ensured consistency of the plan with community values and priorities. The management plan is ultimately to be incorporated into the Sahtu Land Use Plan as complementary to the settlement of the land claim (Canada 1993; Sahtu Land Use Planning Board 2010).

The management vision (broad goal) for the Great Bear Lake is as follows:

> Great Bear Lake must be kept clean and bountiful for all time.

This vision reflects the beliefs and values of the Sahtudene, but also the sport fishing lodge owners in that the intention is to ensure healthy sustainable lake trout populations for generations to come. The Great Bear Lake management plan is comprehensive in that it considers all resource management, not just the fishery. The plan outlines co-management policy recommendations for land use within management zones, conservation zones, and protected areas, culture and education, research and monitoring, enforcement, contaminated site remediation, and trans-boundary issues. Within each of the six sections of the plan, a vision is stated and goals and objectives are documented. The number of objectives is extensive, and therefore, not reproduced herein (see Great Bear Lake Working Group 2005 for details). In some ways, the "objectives" of the plan are more comparable to strategies to solve problems and actions that should be taken to enhance the information or knowledge base for future decision making rather than specific end points or objectives for resource use. The need to improve the information base should not be surprising considering the remoteness of the lake and the few studies that have been conducted in the past. Whereas no specific steps were documented to identify problems, the short comings can be inferred by these "actions" that are recommended. The research and monitoring section of the management plan is also supported by a second, more detailed document entitled: "ecological and cultural research and monitoring plan" (Andrews et al. 2005). The research and monitoring plan establishes an objective-based program toward achieving the management vision.

The goal of the research and monitoring plan is as follows (Great Bear Lake Working Group 2005):

> promote and support the development of a community-based monitoring program that integrates scientific knowledge through collaborations to further understanding of ecosystem form, function, and health and the impacts of climate change on Great Bear Lake.

Research and monitoring objectives are as follows: (1) collect and analyze information to establish current environmental conditions; (2) acquire a better understanding of climate change and the effects of long-range transport of atmospheric pollutants; (3) better understand ecosystem functioning through scientific and traditional ecological research; (4) document culturally significant sites in the Sahtu; (5) document elders' place names and stories and the oral histories associated with culturally significant sites; (6) measurably increase the role that Déline plays in research and monitoring; (7) involve Déline schools, youth, teachers, and elders in the research and monitoring program; and (8) use the research and monitoring program to aid in the transmission of Sahtudene culture from the elders to the younger generations—both in the schools and on the land (Andrews et al. 2005). Like the management plan, several of the research and monitoring "objectives" are documented as strategies or actions. Unlike the water heart management plan, the research plan outlines specific projects and provides some background information, a project description, and a timeline for completing each project. The inclusion of a timeline for completion is an excellent component of the plan as this allows for accountability in the implementation of the plan.

Impediments to achieving management objectives—Fisheries and Oceans Canada uses an internal assessment tool called the "fishery stewardship and sustainability checklist" to summarize available knowledge for a particular fishery, assess the state of its current management system, and to identify gaps in knowledge or problems regarding the status of target and non-target species. The checklist was developed using Marine Stewardship Council principles for a sustainable fishery and is intended to support ecosystem-based management. Results from the 2009 analysis showed that management of the Great Bear Lake fishery could be improved. Recent population status assessments are lacking and management decision making has not been documented or subjected to formal scientific peer-review (Howland and Tallman 2005). Gaps in available data and the quality of those data were identified in the analysis; including age estimates, fishery-independent netting data, lower food web status, and fishery harvest. In addition, little is known about population structure, early life history, recruitment, and mortality for any fish species in Great Bear Lake. This paucity of data has prevented development of a fishery assessment model. To overcome some of these shortcomings, Howland and Tallman (2005) proposed a decision analysis tool that could incorporate western scientific data, TEK, stakeholder views, and social and economic concerns into management decision making for Great Bear Lake. An analytical approach, such as decision analysis, would help formalize and document the decision making process and could provide a means for dealing with uncertainties associated with managing a remote, data-limited fishery, such as the lake trout fishery of Great Bear Lake.

Below we provide a summary of the main problems that could impede fishery co-management on Great Bear Lake, and recommend actions to overcome those obstacles in moving toward achievement of the management goal. The current management challenges on Great Bear Lake are heightened by a lack of financial resources to implement management, an inadequate information base for decision making, and environmental issues that could affect lake trout populations in the future.

1. *Funding*—A major roadblock to achieving management objectives is that dedicated long-term funding for implementing the Great Bear Lake management plan has not been secured. Without commitment to funding a long-term community-based monitoring and research program to improve the information base and to guide management actions, detecting changes in the lake's biota will be difficult and identifying sources of change even more problematic.
2. *Data*—Data sets may not ever be robust enough to permit strong quantitative assessments of fish

population status in Great Bear Lake; however, if the current trend of reduced exploitation and harvest continues, management problems requiring regulatory action to restrict fisheries seem unlikely. Existing data should be consolidated into a common database to facilitate future lake trout population assessments. Lake trout population status on Great Bear Lake has not been analyzed since the late 1980s. Compiling and analyzing angler diary data (2004-2008) and data from the two DFO-SRRB experimental gillnetting programs (2000–2006) should become a priority for completion. The success of management actions during the past decade cannot be fully evaluated (the evaluation step in the management process) until lake trout population status is assessed. Several data limitations or gaps have also been identified. For example, the current fish management areas were established because lake trout populations were thought to be localized; however, that conclusion may not be accurate because it was drawn from limited data collected using technology that does not permit tracking of fish movement between marking and recapture. More powerful tools for studying fish movements are now available (e.g., acoustic telemetry) and can help reduce this uncertainty. Identifying and protecting spawning areas from anthropogenic effects is also critical to sustaining the fishery. Another impediment to data collection is that the community of Déline is currently opposed to new research (e.g., fish tagging) on fish populations, unless strong rationale and necessity of the work can be demonstrated. Apprehension by the community to engage in new projects highlights the need to resolve other management issues and fully engage the community in monitoring and assessment planning.

3. *Management structure*—Managing across jurisdictional boundaries can be complex, especially during active land claim negotiations (e.g., Deh Cho; Fig. 1b). The Great Bear Lake Working Group was a major achievement toward co-management, but that group has been inactive since completion of the management plan. Currently, management is the responsibility of DFO, with co-management responsibilities under the Sahtu landclaim including Déline Renewable Resource Council, and the Sahtu Renewable Resource Board. To achieve timely revision of the management plan, the question of whether to reconvene the Great Bear Lake Management Group or to establish a new technical fisheries working group should be answered. If ecosystem management at the level of the whole Great Bear Lake watershed is the goal, then the working group will have to expand to accommodate other jurisdictions.
4. *Anthropogenic change*—The Mackenzie Gas Project proposes natural gas field development in the Mackenzie Delta and delivery to southern markets via a pipeline extending through the Mackenzie Valley within the Great Bear Lake watershed (Stein et al. 1973). Permanent roads associated with the pipeline project would facilitate further development within the watershed and possible increased exploitation of fishery resources. Currently, the lake is only accessible by air or winter ice-road. The Northwest Territories Power Corporation partnered in 2004 with the Déline Land Corporation to create a subsidiary, the Sahdae Energy Limited, for the purpose of pursuing hydroelectric development of the Bear River. Construction of a 120 MW project is proposed for 2014–2017 (GNWT 2007). In addition, diamond-bearing kimberlite, other minerals, and oil explorations are ongoing within the Great Bear watershed. If deposit extraction begins, these developments could affect the ecology of Great Bear Lake. Obtaining baseline data from the watershed now will help rapid detection and possible mitigation of potential impacts associated with future development.
5. *Climate change*—Climate change is perhaps the most eminent issue for northern ecosystems. The Intergovernmental Panel on Climate Change (IPCC) reported that 11 of the past 12 years (1850–2006) were among the warmest years in the record of global surface temperature (IPCC 2007). In the Arctic, extensive land areas showed a 20th century warming trend in air temperature of up to 5 °C (IPCC 2007). Mean ice cover duration has decreased by 2–3 weeks for the majority of lakes in the Canadian Arctic; however, Great Bear Lake and Great Slave Lake show a slightly longer ice cover duration by about 1 week over the 14-year time series (Duguay et al. 2011). This trend may reverse in the future. Lake trout are

cold-water stenotherms and their optimal temperature for growth is between 10 and 12 °C (Christie and Regier 1988), but only about 30 % of the thermal habitat currently available in Great Bear Lake falls within that range (Melville 1997). If water temperature increases in Great Bear Lake, the preferred thermal niche for lake trout and its prey (*Coregonus* spp.) may expand, growing season may increase in duration, and overall productivity of the lake may increase. Increased lake productivity will result in a host of management issues ranging from a complete ecological regime shift to possibly renewed interest in commercial fishery development. Management actions will be needed to address potential outcomes of climate change.

6. *Contamination*—The Eldorado Mine at Port Radium released high levels of arsenic (1.0–4.4 ppm), radionuclides, heavy metals including mercury, and resulting water turbidity was high (5,000–8,400 JTU) in the eastern end of Great Bear Lake. Levels of heavy metals in fish and bottom sediments in the area were higher than background data from elsewhere in the lake (Falk et al. 1973b, c; Moore and Sutherland 1981); however, levels in fish were not considered in excess of those recommended for human consumption (Falk et al. 1973b), nor were they considered harmful to fish (Moore and Sutherland 1981). Several other mines elsewhere in the watershed, including Terra, Northrim, Norex, Smallwood, and Contact Lake could also affect water quality within the Great Bear Lake watershed. These mines are being assessed for remediation, or are being remediated. Clean-up projects will help improve the health of fish stocks and possibly humans consuming fish. Future contamination associated with the Mackenzie Gas Project and the Bear River hydroelectric project are possible, should be predictable, and practices to mitigate these potential threats should be developed.

Evaluation of management actions (2005-present)—With the exception of a barbless hook policy in 2003, no new fishery management actions have been implemented on Great Bear Lake since 1991. The success of historic actions can be attributed to strong community and stakeholder support as well as to coincident changes in the sport-tourism industry. Strict catch and possession limits, as well as a catch-and-release policy have greatly reduced exploitation compared to the 1970s, the period of greatest exploitation. The current economic climate has reduced lodge bookings, resulting in closure of five of the six lodges on the lake; therefore, angling effort and harvest have steadily declined since the 1970s. Despite these changes, the life history characteristics of the lake's fish populations—long-lived, late age-at-maturity, and slow growth—means that a long time is required for recovery ($\sim$50 years), and those populations are probably still rebuilding from high exploitation between 1970 and 1980. The population status of lake trout should be reassessed.

Recommended actions to address problems—The "water heart" management plan and supporting research and monitoring plan specified a 10–15 years lifespan. Co-managers are currently beginning to consider evaluating and revising the plans. On the basis of our review and understanding of the major obstacles to management, we offer the seven recommendations below to the Great Bear Lake co-managers as they move forward.

1. *Adopt ecosystem management and resilience thinking*—Ecosystem management was defined by Meffe et al. (2002) as *An approach to maintaining or restoring the composition, structure, and function of natural and modified ecosystems for the goal of long-term stability.* This philosophy is based on a joint vision of desired future conditions that integrates ecological, socioeconomic, and institutional perspectives, and is applied at a broad geographical scale, such as the whole watershed. Under ecosystem management, the lake trout within specific management areas would cease to be the central focus of management and the structure and function of the Great Bear Lake watershed would become the focus. The concept of ecosystem management is adaptive and community-based; and therefore, consistent with aboriginal views of the world where everything, including humans is interconnected. The ecosystem management concept is also consistent with DFO's Sustainable Fisheries Framework. The community of Déline and DFO recognize the need to implement whole system management. Primary (i.e., algae) and

secondary (i.e., invertebrate) production in Great Bear Lake is currently limited by temperature and phosphorous. If global climates warm, we expect the nearshore zone of productivity in the lake to expand due to a greater availability of warm water and possibly increased overland phosphorous inputs. We do not expect that change will be great enough to affect the offshore waters. Understanding the current structure and function of the ecosystem will be important for adapting to those changes.

An ecosystem management approach that encompasses resilience thinking can provide a means to understand how the lake may adapt to anthropogenic and climate change. Resilience can be defined as the capacity of a system to absorb disturbance and still retain its basic function and structure (Walker and Salt 2006)—that is, its ability to return to a stable state following a disturbance. In ecology, resilience can also refer to systems in a non-stable state, where instabilities can shift a system into a completely different state. In this case, resilience refers to the amount of change that the system can absorb before it is completely restructured to another state (i.e., regime shifts; Gunderson et al. 2002). Given the northern location of Great Bear Lake, its paucity of species, and low biological productivity, the lake may not be able to absorb the disturbance associated with climate and anthropogenic change without shifting states. Resilience thinking is a way of understanding and engaging a changing world—considering the ability of Great Bear Lake to adapt to these changes will promote the successful management of the lake and its fishery for generations to come. Proactive ecosystem management that includes resilience thinking should be considered when the next revision of the management plan is undertaken.

2. *Establish a technical aquatic resource committee*—We recommend establishing a technical aquatic resource team consisting of select community elders, fishers, and leaders, federal and territorial scientists, and possibly academics to assist with the revision of the existing management plan and to guide plan implementation. Replacing the large, 20-member Great Bear Lake Working Group with a more focused and smaller group of technical experts and resource users may streamline the management process. On the basis of coordinated research results, the technical fisheries team could then make management recommendations to the co-managers for decision making. Déline elders are concerned about the invasiveness of scientific investigations and are concerned about engaging in new research that is uncoordinated and inconsistent with community concerns. A technical fishery team with community participation could help alleviate community concerns by coordinating research, prioritizing projects, and facilitating collaboration among researchers. Vetting new research through a technical fisheries team would ensure collaboration, peer review, and community support and oversight. Enhanced communication, using technologies, such as community television broadcasting, between the technical committee and the community may help garner community support for the implementation of technical committee projects.
3. *Reformulate the management and research and assessment plans*—The current management and research plans have been an excellent step toward conserving the ecological integrity of Great Bear Lake; however, the plans possess some shortcomings relative to the management process model presented by Krueger and Decker (1999; described above). For example, many of the objectives identified in the plans are unclear, fail to specify measurable outcomes, and do not indicate a date for accomplishment. For example, the "objectives" documented in the research and monitoring plan, are a mixture of actions and goals (c.f., Krueger and Decker 1999). During revision of the management plan, the technical working group should consider that management objectives are not methodological steps (e.g., collect data, conduct experiments, analyze data, write report), rather, objectives should specify measurable, expected outcomes that indicate progress toward attainment of goals and specify a timeline for achieving those outcomes. Making this change to the plans will increase accountability and facilitate effective evaluation of management actions that provide leaning and information to revise the management objectives.

One means of achieving this recommendation would be to develop a DFO Integrated Fisheries Management Plan (IFMP).

Fisheries and Oceans Canada employs a national model for developing an IFMP. An IFMP is not unlike the current "water heart" plan in that it is collaborative (i.e., integrates all levels of government and users) and defines collective goals and objectives for the fishery, but an IFMP would also incorporate performance measures (objectives) and timelines, which are generally lacking in the current management plan. The primary goal of an IFMP approach is to provide a planning framework for the conservation and sustainable use of fishery resources and the process by which a particular fishery will be managed for the specified time period. The IFMP model also incorporates all components of the management cycle described by Krueger and Decker (1999) by providing a clear and concise summary of the characteristics of fishery, scientific aspects, management objectives, management measures used to achieve those objectives, and evaluation criteria for management actions.

4. *Plan and implement evaluation studies*—A second shortcoming of the current management plan is a lack of explicit evaluation and monitoring criteria with timelines for completion. Evaluation of management actions, in terms of their effectiveness is moving towards measurable objectives that support management goals, is the critical step required to close the loop of the management process. This step is part of what makes a management plan adaptive in that goals and objectives can be recast in light of new knowledge and the cycle of new actions and evaluation will then continue. Reporting research and assessment data is central to our ability to evaluate management actions and to building an information base from which to generate informed decisions. Efforts toward achieving several of the eight research projects described in the fishery section of the research and monitoring plan (Andrews et al. 2005) are ongoing, but accountability for reporting results is lacking. An IFMP would lay out the commitments and timelines, as well as performance measures and necessitate a greater commitment for reporting results of research and assessment programs on Great Bear Lake. We recommend that all data be analyzed and reported prior to management plan evaluation.
5. *Learn from other management plans*—As the process of evaluating past management actions and revising management goals and objectives unfolds, the co-managers should draw upon the experience in both successful and unsuccessful (e.g., Murray 2007) management programs elsewhere to help guide the revision and implementation of a fishery management plan for Great Bear Lake. The guide for the rehabilitation of lake trout in Lake Michigan provides one good example of an explicitly defined management goal and clear objectives toward that goal (Bronte et al. 2008).
6. *Conduct community-based monitoring*—The original Great Bear Lake management plan called for development and implementation of a community-based monitoring program (CBMP) to collect data adequate for the maintenance of the ecological and cultural integrity of the watershed. Community involvement in resource management is essential to achieving the objectives outlined in the Great Bear Lake management plan. We recommend that a timeline and strategy be developed to shift some fishery management, assessment, and enforcement responsibilities to the community of Déline. The community could monitor subsistence fishery harvest and use practices, issue licenses, patrol activities in the watershed, and provide logistical support and aid in fishery research and monitoring (Great Bear Lake Working Group 2005). Community-based monitoring occurs in Alaska. For example, at the George River weir in the Kuskokwim River drainage (Linderman and Bergstrom 2009), local residents and the Alaska Department of Fish and Game collaborate to annually count migrating salmon and sample the harvest for age, sex, and length. A CBMP would be an important determinant of the success of any fishery management responses to changes in the resource, would advance our knowledge base of Great Bear Lake ecology, would provide much more rapid detection of change, and if implemented each year, could build an important time-series dataset to study the effects of climate change and build environmental monitoring capacity in the local community.
7. *Develop and use a joint strategic co-management structure*—A complicated co-management

structure emerged from the land claim and the Mackenzie Valley Resource Management Act. Coordinating the 20 parties of the 2002 Great Bear Lake Working Group was a major challenge. This management structure will be further complicated, and the political divide will broaden, if the Tli Cho and the Deh Cho come to the table under their land claims. Critical to the effectiveness of a revised Great Bear Lake plan, will be the adoption and use of a process for all parties to interact effectively. Gaden et al. (2008) provided an example of how the development and use of a joint strategic plan can help disparate parties cooperate across jurisdictional boundaries by implementing four strategies—consensus, accountability, information sharing, and ecosystem management. We recommend that a joint-strategic plan among the management jurisdictions be developed to clearly articulate the roles and responsibilities of each party involved in the management of Great Bear Lake fishery. This plan is consistent with an aboriginal model for consensus decision making and will help facilitate coordination, accountability, information exchange, and resource sharing (Gaden et al. 2009).

Summary and conclusions

Changes in regulations, sport trophy and tourism industries, subsistence resource use, and social and cultural norms and practices have all contributed to changes in the Great Bear Lake fishery and its management. As a result of these changes, sport and subsistence fishery harvests have steadily declined over the past three decades. Going forward, anthropogenic impacts and climate change are two of the most significant issues facing co-management of the lake's resources. We offer four proactive recommendations to co-managers as they begin to develop adaptive strategies for dealing with management and ecological uncertainties and revise the Great Bear Lake management plan. These recommendations are as follows: (1) adopt ecosystem management and resilience thinking; (2) develop a joint strategic co-management structure, which includes other jurisdictions within the Great Bear Lake watershed; (3) establish a technical committee to reformulate the management and research and assessment plans drawing on other management plans as models, and to develop and implement studies to evaluate management actions; and (4) secure funding to develop and build capacity for a community-based fishery monitoring program. In closing, we intend our synthesis to advance fishery management towards the vision of *keeping Great Bear Lake clean and bountiful for all time.*

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