

Production and dispersion of freshwater, anadromous, and marine fish larvae in and around a river plume in subarctic Hudson Bay, Canada

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Abstract. From 1988 to 1990, fish larvae were sampled before, during, and after ice breakup within and outside the plume of the Great Whale River off Kuujuaupik, southeastern Hudson Bay, Canada. Arctic cod (*Boreogadus saida*) and sand lance (*Ammodytes* spp.) were the most abundant larvae. Half of the larval fish taxa emerged before the ice broke up in the Bay. The highest densities of Arctic cod, sand lance, slender eelblenny, and gelatinous snailfish larvae were in salinities exceeding 25 practical salinity units (p.s.u.). Arctic shanny, sculpins, and capelin larvae were more abundant at salinities between 1 and 25 p.s.u.. Burbot and coregonid larvae were clearly associated with fresh or brackish waters even when caught in the Bay. The timing and extent of the Great Whale River freshet influenced the distribution of marine fish larvae in southeastern Hudson Bay and determined the moment when the larvae of anadromous and freshwater species entered the Bay.

Arctic and subarctic seas are characterized by a short season of production which begins with the development of ice algae at the ice bottom (Apollonio 1961; Horner 1976; Alexander 1980). Fish larvae emerging in these environments often present a protracted larval phase due to poor feeding conditions and slow growth (Houde 1989). Because of this slow development and the short production season, fish larvae are presumably more likely to encounter adverse environmental conditions at these high latitudes than at lower latitudes (Houde 1989). Hence, the timing of spawning (Cushing 1975) and the selection of

favorable spawning sites by adults (Iles and Sinclair 1982) should be particularly critical for the recruitment success of fish species inhabiting Arctic and subarctic environments.

Hudson Bay is a large subarctic inland sea usually covered by ice from December to early June (Markham 1986; Larouche and Galbraith 1989). Several studies have been conducted on the distribution and basic biology of adult fish in this area (Vladykov 1933; Hunter 1968; Auger and Power 1978; Morin et al. 1980; Morin and Dodson 1986) especially for anadromous coregonids (Dymond 1933; Kemp et al. 1989; Morin et al. 1981). Yet, except for a study of the ichthyoplankton assemblage of the Eastmain River estuary, James Bay (Ochman and Dodson 1982), the early life history of both marine and anadromous species in the general area of Hudson Bay is poorly known.

In southeastern Hudson Bay primary and secondary production dynamics have been intensively studied (Gosselin et al. 1985, 1986, and 1990; Legendre et al. 1981 and 1989; Runge and Ingram 1988; Runge et al. 1991; Tourangeau and Runge 1991). Research on the early life history stages of fish has been initiated only recently and has focused on the survival (Drolet et al. 1991), feeding success (Gilbert et al. 1992), and vertical distribution (Ponton and Fortier 1992) of marine fish larvae in relation to light and food availability under the ice cover.

In this paper we present the seasonal occurrence and general distribution of the larval stages of freshwater, anadromous and marine fish sampled in and around the plume of the Great Whale River in the spring and early summer of 1988, 1989 and 1990. In particular, we relate the timing of the emergence of the different species to the development of the river plume and the breakup of the ice cover in the Bay. Previous information on the spawning strategy and early life history of Arctic and subarctic fish is reviewed and discussed in the light of this new data set.

Materials and methods

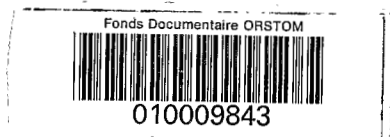
Study area

The waters of southeastern Hudson Bay are strongly influenced by freshwater inputs from rivers. The Great Whale River (Fig. 1) is one

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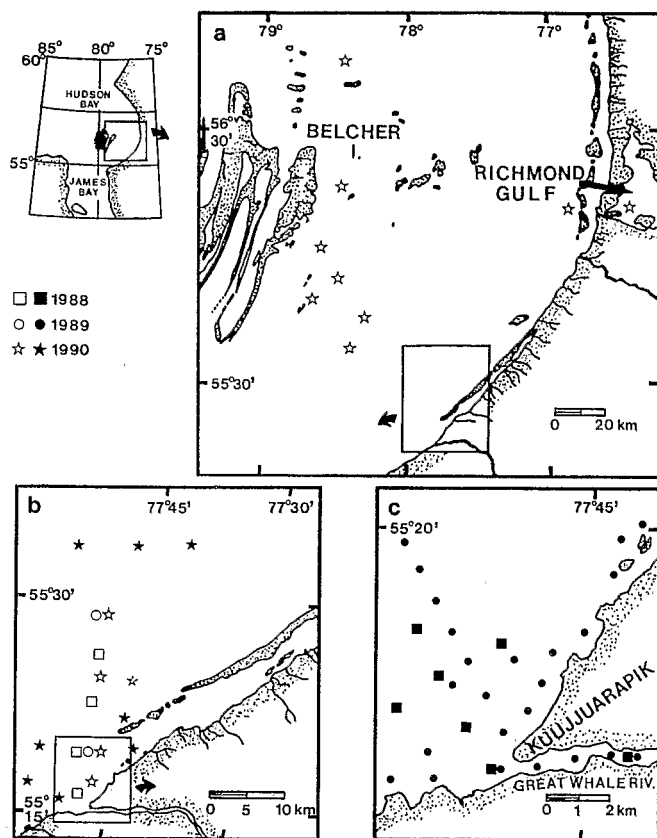


Fig. 1. Sampling stations in southeastern Hudson Bay, Canada. Open symbols: location of underice sampling with snowmobiles (UIS) and open-water sampling by helicopter (HS). Solid symbols: open water stations sampled from a boat (BS)

of the most important sources of freshwater in the Bay. At the freshet in May, its outflow increases from $135\text{--}200\text{ m}^3\cdot\text{s}^{-1}$ to ca. $900\text{ m}^3\cdot\text{s}^{-1}$, forming a plume that extends NNE under the ice of the Bay over a 1000 km^2 area (Ingram 1981; Ingram and Larouche 1987). Ice generally breaks up around May 20 in the Great Whale River (Wilson 1973), i.e., about 10 days earlier than in the Bay itself off Kuujjuarapik. Once the pack-ice has broken up, increased wind stress and larger tidal flow induce rapid mixing of the plume waters with the underlying saline waters, hence reducing stratification in the Bay (Lepage and Ingram 1991).

Sampling techniques and data treatment

Two to four stations located on a 20-km transect heading northward from the mouth of the Great Whale River were sampled before, during and after ice breakup (April to June) in 1988, 1989, and 1990 (Fig. 1b). As ice broke up, open-water stations were added in the lower part of the River and along the Kuujjuarapik coastal area (Fig. 1c). Several ichthyoplankton samples were obtained also in the Richmond Gulf and Belcher Islands areas in June 1990 (Fig. 1a).

Sampling methods were adjusted for changes in ice-cover conditions (Table 1). Under ice cover, two 1 m^2 , $500\text{ }\mu\text{m}$ mesh plankton nets fitted side by side on a rectangular metal frame were used to sample horizontally at depths of 0–2 m and ca. 6–8 m (ca. 8–10 m in 1988). These nets were attached to a cable forming a loop between two holes separated by 150 m (200 m in 1988) and towed with a heavy-duty snowmobile. After ice breakup, a 1 m diameter, $500\text{ }\mu\text{m}$ mesh conical net with an $80\text{ }\mu\text{m}$ mesh rigid codend was towed at

Table 1. Characteristics of sampling for each period. UIS: underice sampling, HS: helicopter sampling, and BS: boat sampling (see explanation in text)

Year	1988			1989			1990		
sampling periods	24 Apr to 27 May	23 May to 14 Jun	20 May to 13 Jun	19 Apr to 30 May	31 May to 9 Jun	16 Jul to 20 Jul	21 Apr to 2 Jun	3 Jun to 11 Jun	1 Aug to 7 Aug
type of sampling	UIS	HS	BS	UIS	BS	BS	UIS	HS	BS
number of stations	4	4	3	2	6	28	3	13	22
sampling depth (m)	0–2 and 8–10	0–2 and 8–10	0–2	0–2 and 6–8	0–2	0–2	0–2 and 6–8	0–2 and 6–8	7 to 26
total number of samples	59	74	83	58	41	46	79	46	37
mean sampling speed ($\text{m}\cdot\text{sec}^{-1}$) \pm SD	1.1 ± 0.2	1.0 ± 0.2	1.5 ± 0.1	1.1 ± 0.1	1.0 ± 0.2	1.2 ± 0.3	0.9 ± 0.2	0.6 ± 0.3	0.8 ± 0.2
total effort (min)	187	894	769	127	411	460	235	326	465
mean volume of water filtered per sample (m^3) \pm SD	371 ± 29	539 ± 144	653 ± 147	284 ± 28	527 ± 38	496 ± 66	324 ± 37	342 ± 104	356 ± 113

similar depths from a float-mounted helicopter that alighted in ice-free areas near the sampling locations. Details of both underice (UIS) and helicopter (HS) sampling are described in Drolet et al. (1991) and Gilbert et al. (1992). In ice-free conditions, a 1 m diameter, 6 m long and 500 μ m mesh size net was pulled by a 35 HP power-boat. Boat sampling (BS) was limited to the surface layer (0–2 m) except in August 1990 when a more powerful boat equipped with a winch allowed sampling between 7 and 26 m depths using the same net. Filtered volume was measured with a calibrated TSK flowmeter installed in the center of the net opening. Depending on the sampling technique, nets were towed from 3 to 15 min and average filtered volumes ranged from 284 m³ to 653 m³ (Table 1). All samples were preserved in 4% neutralized formalin.

A CTD profile was obtained with a portable Seacat probe before plankton sampling at each station. Temperature ($^{\circ}$ C) and salinity (practical salinity units p.s.u.) values were later associated with each ichthyoplankton sample. They were calculated as the arithmetic means of the observations in a 2 m thick water layer corresponding to the plankton sampling depth.

All larvae were sorted, counted and measured to the nearest 0.1 mm. Most of marine fish larvae were identified according to Fahay (1983). Other descriptions used were from Dunn and Vinter (1984) for *Boreogadus saida*, Faber (1976) for Stichaeidae and Lumpenidae, Cucin and Faber (1985) for *Coregonus clupeaformis*, *C. artedii* and *Lota lota*, Auer (1982) for other freshwater species and Khan (1971) for larvae of *Myoxocephalus* spp.

Results

Temperature and salinity

Our sampling design allowed us to cover most of the temperature-salinity conditions existing in spring and summer in the coastal area of southeastern Hudson Bay. Under the ice cover in April–May, the cold ($< -1^{\circ}$ C) and saline (> 25 p.s.u.) marine layer mixed little with the warmer ($> 0^{\circ}$ C) and brackish (< 5 p.s.u.) plume of the Great Whale River (Fig. 2a). Mixing increased in June when ice broke up in the Bay (Fig. 2b). The July–August period presented a classical estuarine situation where the warm freshwater progressively mixed with the cold, marine Hudson Bay water (Fig. 2c).

Larval fish community

Individuals from 21 species belonging to 12 families were caught over the three-year period (Table 2). Arctic cod (*Boreogadus saida*) and sand lance (*Ammodytes* spp.) contributed 50.4% and 37.9% of the total respectively. Burbot (*Lota lota*), Stichaeidae (Arctic shanny, *Stichaeus punctatus*) and slender eelblenny, *Lumpenus fabricii*, Cottidae (Arctic staghorn sculpin *Gymnocanthus tricuspidis* and other sculpins *Myoxocephalus* spp.), Cyclopteridae (gelatinous snailfish, *Liparis fabricii*) and Osmeridae (capelin, *Mallotus villosus*) were one order of magnitude less abundant. Salmonidae represented 0.25% of the larvae with 26 cisco (*Coregonus artedii*) and 6 lake whitefish (*C. clupeaformis*). Other species were scarcer.

Seasonal occurrence and abundance

Larvae from 56% of the fish taxa emerged before the ice breakup in the Bay (Fig. 3). Arctic cod (*Boreogadus saida*)

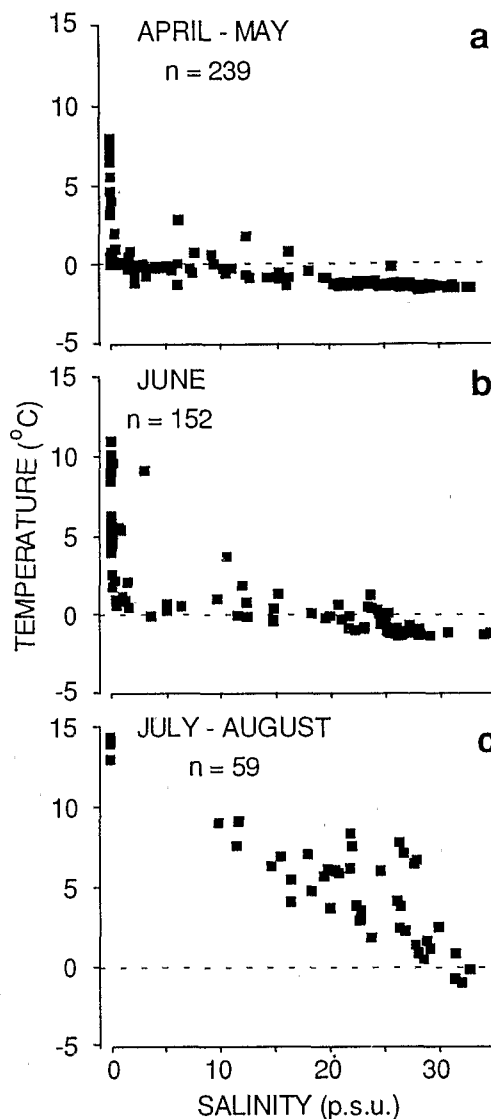


Fig. 2a–c. Temperature-salinity values observed at depths of ichthyoplankton sampling in April–May (a), June (b), and July–August (c)

and sand lance (*Ammodytes* spp.) were first to appear at the end of April and persisted throughout each sampling period. Hatching of Arctic cod probably began earlier than our sampling as some individuals were present in the very first collections (Fig. 3). Larvae of burbot (*Lota lota*) and coregonid (*Coregonus* spp.) which hatched in the Great Whale River, first occurred in the Bay in early and late May respectively, i.e. generally just before and after ice breakup in the River. Larvae of two freshwater species, lake chub (*Couesius plumbeus*) and longnose sucker (*Catostomus catostomus*), occurred in July in the lower part of the River. Hatching of Arctic alligator fish eggs (*Aspidophoroides olkiri*) probably began in early June as some yolk-sac larvae were sampled at that time. Capelin (*Mallotus villosus*) and Greenland cod (*Gadus ogac*) larvae did not occur until July.

Arctic cod (*Boreogadus saida*) and sand lance (*Ammodytes* spp.) densities ranged between 5 and 50 larvae per

Table 2. List of the larval fish species caught in the southeastern coastal zone of Hudson Bay and in the Great Whale River. Uncertain identifications are in brackets

Scientific name	Common name	Total number captured
Salmoniformes		
Salmonidae		
Coregoninae		
<i>Coregonus artedii</i> LeSueur, 1818	cisco	26
<i>C. clupeaformis</i> (Mitchill, 1818)	lake whitefish	6
Osmeridae		
<i>Mallotus villosus</i> (Müller, 1777)	capelin	88
Cypriniformes		
Cyprinidae		
[<i>Couesius plumbeus</i> (Agassiz, 1850)]	[lake chub]	3
Catostomidae		
<i>Catostomus catostomus</i> (Forster, 1773)	longnose sucker	4
Gadiformes		
Gadidae		
<i>Boreogadus saida</i> (Lepechin, 1774)	Arctic cod	6420
<i>Gadus ogac</i> Richardson, 1836	Greenland cod	5
<i>Lota lota</i> (Linnaeus, 1758)	burbot	334
Perciformes		
Stichaeidae		
<i>Lumpenus [fabricii]</i> (Valenciennes, 1836)	[slender eelblenny]	148
<i>Stichaeus punctatus</i> (Fabricius, 1780)	Arctic shanny	498
Pholidae		
<i>Pholis [fasciata]</i> (Bloch and Schneider, 1801)	[banded gunnel]	1
Ammodytidae		
<i>Ammodytes</i> spp.		
[<i>A. americanus</i> DeKay, 1842 and <i>A. dubius</i> Reinhardt, 1838]	[American sand lance and northern sandlance]	4830
Cottidae		
<i>Gymnocanthus tricuspis</i> (Reinhardt, 1832)	Arctic staghorn sculpin	102
<i>Icelus</i> sp.		
[<i>I. bicornis</i> (Reinhardt, 1841) or <i>I. spatula</i> Gilbert and Burke, 1912]	[two-horn sculpin or spatulate sculpin]	4
<i>Myoxocephalus quadricornis</i> (Linnaeus, 1758)	fourhorn sculpin	152
<i>M. scorpioides</i> (Fabricius, 1780)	Arctic sculpin	
<i>M. scorpius</i> (Linnaeus, 1758)	shorthorn sculpin	
<i>Triglops</i> sp.		
[<i>T. murrayi</i> Günther, 1888 or <i>T. pingeli</i> Reinhardt, 1832]	[moustache sculpin or ribbed sculpin]	9
Agonidae		
<i>Aspidophoroides olriki</i> Lütken, 1876	Arctic alligatorfish	6
Cyclopteridae		
<i>Liparis [fabricii]</i> Kroyer, 1847	[gelatinous snailfish]	90
Pleuronectiformes		
Pleuronectidae		
<i>Hippoglossoides platessoides</i> (Fabricius, 1780)	American plaice	19

100 m³ (Fig. 4a and b). Arctic cod densities sometimes exceeded 100 larvae per 100 m³ (Fig. 4a) and the maximum (470 larvae per 100 m³) was observed at a station off the Gulf of Richmond. Other species seldom reached densities in excess of 5 · 100 m⁻³. *Coregonus* spp. larvae were always scarce in the Bay or the River where densities never exceeded 1 · 100 m⁻³ (Fig. 4j).

Larval abundance, water salinity and temperature

Larval distribution with respect to salinity and temperature varied between species and over time (Table 3). The highest densities of sand lance (*Ammodytes* spp.) larvae

were always found in cold waters of salinity exceeding 25 p.s.u.. Similar trends were observed for gelatinous snailfish (*Liparis fabricii*). Arctic cod (*Boreogadus saida*) and slender eelblenny (*Lumpenus fabricii*) larvae were more abundant in waters of intermediate to high salinity (15–25 p.s.u.) and low temperature (–1.3 to 0.8°C) in April–May (Table 3, Wilcoxon test, $P=0.049$). In June, both Arctic cod and sand lance larvae were much more abundant at salinities >25 p.s.u. and found only in small numbers, albeit regularly, in warmer waters of low salinity (Table 3). Arctic shanny (*Stichaeus punctatus*), sculpins (*Myoxocephalus* spp. and *Gymnocanthus tricuspis*) and capelin (*Mallotus villosus*) larvae were more abundant in waters of salinity and temperature ranging respectively

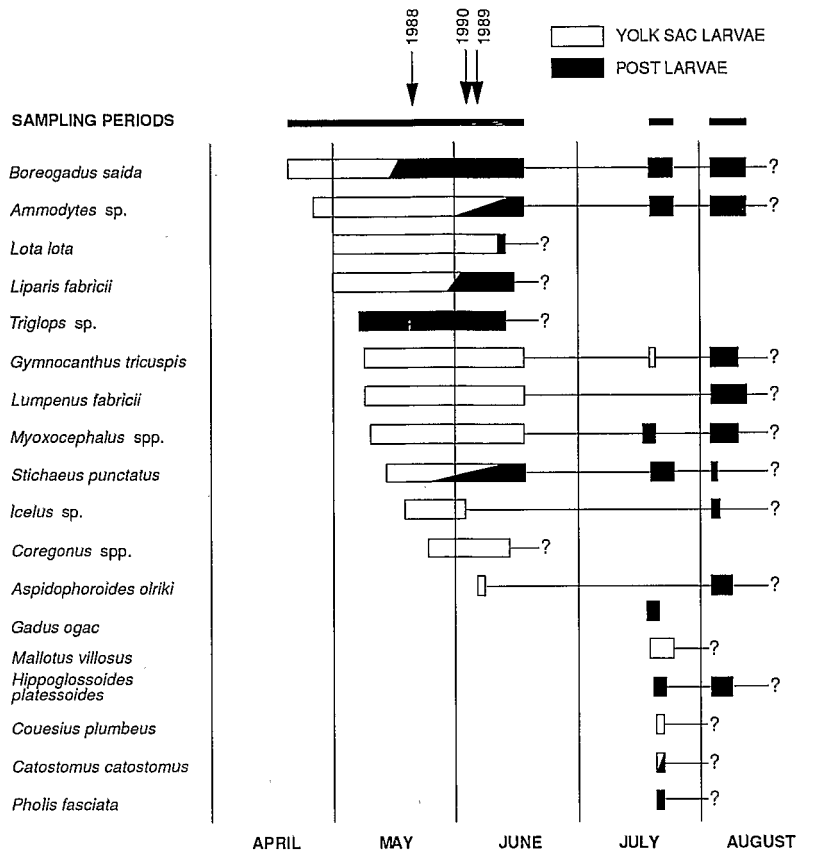


Fig. 3. Seasonal occurrence of all the larval fish species caught during 1988–1990. Arrows indicate the beginning of ice breakup in the Bay off Kuujjuarapik. Note that ice breakup generally occurred ten days earlier within the Great Whale River itself

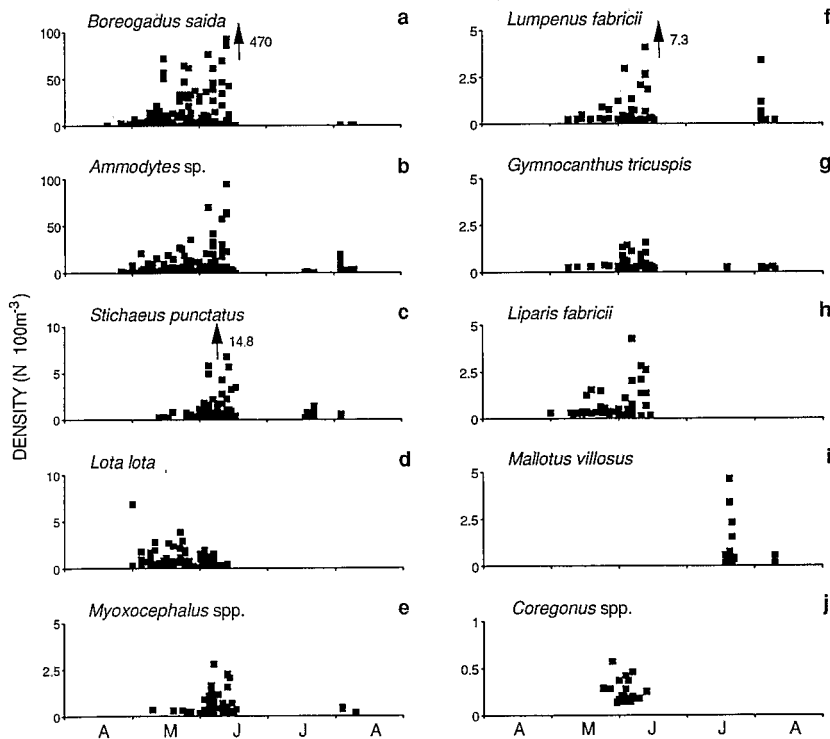


Fig. 4a–j. Densities of the ten most abundant species caught during 1988–1990. Null densities are not represented for clarity

Table 3. Occurrence (percent of samples in which the species was present) and mean densities ($N/100m^{-3}$) of the ten most abundant species at various salinities (practical salinity units p.s.u.) and corresponding temperature ranges ($^{\circ}C$) for the three sampling periods. SD: standard deviation, *P*: associated probability of the Kruskal-Wallis test of differences between mean densities

	APRIL-MAY				JUNE				JULY-AUGUST			
Salinity (p.s.u.)	>1	1-15	15-25	>25	>1	1-15	15-25	>25	>1	1-15	15-25	>25
Temperature	0	-1.3	-1.3	-1.5	0.6	-0.5	-1.0	-1.3	13.0	6.6	1.9	-1.0
ranges (°C)	to 8.0	to 2.9	to 0.8	to -0.1	to 10.8	to 9.0	to 1.4	to 0.2	to 14.3	to 9.3	to 8.4	to 8.1
Marine water species												
<i>Boreogadus saida</i>												
Occurrence	24	45	97	78	25	58	67	76	0	0	0	14
Mean Density	0.84	3.40	9.78	8.61	0.65	1.37	0.78	12.55	0	0	0	0.50
SD	3.77	10.43	16.81	17.28	1.99	2.45	1.46	19.94	-	-	-	0.12
P		<0.0001				<0.0001				-		
<i>Ammodytes</i> sp.												
Occurrence	54	59	89	74	35	79	78	82	0	20	55	85
Mean Density	1.18	1.87	3.03	4.02	0.87	1.43	0.67	9.73	0	0.04	0.81	2.21
SD	2.23	5.29	3.05	5.60	1.73	1.84	0.76	14.33	-	0.09	2.23	3.30
P		<0.0001				<0.0001				<0.0001		
<i>Lumpenus fabricii</i>												
Occurrence	0	0	17	11	1	5	27	47	0	0	5	24
Mean Density	0	0	0.07	0.05	<0.01	<0.01	0.07	0.27	0	0	0.06	0.09
SD	-	-	0.18	0.17	0.01	0.02	0.17	0.45	-	-	0.26	0.19
P		<0.0001				<0.0001				<0.0001		
<i>Liparis fabricii</i>												
Occurrence	10	12	22	11	1	10	0	23	0	0	0	0
Mean Density	0.03	0.03	0.06	0.08	<0.01	0.02	0	0.43	0	0	0	0
SD	0.10	0.09	0.11	0.28	0.01	0.05	-	0.98	-	-	-	-
P		0.4400				0.0002				-		
Brackish water species												
<i>Stichaeus punctatus</i>												
Occurrence	4	10	25	14	9	63	72	44	0	20	45	5
Mean Density	0.03	0.05	0.18	0.06	0.03	1.16	1.45	0.32	0	0.16	0.34	0.03
SD	0.13	0.15	0.43	0.20	0.10	1.65	3.32	0.58	-	0.35	0.50	0.12
P		0.0235				<0.0001				0.0020		
<i>Myoxocephalus</i> spp.												
Occurrence	1	4	3	6	4	47	50	23	0	0	5	9
Mean Density	<0.01	0.02	<0.01	0.02	<0.01	0.37	0.26	0.13	0	0	0.02	0.03
SD	0.03	0.13	0.05	0.07	0.03	0.69	0.54	0.28	-	-	0.10	0.09
P		0.5742				<0.0001				0.6300		
<i>Gymnocanthus tricusps</i>												
Occurrence	6	8	8	3	4	47	22	18	0	0	5	19
Mean Density	0.02	0.03	0.06	0.01	0.02	0.23	0.08	0.06	0	0	0.01	0.04
SD	0.07	0.12	0.24	0.10	0.13	0.39	0.18	0.16	-	-	0.06	0.09
P		0.6082				0.0001				0.1830		
<i>Mallotus villosus</i>												
Occurrence	0	0	0	0	0	0	0	0	8	100	20	5
Mean Density	0	0	0	0	0	0	0	0	0.01	1.88	0.08	<0.01
SD	-	-	-	-	-	-	-	-	0.04	2.00	0.17	0.04
P		-				-				<0.0001		
Freshwater species												
<i>Lota lota</i>												
Occurrence	51	10	25	7	37	5	0	9	0	0	0	0
Mean Density	0.60	0.13	0.07	0.05	0.23	0.01	0	0.04	0	0	0	0
SD	1.12	0.51	0.13	0.22	0.45	0.06	-	0.13	-	-	-	-
P		<0.0001				<0.0001				-		
<i>Coregonus</i> spp.												
Occurrence	15	2	0	0	14	0	0	0	0	0	0	0
Mean Density	0.04	<0.01	0	0	0.03	0	0	0	0	0	0	0
SD	0.11	0.02	-	-	0.09	-	-	-	-	-	-	-
P		<0.0001				-				-		

Table 4. Mean length of Arctic cod larvae caught in Kuujjuarapik (K), Richmond Gulf (RG), and Belcher Islands (BI) areas in 1990. Z: Mann-Whitney statistic and P: associated probability

Area	Date	Nb of stations	Nb of larvae	% yolk-sac larvae	Mean standard length (mm) \pm SD	Z	P
K	2 Jun	3	127	2.4	6.23 \pm 0.72	4.63	<0.0001
RG	3 Jun	3	405	2.7	5.91 \pm 0.72		
K	5 Jun	3	296	0.3	7.47 \pm 0.64	7.21	<0.0001
BI	6 Jun	3	22	0	5.71 \pm 0.71		
K	11 Jun	3	556	1.9	7.99 \pm 0.75	17.39	<0.0001
BI	12 Jun	3	144	0	6.06 \pm 0.64		

from 1 to 25 p.s.u. and from -1.3 to 9.0°C (Table 3). This trend was already present in April–May for Arctic shanny but developed only later for sculpins. Most burbot (*Lota lota*) and all coregonid (*Coregonus clupeaformis* and *C. artedii*) larvae were clearly restricted to the warm ($>0^{\circ}\text{C}$) and fresh or low salinity waters of the River or its plume (Table 3).

Spatial variations in size distributions

Differences in the size distribution of Arctic cod were detected at the larger geographic scale surveyed in June 1990 (Table 4). At a given date, the larvae caught near Kuujjuarapik were significantly larger than those captured in the Richmond Gulf and Belcher Islands areas. Most larvae had lost their yolk-sac at that time (June).

Discussion

Hudson Bay marine waters originate mostly from the adjacent Arctic ocean but are marginally influenced by inflows from the North Atlantic (Dunbar 1958). Freshwater inputs from large rivers around the Bay contribute to lower the surface salinity in coastal areas (Barber 1967, Prinsenberg 1986). As a result, three main groups of fishes are found in Hudson Bay: 19 Arctic marine species (15 genera), 15 non-Arctic marine species (13 genera), and 31 brackish and freshwater species (24 genera) (Morin and Dodson 1986). Three of the 14 families of marine fish inhabiting Hudson Bay were not represented in our samples: Zoarcidae (three Arctic species) whose reproduction is poorly documented (Scott and Scott 1988), Cyclopteridae (three non-Arctic species) whose larvae are never truly planktonic (Russel 1976), and Clupeidae (*Clupea harengus*). Adult Atlantic herring (*C. harengus*) migrate into the Kuujjuarapik coastal area in summer (C. Michel, GIROQ, Université Laval, Québec, Canada, pers. comm.). The absence of herring larvae in our samples may indicate that this species does not spawn in the spring in the area studied. The freshwater fish larvae belonged to only five of the 11 species reported to colonize either the estuary or the lower part of the Great Whale River (Auger and Power 1978, Morin et al. 1980). Larvae distributed along the river and estuary banks may have been under-represented as we sampled only the main channel.

The ichthyoplankton was dominated by Arctic cod *Boreogadus saida*. Although densities of Arctic cod larvae

in southeastern Hudson Bay were similar to those observed in high Arctic areas (Sekerak 1982, Chipperzak et al. 1990), their relative abundance was much lower. On average, they contributed only about 50% of the ichthyoplankton community off Kuujjuarapik as opposed to 85–95% in the high Arctic. This difference resulted from the high abundance of *Ammodytes* spp. larvae which accounted for more than 33% of the total (Table 2) and occurred at densities comparable to those observed in temperate seas (Potter and Lough 1987). While *B. saida* is the key species in the high Arctic marine food web (see Bain and Sekerak 1978 for a review), it may have to share this role in southeastern Hudson Bay where its distribution area overlaps that of *Ammodytes* spp., a non-Arctic species. This hypothesis is consistent with the observation that sand lance adults represent a large proportion of the diet of ringed seals (*Phoca hispida*) at least in late summer and fall in the Kuujjuarapik area (Breton-Provencher 1979).

Anadromous coregonids generally represent the most abundant component of estuarine fish communities in Hudson Bay (Morin et al. 1980). However, lake whitefish (*Coregonus clupeaformis*) and cisco (*C. artedii*) accounted only for 0.25% of the total number of larvae and 8.6% of the freshwater larvae caught in the Great Whale River – Kuujjuarapik area. Their densities remained one to two orders of magnitude lower than in the estuary of the Eastmain River in nearby James Bay (Ochman and Dodson 1982). Kemp et al. (1989) observed that adult lake whitefish and cisco represented 42 to 98% of the Salmonids and 34 to 90% of all fish species by number in five rivers entering James and Hudson Bays between $52^{\circ}15'$ and $60^{\circ}01'N$. However, the authors found that these two species accounted for only 23% of the Salmonids and 7% of all fish species in the Great Whale River. This lower abundance of adults coregonids may explain the low densities of coregonid larvae observed in the river and its estuary.

Knowledge of the early life history of the major fish species found in southeastern Hudson Bay is scarce and generally incomplete (Table 5a, b and c). Our observations complement the available information. For example, Arctic cod larvae first occurred in our samples in late April. This species therefore spawned in early winter in Hudson Bay as in most other Arctic areas (Table 5a). Data from various locations indicate that sand lance reproduces between December and April (Table 5b). In our sampling

area, sand lance larvae emerged later than Arctic cod perhaps as a result of protracted embryonic development at low temperatures (Table 5b).

To our knowledge, development time of Arctic shanny (*Stichaeus punctatus*) eggs has never been documented. If spawning occurs in February–March in Hudson Bay as it does along Newfoundland shores (Table 5a) and since we first caught these larvae in mid-May (Fig. 3), egg incubation could last 2 to 3 months at temperatures below 0°C. No yolk-sac larvae of sculpin (*Myoxocephalus* spp.) and slender eelblenny (*Lumpenus fabricii*) were caught in early summer (Fig. 3). These species therefore most likely reproduce in winter as they do in the Baltic and the White Seas rather than in spring as in Alaska and off west Greenland (Table 5a and b). Winter spawning also appears to be the strategy adopted in subarctic areas by Arctic staghorn sculpin (*Gymnocanthus tricuspidis*) and gelatinous snailfish (*Liparis fabricii*). Their larvae appeared in our samples during the first weeks of May (Fig. 3). Our results confirm that capelin (*Mallotus villosus*) spawn in early July in Hudson Bay as observed by Vladikov (1933).

Arctic cod larvae sampled near the Belcher Islands and the Gulf of Richmond in June 1990 were smaller, and presumably younger, than those caught near Kuujuaupik (Table 4). This raises the question of spawning site location for this species in Hudson Bay. Spawning sites of

Arctic cod in Arctic and subarctic regions are generally unknown (Bain and Sekerak 1978; Craig et al. 1982) but are presumed to be associated with ice edges (Benko et al. 1970). An ice-free area persisting annually until mid-December northwest of the Belcher Islands (Markham 1988) may provide an ice edge suitable for Arctic cod spawning. As Arctic cod eggs and larvae can be transported by surface currents over long distances (Baranenkova et al. 1966, Althukhov 1979a), the general circulation (Prinsenberg 1986) may play an important role in achieving their transport towards the coastal areas of Hudson Bay. Testing this hypothesis would require a better knowledge of the local surface current patterns (see Larouche 1989) and of the age of the larvae caught in each area.

The early life of freshwater, anadromous and marine fish in the coastal areas of southeastern Hudson Bay is strongly influenced by the outflow of the Great Whale River. At the time of river run-off, some coregonid and burbot larvae were observed in the Bay. However, their survival after the plume begins to contract remains unknown. Larvae from over 50% of the marine fish species were first caught before ice breakup in the Bay (Fig. 3) when the brackish plume was near full expansion. Ice cover and the underlying plume influence the spatial distribution of marine fish larvae, both horizontally (Gilbert et al. 1992) and vertically (Ponton and Fortier 1992).

Table 5a–c. Summary of data on spawning period, egg development duration, and size of larvae at hatching

a) most abundant Arctic marine species

Location	Spawning period	Egg development duration	Size of larvae at hatching (mm)	Reference
<i>Boreogadus saida</i>				
White Sea	Jan to Feb rarely Apr	77 to 79 d (–1.5°C)	5.5 to 6.1 ave = 5.81	Altukhov 1979a
White Sea	Dec to Feb	26 to 35 d (–0.3 to 2.5°C)	5.5 ± 0.1	Aronovich et al. 1975
Barents Sea	Oct to Mar	–	3.5	Baranenkova et al. 1966
Barents Sea	Early spring	–	–	Benko et al. 1970
Beaufort Sea	Late Nov to early Feb	–	–	Craig et al. 1982
Barents Sea	End Dec to end Mar	1.5 to 3 months	5.5	Rass 1968
<i>Stichaeus punctatus</i>				
Logy Bay, Newfoundland	Feb to March	–	–	Farwell et al. 1976
<i>Myoxocephalus quadricornis</i>				
White Sea	Dec to Jan	–	7.0 to 11.5 ave = 8.0	Altukhov 1979b
Tuktoyaktuk, Beaufort Sea	January	–	–	Bond 1982
Alaska	Summer	–	–	Goldberg et al. 1987
White Sea	Dec to late Jan	–	–	Mukhomedianov 1967 in Khan 1971
Baltic Sea	Dec to Jan	–	–	Westin 1969
<i>Gymnocanthus tricuspidis</i>				
Trinity Bay, Newfoundland	Fall	–	–	Ennis 1970
<i>Liparis fabricii</i>				
White Sea	Feb to Mar	–	–	Altukhov 1979c
USSR coast	Sep to Oct	–	–	Andriashev 1954 in Scott and Scott 1988

Table 5 (continued)

b) most abundant non-Arctic marine species

Location	Spawning period	Egg development duration	Size of larvae at hatching (mm)	Reference
<i>Ammodytes americanus</i>				
Fortune Bay, Newfoundland	Dec to Apr	—	—	Dalley and Winters 1987
Laboratory		135 d (2°C)	6.2	Smigielski et al. 1984
Eastern Newfoundland	Late autumn to early winter	—	—	Winters 1989
<i>Ammodytes dubius</i>				
Long Island	Dec to Feb	—	3.6	Richards 1982
Scotian Shelf	—	—	4.0	Scott 1972
Eastern Newfoundland	Later than <i>A. americanus</i>	—	—	Winters 1989
<i>Myoxocephalus scorpius</i>				
White Sea	Nov to mid-Jan	ca. 4 months (<0°C)	7.4 to 8.6	Altukhov 1979b
US coast, North Atlantic	Nov to Feb	—	—	Bigelow and Schroeder 1953 in Khan 1971
Bay Bulls, Newfoundland	late Nov to early Dec	3 months ($\pm 0^\circ\text{C}$)	—	Ennis 1970
Kiel Fjord, Baltic Sea	Dec to Feb	—	6.0	Lamp 1966
Gdansk Bay, Baltic Sea	Dec to end Mar	—	—	Raciborski 1984
<i>Lumpenus fabricii</i>				
White Sea	Oct to Nov	—	—	Altukhov 1979c
off west Greenland	July	—	—	Jensen 1964 in Scott and Scott 1988
<i>Mallotus villosus</i>				
Barents Sea	Feb to June	—	—	Benko et al. 1970
North Atlantic		—	6.0 to 7.0	Fahay 1983
Hudson Bay	end Jul to Aug	—	—	Vladykov 1933

c) most abundant freshwater species

Location	Spawning period	Egg development duration	Size of larvae at hatching (mm)	Reference
<i>Lota lota</i>				
Lake Opeongo, Canada	—	—	3.0 to 4.0	Cucin and Faber 1985
L. Angersjo, Sweden	Late Feb	—	—	Hedin 1983
Laboratory	—	52 d (2°C)	3.7 \pm 0.1	Jaeger et al. 1981
<i>Coregonus clupeaformis</i>				
Mackenzie Basin	Fall	—	—	Bodaly et al. 1989
Laboratory	—	236 d (0.5°C)	—	Colby and Brooke 1973
L. Opeongo & laboratory	Mid-Nov to Dec	155 to 175d (1.0 to 8°C)	7.5 to 8.5	Cucin and Faber 1985
James and Hudson Bays	Late autumn	—	—	Dymond 1933
Eastmain and La Grande Riv., Canada	Autumn	—	—	Morin et al. 1981
<i>Coregonus artedii</i>				
Laboratory	—	182 d (0.5°C)	13.3 \pm 0.54	Brooke 1975
Mackenzie Basin	Oct to Nov	—	—	Bodaly et al. 1989
L. Opeongo & laboratory	End Oct to mid-Nov	4 to 6 months (1.0 to 8°C)	9.5 to 10.5	Cucin and Faber 1985
James and Hudson Bays	Early autumn	—	—	Dymond 1933
Eastmain and La Grande Riv., Canada	Fall	—	—	Morin et al. 1981

Accordingly, our highest densities of Arctic cod larvae were obtained at intermediate (15–25 p.s.u.) salinities under ice cover and in salinities in excess of 25 p.s.u. when light limitation was alleviated after ice breakup.

Although limited to the spring and summer periods, our observations provide new insights into the poorly known early life history of fish species in subarctic coastal areas. At those intermediate latitudes, the distributions of Arctic and temperate marine fish species overlap and, contrary to the situation further north, more than one species may dominate the ichthyoplankton community. Processes associated with river outflow clearly influence the spatial distribution of marine fish larvae in the coastal zone. They also affect the flushing in the Bay of freshwater and anadromous species. It can thus be hypothesized that interannual variations in the timing of the spring freshet, in the extent of the plume underneath the ice, and the timing of ice breakup significantly impact on the environmental conditions encountered by the young stages of several fish species in subarctic coastal areas such as southeastern Hudson Bay.

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