Coastal Marine Institute

North Slope Amphidromy Assessment

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Abstract

Natural stable isotope abundances measured in tissues of Alaska North Slope coregonine fishes were shown to reflect differences in feeding habitat relative to size and age. Stable isotope methodology may be used as a tool for proxy analysis of fish behavior in future North Slope environmental monitoring studies. We sampled Arctic and least ciscos, broad whitefish, Dolly Varden, and representative non-commercial fish and forage species **through** collaboration with existing sampling programs being conducted by the North Slope Borough Department of Wildlife Management and BP Exploration through contracts to LGL, Ltd. Intensive sampling at a limited number of sites allows one to determine population structure using natural stable isotope abundance techniques.

Introduction

Fishes of the genus *Coregonus* numerically dominate coastal and freshwaters of the Alaskan Arctic coastline (see review by P. C. Craig, 1989, Biol. Pap. Univ. Alaska). In addition to being obligate freshwater spawners, they undergo feeding migrations into coastal waters during the summer. The migration passages used by these fishes have **been** subjected to physical alterations as a result of the industrial development necessary for oil exploration and extraction. Considerable effort has been made to ascertain whether structures such as causeways located in migration routes have had a detrimental effect on these species. Thus far, no detrimental effects have been detected using conventional research tools. However, subtle effects on life-history migrational behavior with long-term consequences may not be detectable with the technologies currently being employed. An example: of a potential **effect** of shifts would be an alteration in life history feeding strategy. Evidence that different life history strategies exist on the North Slope is found in Teshekpuk Lake where a portion of the least cisco and broad whitefish populations are thought to be non-migratory because they grow at a slower rate compared to migratory populations (C. George, pers. comm.). A potential consequence of industrial development could be increased dwarfism if migration is **restricted. Fecundity loss and thus** population **reduction is another possible consequence if spawning** ground access is made more difficult. New techniques that assess subtle changes in the migrational behaviors of these fishes could allay these fears.

Large gradients in the natural abundance of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ exist between freshwater and marine habitats on the Alaskan Arctic coastline. This is due to the existence of massive

peat deposits that provide an important carbon source (directly via peat consuming insects and indirectly via respiration of peat carbon) to food chains there and their distinctive isotopic signatures. Because stable isotope ratios are conserved during feeding processes, they make effective tracers of food sources enabling one to distinguish between peat versus marine carbon. An ability to detect food source signatures in fishes also enables one to ascertain whether migration has taken place by knowing where the sample was collected in relation to potential feeding locations.

Background and relevance to **CM/ framework issues.** The North Slope Borough Department of Wildlife Management (DWM) has been undertaking research on harvested and potentially harvestable fish populations that occur concomitantly with oil on the Alaska North Slope. This research has involved investigators outside of DWM, as well as their own personnel. T. Kline collaborated with the DWM in a multi-disciplinary research effort on coregonine fishes of Teshekpuk Lake (the largest lake on the Alaskan Arctic coastal plain and third largest lake in Alaska) and the Chipp River. The latter, as well as other watersheds between Barrow and the Colville River, have recently been discovered to be important habitats for the recruitment of Bering and Arctic cisco (pers. comm. Benny Gallaway, LGL Ecological Research Associates, Inc., Bryan, TX). Kline's component in this investigation was to determine whether differences in feeding habits among the different species and species forms can be evidenced with stable carbon (C) and nitrogen (N) isotopic analyses. Preliminary data suggested that the dwarf form of the least cisco deviates from the isotopic composition of normal and intermediate forms. Two carbon isotope ratio clusters suggest at least two separate food chains, whereas the shift in nitrogen isotope ratio suggests a l-step trophic level shift or a different nitrogen source. Although Teshekpuk Lake broad whitefish stable isotope data with respect to form were not as clear cut, there was a significant difference in the carbon isotope distribution. These results corroborated other stable isotope fish studies conducted in this region that suggest significant isotope ratio gradients.

This project complemented other research underway on the North Slope being conducted by the DWM and LGL Alaska Research Associates, Inc. (LGL) for BP Exploration (Alaska) Inc. (BPX). Sampling was designed to complement these studies so that they could provide the basis for the CMI match requirements. Also by sampling alongside existing sampling, fish loss is minimized. That is, fish that are killed for another purpose are also being used for stable isotope measurement. This has helped to justify the required Alaska Department of Fish and Game collection permit.

The purpose of this project was to develop the stable isotope measurement as a proxy for amphidromous behavior. The goal is to be able to collect a sample fish, measure the $^{13}C/^{12}C$ and $^{15}N/^{14}N$, and then ascertain their recent migrational behavior. Objective (1) of this study was to establish baseline isotope attributes of an unaffected population before development occurs, so that during and following development, fish populations can be monitored to determine if they are being excluded from feeding habitats by alterations in their expected isotope chemistry. Objective (2) consisted of sampling in the developed area of the Sagavanirktok River (Sag River) delta, Prudhoe Bay.

Objective (1) was met by sampling in the Chipp River. Species sampled included (1) least cisco, **(2)** broad whitefish, (3) humpback whitefish, (4) other fishes including obligate freshwater species, and (5) potential forage species. Sampling in the Chipp River system took

place during July 1994 and **1995** in collaboration with the North Slope Borough `Department` of Wildlife Management. Objective (2) was met through collaboration with BPX and their contractor LGL Alaska Research Associates, Inc. LGL Alaska Research Associates, `Inc.` collected samples of the following species in 1994 for this project (l) least cisco, (2) Arctic cisco, (3)broad whitefish, (4) Dolly Varden, (5) Arctic grayling, and (6) Arctic flounder. In 1995 LGL collected Arctic cisco and broad whitefish. Objective (1) field studies are `being` conducted to coincide with DWM needs with respect to fish stock assessment. Effort was concentrated in the western portion of the Ikpikpuk watershed (Chipp River). Similarly, objective (2) field studies are being conducted to coincide with BPX and **ARCO** needs with respect to fish stock assessment and impacts. The fusion of objective (l) and (2) field studies with collaborating agencies came in part from their role in matching CMI funding as well as facilitating sample collections within the operational constraints that exist in working in the Arctic (e.g., the very short season and high financial costs).

Analyses in this study followed established isotope chemistry laboratory and data analysis protocols. Students at the University of Alaska Fairbanks were directly involved in pre-mass-spectrometry laboratory aspects of the project.

Potential benefits **in relation** to **mineral exp/oitation.** Monitoring the subsistence and commercially harvested fish species (i.e., Arctic and least ciscos, and broad whitefish) has been an on-going process because of potential impacts resulting from oil development of the Alaska North Slope. Much of the focus has been on the impact of causeways in altering the migratory behavior of these species. These species are classified as amphidromous because they migrate between the freshwater and marine environments for non-reproductive activities and anadromous because they must reproduce in freshwater. Maintenance of these populations depends on their continued abilityto move back and forth between freshwater and marine environments. The migratory pathways are complex because of the low topology and thermokarst features of the Arctic Coastal Main and consequent intricate and tortuous pathways among, lakes, streams, lagoons, and open water and varied tolerance to salinity by the various fish species. The fish monitoring program has consisted of extensive monitoring stations in the developed area, e.g. Prudhoe Bay, and existing fisheries, e.g. Colville River.

Exploration for oil to the west of Prudhoe Bay, including the Ikpikpuk watershed (including Teshekpuk Lake) has commenced (pers. comm. Craig George, DWM) suggesting that impacts in this coastal area are imminent. Previous exploration and exploitation of North Slope oil has required the construction of roads and causeways that have potential impacts on amphidromous and anadromous fishes such as the least cisco and broad whitefish.

Considerable effort has been made to ascertain whether man-made structures such as causeways located in the near-shore Beaufort Sea have had a detrimental effect on North Slope fishes. Thus far, little detrimental effect has been detected but considerable advances have been made in understanding fish life histories in the central Alaskan Beaufort Sea. Stable isotope analysis may be an important tool in advancing this knowledge further. For example, shifts in migrational behavior could affect feeding location and prey selection. Differences in metabolic rates between migrating and non-migrating North Slope coregonines suggest physiological adaptations related to differences in life history strategy. Natural stable isotope abundance is a technique that could assess subtle changes in the migrational patterns of these fishes. This is especially relevant in the Alaskan Arctic where

fishes display widely varying life history strategies for seasonal feeding and migration to cope with a dynamic and harsh Arctic environment. Natural stable isotope abundance data provide additional understanding of the feeding ecology of important subsistence and commercial fish, and provide a useful tool for analyzing effects of nearshore development in Arctic fishes.

Applications of *amphidromy assessment.* Stable isotope abundance characterized the recent feeding of the individual fishes sampled since they incorporated this natural tracer by having fed in habitats with characteristic isotopic signatures (Kline et al. in press). Characteristic isotopic signatures of feeding in fresh- and saltwater habitats were established. A sample size of ~ 100 fish, broadly distributed in age, enabled the assessment of how a fish population shifts in feeding migratory behavior over its life history. If life history migratory behavior changes over time, a concomitant isotope shift can be used to quantitatively assess the change. No other methodology currently exists that provides such data or analysis.

The following scenario may explain how stable isotope data can be used for such assessment: It may be necessary to build roads with associated culverts and causeways during **future oil development in this area. These constructions may reduce the migratory ability of** coregonines (as an example) thus restricting a greater proportion of the population to freshwater. Possible consequences of development, such as an increased proportion of dwarfism and reduction of population size, could be shown to be the result of a deprivation of coastal feeding grounds if the fish lost the high ^{13}C marine signature that is now present. Similar shifts could occur within any of the watersheds of the Arctic Coastal Plain. Stable **isotope chemistry shifts would thus provide direct evidence of oil development effects on** fish populations. Use of the natural stable isotope abundance method thus enables a predictive capability in assessing oil development impact, thus embracing the CMI technical framework.

Changes in the observed stable isotope signatures may be used to determine how migratory and consequently feeding behavior shifts in response to alterations of fish habitats. Habitat alteration from activities such as oil exploration and mining, e.g. causeway construction, may alter migratory pathways of anadromous and amphidromous fishes. Population interactions may thus change. Potential evidence of change by stable isotope analyses may include (1) forced overlapping of population signatures that were formally separate, (2) alteration of the nature of nutritional sources, (3) relationship of population characteristics with respect to ^{13}C and ^{15}N suggesting shifts in habitat use enabling prediction of potentially sensitive stages to environmental perturbation, and (4) shifts in other population characteristics such as parasitism, genetics and population structure (e.g. length at age and population age distribution) with concomitant isotopic change.

Stable isotope analysis elucidates aspects of North Slope fish populations not available by other methods through (1) the isotopic characterization of fish populations which enables one to determine spatial and temporal patterns, (2) assessment of interaction among populations by trophic status and food web characterization, and (3) assessment of habitats and food chains important as nurseries for recruitment.

Goering, J. J. 1996. North slope amphidromy assessment. Coastal Marine Institute Annual Symposium, February 1996, Fairbanks, Alaska.

Kline, T. C. 1995. Assessing the role of amphidromy in the production of North Slope Alaska coregonine fishes using $\delta^{13}C$ and $\delta^{15}N$. Presentation at the annual meeting of the American Society of Limnology and Oceanography, Reno, Nevada.

Kline, T. C. 1996. Natural stable isotope abundance used for assessment of anadromous and amphidromous migrations in fish ecology: implications for fisheries management and habitat protection. Pages 118-119 *In* D. A. Hancock and J. P. Beumer (eds). Developing and sustaining world fisheries resources: the state of science and management, Proceedings of the second world fisheries congress, Brisbane, Australia. Volume 1.

Kline, T. C. and J. J. Goering. 1995. North slope amphidromy assessment. Presentation at Coastal Marine Institute Annual Symposium, February 1995. Fairbanks.

Kline, T. C. and J. J. Goering. 1995. North slope amphidromy assessment. Pages 55-67 *In: V. Alexander (dir.) U niversity of Alaska Coastal Marine Institute **Annual** Report No. 2, OCS Study MMS 95-0057.* Fairbanks. 121 pp.

Kline, T. C. and J. J. Goering. 1996. North slope amphidromy assessment. Pages 85-101 *In:* V. Alexander (dir.) University of Alaska Coastal Marine Institute Annual Report No. *3, OCS Study MMS 97-0001.* Fairbanks. 191 pp.

Kline, T. C. and J. J. Goering. 1997. North slope amphidromy assessment. Presentation at Coastal Marine Institute Annual Symposium., 25 February 1997, Fairbanks, Alaska.

Kline, T. C. and J. J. Goering. 1998. North slope amphidromy assessment. Pages 23-25 *In: V. Alexander (dir.) University of Alaska Coastal Marine Institute Annual Report No. 4, OCS Study MMS 97-0001.* Fairbanks. 81 pp.

Kline, T. C., and J. J. Goering. 1998. North Slope Amphidromy Assessment.   Final Report for Task Order 11984 , CMI, MMS Cooperative Agreement Number 14-35-0001-*30661.*

Kline, T. C., W. J. Wilson and J. J. Goering. in press. Natural isotope indicators of fish migration at Prudhoe Bay, Alaska. Canadian Journal of Fisheries and Aquatic Sciences.

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Natural Isotope Indicators of Fish Migration

at Prudhoe Bay, Alaska

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Abstract

A dichotomy in the natural stable carbon isotope abundance measured in tissues of obligate freshwater and marine fishes from the Alaskan Arctic coastal plain suggested that the methodology can be used to differentiate recent freshwater from marine feeding in migratory fishes. Natural stable carbon isotope ratio of **migratory** fishes reflected differences of feeding habitat in relation to known life history patterns. Use of the stable isotope methodology as a tool for proxy analysis of fish behavior in present and future Arctic environmental monitoring studies is suggested from analysis of age-specific isotopic ratio differences in broad whitefish and Arctic cisco.

Introduction

Isotope chemistry is a powerful tool for use in ecological studies because of naturally-existing isotope gradients and the fidelity of consumer isotope ratios with their diet (Fry and Sherr 1984, Owens **1987,** Wada et al. 1991). Large gradients occur in the natural abundance of the stable heavy isotope of carbon, ^{13}C, as well as the radioactive isotope of carbon, ^{14}C, between freshwater and marine habitats of the Alaskan Arctic coastal plain because of the existence of massive ^{14}C-depleted (because of radioactive decay) and ^{13}C-depleted (Barnett 1994) peat deposits. Peat provides an important carbon source (directly via peat consuming invertebrates and indirectly via respiration of peat carbon) to coastal plain freshwater food chains (including anadromous/amphidromous fishes) but not to coastal marine food chains (Schell 1983, Schell and Zieman 1989). Because stable isotope ratios are conserved during **feeding** processes, **they** make **effective tracers of** food sources used by anadromous and amphidromous fishes, enabling one to distinguish between peat versus marine carbon utilization by fishes (and other consumers).

The data obtained from stable isotope measurements are unique in that they trace assimilated material. Nitrogen stable isotope ratios provide excellent definition of relative trophic level (Fry 1988, Wada et al. 1991, Hobson and Welch 1992, Kiriluk et al. 1995). The heavy isotope of nitrogen, ^{15}N, is enriched by about 0.34 % (or 3.4 ‰ in conventional delta units, see materials and methods) with each trophic level (Minagawa and Wada 1984) and can accurately indicate the trophic level of species within an ecosystem (Kling et al. 1992,

Cabana and Rasmussen **1994).** Carbon isotope signatures were used to trace multiple sources of carbon into food webs (Fry and Sherr 1984, Wada et al. 1991) by exploiting the ^{13}C gradient in Alaskan Arctic coastal plain food web carbon sources (Schell1983, Schell and Zieman 1989) while using C/N ratio and nitrogen stable isotope measurements to correct ^{13}C/^{12}C values for lipid storage- and trophic level isotope effects (Kline **1997).**

Fishes of the genus *Coregonus* and *Salvelinus* are abundant in the coastal and fresh waters of **the Alaskan Arctic. In addition to being obligate freshwater spawners, they undergo summer** feeding migrations into coastal waters during which they take on lipid reserves to maintain body condition through the subsequent winter season (Craig **1989,** Fechelm et al. **1995,** 1996). Nearshore Beaufort Sea monitoring programs focused on the subsistence- and commercially-harvested Arctic cisco (C. *autmnalis*), least cisco (C. *sardinella),* and broad whitefish *(C. nasus)* have been on-going since the **1970s** because of concerns over potential impacts on these species from oil development (Gallaway et al. **1991).** Much of the focus of these monitoring studies has been assessing the impact of causeways because of their potential for altering the migratory behavior of these species (Gallaway et al. **1991).**

These coregonine species are either amphidromous, because they seasonally migrate between the freshwater and marine environments and over-winter in fresh water, or anadromous, because they undertake similar seasonal migrations, but over-winter in brackish river delta environments (Craig **1984, 1989).** Arctic cisco are anadromous, and they eventually spawn in freshwater tributaries of the Mackenzie River, at age 6 to 9 (Gallaway et al. 1983). Least cisco, broad whitefish, and Dolly Varden *(Salvelinus malma,* salmoninae) are amphidromous since they over-winter in fresh water. All of these species seasonally migrate out of river systems (deltas for Arctic cisco) into the nearshore Beaufort Sea to forage along the coast, returning in the fall to the rivers or river deltas to overwinter (Craig 1989). Maintenance of **these populations depends on their continued ability to move back and forth between the** freshwater and marine environments. In some portions of the Alaskan **Arctic,** the migratory pathways are complex because of the low topology and thermokarst features of the Arctic coastal plain and consequent intricate and tortuous pathways among lakes, streams, lagoons, and open water.

We hypothesized that stable isotope composition of fish tissues could be used to discern feeding strategies of the different life history forms of Arctic fishes. Fish feed either on marine-derived or freshwater-derived production, depending on their life history form or stage (freshwater resident, marine resident, **or anadromous/amphidromous). Each form** tends to feed at a specific trophic level because of metabolic requirements, mouth structure, competition, and seasonal food availability Hypothetically, the ^{13}C/^{12}C ratio in fish tissues can be used to indirectly determine migratory behavior by knowing where a fish sample was collected in relation to potential carbon sources. For example, a fish obtained from the marine habitat but containing a carbon signature consistent with freshwater feeding had to have recently migrated there. If a fish "switches" to alternate carbon sources because of environmental pressures (temperature/salinity changes, crowding, etc.), there will be a concomitant change in their isotopic composition.

This study examines ^{15}N/^{14}N and ^{13}C/^{12}C ratios in tissues of Alaskan North Slope freshwater, anadromous/amphidromous, and marine fishes to explore the possible use of tissue isotope chemistry in Arctic ecological studies. Our objectives were to validate this

methodology, and to determine carbon signature differences in these different ecological life forms of Arctic fishes.

Materials and Methods

Anadromous Arctic cisco and amphidromous least cisco, broad whitefish and Dolly Varden were collected in fyke nets in coastal waters of the Prudhoe Bay region, Alaska (Fig. la), during the summers of 1994 and 1995 following the methods of Fechelm et al. (1995, 1996). Two seasonal samples were collected each year, one in early (24 June to 23 July, 1994 and 23 June to 4 July, 1995) and late **(11** to 22 August, 1994 and 14 to 20 August, 1995) season. Subsamples of fish were measured for length to the nearest millimeter. Saggital otoliths were excised and then aged by counting annuli under a dissecting microscope at 10 to 70 X magnification. Marine fourhorn sculpin and Arctic flounder were collected during the **summer** in the coastal fyke nets (above) and from gill nets set near the Chipp River Delta (Fig. lb), while the freshwater species Arctic grayling, lake trout, longnose sucker, burbot, ninespine stickleback, and northern pike were collected from gill and fyke nets placed in Teshekpuk Lake (1992) **and in the** Chipp River (1994 and 1995).

Whole fish carcasses (from Prudhoe Bay) or epaxial muscle tissue samples (from Teshekpuk Lake and Chipp River) were frozen and **sent to our laboratories in either Fairbanks (1994) or** Cordova (1995) for preparation for isotopic analysis. Preparation consisted of sampling epaxial muscle from Prudhoe Bay samples, followed by freeze drying. Epaxial muscle samples sampled in the field (Teshekpuk Lake and Chipp River samples) were freeze-dried directly. Freeze-dried samples were ground to a fine powder with a dental amalgamator (Crescent Dental Wig-L-Bug), Ground freeze-dried samples stored in LSC vials were sent to the Stable Isotope Facility at the University of Alaska Fairbanks where replicate aliquots of -1.5 mg were weighed to the nearest μg and loaded into combustion boats for mass spectrometric analysis.

Isotopic determination. A Europa Scientific model 20/20 stable isotope analyzer equipped **with a Europa Scientific Roboprep sample preparation and purification unit was used for the** analysis. Analytical results include $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios in standard delta units, $\delta^{13}C$ and $\delta^{15}N$, respectively, and %C and %N (g C or N / g dry weight).

The standard delta notation is used to express stable isotope ratios relative to international standards (air for N and Vienna Peedee belemnite (VPDB) for C) and defined by the following expression:

$$(1) \quad \delta^{15}N \text{ or } \delta^{13}C = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000 \text{ ‰}$$

where $R = {}^{15}N/^{14}N$ or $^{13}C/^{12}C$. **The isotope standards have delta values of 0 by definition,** i.e., $\delta^{15}N = 0$ for atmospheric N_2. Naturally-occurring $\delta^{15}N$ and $\delta^{13}C$ values observed in biota range from ~0 to ~+20 and from ~0 to ~-50, respectively. Negative $\delta^{13}C$ values reflect the relative enrichment of ^{13}C in the limestone standard compared with biota.

Replicate isotopic analyses were performed on each sample using aliquots of ~ 1.5 mg dry weight. Samples were rerun when replication was poor (difference > 0.6 ‰). Typically replication yielded results which were within 0.2 ‰. The %C and %N data were used to calculate C/N atomic ratios. Mean of $\delta^{13}C$, $\delta^{15}N$ and C/N replicates were used for data modeling. Although $\delta^{15}N$ values of biota vary principally as a function of trophic level (Fry 1988), there can be significant nitrogen source isotope-effects (Kline et al. 1997a). Determination that nitrogen source isotope-effects were not present was based on comparing $\delta^{15}N$ values of similar trophic level fishes across the study area. Following validation, $\delta^{15}N$ values were then used to normalize for the trophic enrichment of ^{13}C using the procedure described below. The lipid normalization procedure of McConnaughey and McRoy (1979) was used to remove lipid isotope-effects (DeNiro and Epstein 1977). The combined normalizations for trophic level and lipid storage resulted in ^{13}C values dependent primarily on source, thus enabling the identification of the source of carbon in samples based on the natural ^{13}C gradient (Kline 1997b).

Normalization protocols. Normalization for lipid content is needed because lipid synthesis and storage can alter ^{13}C content (DeNiro and Epstein 1977). The normalization technique used was developed by McConnaughey and McRoy (1979) and validated by Kline (1997b). The C/N atomic ratio derived from mass spectrometry provided an inexpensive proxy for lipid content that was used to calculate lipid-normalized $\delta°C$ [expressed as $\delta^{13}C'$].

The constant enrichment of ^{15}N in animal tissues compared with that in their diet was used to compute a relative trophic level (TL) by comparing $\delta^{15}N$ values to a TL reference value (e.g., Cabana and Rasmussen 1994). The $\delta^{15}N$ of higher trophic levels were calculated by adding the trophic enrichment factor, ε_N [see (2), below], to a reference TL value. Although obligate herbivores, i.e., TL = 2, thus well-defined by TL, are suitable for the TL reference, a substantial sample size (e.g. ~ 1000) may be required (Kline 1997b). Instead, TL of fishes in this study were determined in relation to low TL fishes which were assumed to be TL = 3.

Normalization for TL enabled comparison of $\delta^{13}C'$ values among species or individuals within a species with multiple TL since residual $^{13}C / ^{12}C$ delta values reflected carbon source. The normalization procedure used the trophic enrichment factors, ε_C and ε_N, (Fry and Sherr 1984, Minagawa and Wada 1984) and the $\delta^{15}N$ value of the reference TL. Normalized values were computed using the -following relationship:

(2) $\delta^{13}C'_{TL} = \delta^{13}C' - \varepsilon_C \varepsilon_N (\delta^{15}N_{sample} - \delta^{15}N_{reference})$

where $\delta^{13}C'_{TL}$ is the "N-based 'TL-normalized derivative of $\delta^{13}C'$, $\varepsilon_C = 1$, and $\varepsilon_N = 3.4$.

Validation of trophic level determination and normalization procedures. In general, $\delta^{15}N$ of aquatic organisms reflect their TL (Owens 1987, Fry 1988, Wada et al. 1991, Cabana and Rasmussen 1994). Although $\delta^{15}N$ values of terrestrial, freshwater and estuarine organisms are similar (Owens 1987), processes that introduce N with anomalous $\delta^{15}N$ values (thus affecting TL assessment) to the system may occur (e.g., Kline et al. 1997a), particularly at the freshwater-marine ecotone (France 1995). Validation consisted of demonstrating no N

source isotope-effect in non-migratory fish species from the North Slope. Their $\delta^{15}N$ variability was qualitatively assessed in relation to known feeding habits (Craig and McCart 1976, Craig et al. 1984, Craig 1989). The lack of significant N source isotope-effect would be confirmed if the variability in $\delta^{15}N$ accounted for by TL was greater than differences in $\delta^{15}N$ among species of similar TL.

Mixing model. The following isotopic mixing model based on Kline et al. (1997a) was used to assess the % of a source of a given element in a consumer, given the existence of two sources with a significant stable isotope disparity:

(3) $$\%A = \frac{\delta_B - \delta_{sample}}{\delta_B - \delta_A}$$

where δ_A and δ_B are delta values of the two sources and δ_{sample} is the delta value of the sample.

Results

Freshwater and marine fishes. Non-migratory fishes, consisting of freshwater species from the Chipp River and Teshekpuk Lake and marine species from the Prudhoe Bay region and the mouth of the Chipp River, had $\delta^{15}N$ ranging from -7 to ~ 17 (Fig. 2). The most positive $\delta^{15}N$ values, ~ 17, were found in Teshekpuk Lake lake trout. Longnose sucker, Arctic grayling, and ninespine stickleback had $\delta^{15}N$ -8.5, which was assumed to correspond to TL = 3. Higher trophic levels were estimated in relation to TL = 3 (Fig. 1). Northern pike, Arctic flounder, burbot, and fourhorn sculpin had $\delta^{15}N$ values > 8.5, corresponding to TL > 3 , but less than the $\delta^{15}N$, and therefore TL, of lake trout.

Non-migratory fishes were dichotomous in $\delta^{13}C'_{TL}$ with marine species' values greater than freshwater species' values by at least 2 ‰ (Fig. 3a). Within the freshwater group, lake trout and burbot had $\delta^{13}C'$ elevated by ~ 1 ‰ compared with the others. Normalization of $\delta^{13}C'$ values for trophic level (i.e., $\delta^{13}C'_{TL}$) removed this difference, making lake trout and burbot more similar to other freshwater fishes (Fig. 3b). Only ninespine stickleback had a very hroad $\delta^{13}C'$ range. In summary, fishes feeding in fresh water had $\delta^{13}C'_{TL}$ --30 to ~ -27, whereas fishes feeding in the marine environment had $\delta^{13}C'_{TL}$ of- -22.

Anadromous/amphidromous species. Fishes that migrate between freshwater and marine habitats had $\delta^{13}C'$ ranging from -30 to -21, and thus encompassed the range of $\delta^{13}C'$ values found for marine and freshwater non-migratory species (Fig. 4, compare with Fig. 3b). Migratory species had distinctive curves when $\delta^{13}C'_{TL}$ and $\delta^{15}N$ were plotted as a function of body size (Figs. 4 and 5). The data suggest shifts in food source (Fig. 4) and trophic level (TL, Fig. 5) as a function of length (and thus age) as well as differences among the species.

Cohort feeding histories. Shifts in $\delta^{13}C'_{TL}$ and $\delta^{15}N$ values of Arctic cisco and broad whitefish by cohort or year class (Fig. 6) suggest age-specific differences in food source or

trophic level during 1994-5. Noteworthy is the shift to more positive $\delta^{13}C'_{TL}$ values in the older age classes. Inter-annual variation in $\delta^{13}C'_{TL}$ was apparent even in older (age 4 to 6, i.e. 1990 and 1991 year classes) fish.

The relative importance of marine carbon in the feeding history of the broad whitefish and Arctic cisco cohorts shown in Table 1 was determined using as end members, δ_A and δ_B (6), the $\delta^{13}C'_{TL}$ values of obligate marine and freshwater fishes which were ~ -22 ± 0.5 and ~ -28 ± 1.0, respectively (Fig. 3b). The data suggest 100% dependence on marine carbon by age three for both species.

Discussion

Trophic /eve/. Alaska Arctic coastal plain fish $\delta^{15}N$ values and interpreted TLs were similar to those reported in the literature and generally consistent with no $\delta^{15}N$ source effects (France 1995), supporting $\delta^{15}N$ value-based TL estimation and normalization of $\delta^{13}C'$ for the study area The highest $\delta^{15}N$ value of + 17, and therefore highest relative trophic level (TL) of 5 determined for lake trout in our study, was similar to the mean $\delta^{15}N$ value and interpreted TL of Lake Ontario lake trout (Kiriluk et al. 1995), though greater than that reported at two sites in the lower Mackenzie River basin, Canada (Hesslein et al. 199 1). Conversely, the $\delta^{15}N$ of northern pike found in the Chipp River was less than those from the Kukjuktuk Creek system and a few of those from Travaillant Lake, both in the Mackenzie River system (Hesslein et al. 1991), while ninespine stickleback from all Mackenzie River system and this study's sites were comparable. Longnose sucker from the Chipp River had $\delta^{15}N$ values that were similar to white sucker from Travaillant Lake (Hesslein et al. 199 1). The $\delta^{15}N$ values of fourhom sculpin from Prudhoe Bay and the Chipp River were similar to the $\delta^{15}N$ reported for Myoxocephalus scorpiodes from the Canadian high Arctic (Hobson and Welch, 1992). Broad whitefish were consistently lower in $\delta^{15}N$ than either Arctic cisco, least cisco or Dolly Varden implying *a* lower TL (Fig. 5) which is also anatomically suggested by their small gape and mollusc and aquatic insect feeding habit (McPhail and Lindsey 1970).

^{13} C /^{12}C gradient. The difference in $\delta^{13}C'_{TL}$ values of obligate fresh and coastal marine fishes (Fig. 3b) confirms the existence of a $^{13}C/^{12}C$ gradient in Alaskan Arctic coastal plain biota reported by Schell (1983) and Schell and Zieman (1989). Furthermore, trends in isotopic composition in relation to the size of migratory fishes (Fig. 4) suggest feeding habit shifts dependent on migratory behavior that are consistent with known life history patterns (Craig 1989). For example, Craig (1989) describes two types of life history patterns of coastal plain anadromous fishes. The charr life history pattern of delayed migration from freshwater involves ii-y remaining year-round in streams until age 3 or 4 when they begin annual migrations to sea to feed. This life history pattern is reflected in the Dolly Varden $\delta^{13}C'_{TL}$ since the switch to the more positive $\delta^{13}C'_{TL}$ of marine carbon occurred at a larger size of nearly **300** mm in length (~ age of 4 yr, Craig 1989). These results contrast with broad whitefish and Arctic cisco which follow the cisco life history pattern (Craig 1989) where fish annually migrate to the marine environment to feed at all ages. Accordingly, the broad whitefish and Arctic cisco data show the marine $\delta^{13}C'_{TL}$ signature by 100 mm (Fig 4b). The

consistency of $\delta^{13}C'_{TL}$ with known life history patterns of Alaskan Arctic coastal plain fishes suggest that $\delta^{13}C'_{TL}$ can be used as a migratory indicator in this region. This is unlike the Mackenzie River delta area which does not have a $^{13}C/^{12}C$ gradient (Hesslein et al. **1991).**

Age-dependent isotopic **variability *and shifts.*** Because **of the** predictable relationship between **natural** stable isotope abundance of consumers and their diet (reviewed by Wada et al. 1991), it is being used here to characterize the recent feeding history of Prudhoe **Bay** area fishes as either fresh water or marine. Juvenile fishes rapidly change their isotopic composition in proportion to addition of new tissue while differences in isotopic signatures between individuals in groups of older, slow-growing fish reflect different food "choices" because temporal variations are averaged out (Hesslein et al. **1993).** The potential diet "choice" **in this** study consisted of the spatial and apparent isotopic dichotomy between freshwater and marine carbon (Fig. 3). Arctic fishes are generally long-lived and have slow growth, especially upon reaching sexual maturity (Craig **1989).** Based on the results of **Hesslein et al.** (1993), **mature fishes were not expected to vary significantly** with time since temporal variation in feeding would be averaged out. However the variability in both $\delta^{15}N$ and $\delta^{13}C'_{TL}$ of coregonines in our study did not appear to decrease with increased fish size as expected (Figs. 4 and 5). In contrast Dolly Varden decreased in isotopic range as a **function of size.** Larger (> 300 mm) Dolly Varden range by about 2 per mil in both $\delta^{15}N$ and $\delta^{13}C'_{TL}$ similar to coregonines. However, smaller Dolly Varden exhibited far greater ranges compared to the coregonines suggesting a greater diversity of feeding niches by individual fish. **For** example, fish between 250 and 300mm in length ranged from **100** % freshwater feeding to **100** % marine feeding and had a two TL range (Figs. **4 and 5).** Age 1 and **2 Arctic** cisco and broad whitefish (Fig. 6, Table **1)** have notable $\delta^{13}C'_{TL}$ and corresponding % marine carbon estimation differences between the species. Arctic cisco were more negative by ~ 1 ‰, suggesting a 5 to 20% greater affinity for freshwater-derived carbon than broad whitefish (Table 1).

The change in $\delta^{13}C'_{TL}$ between late summer 19% and early summer 1995 (Fig. 6) suggested a turnover of much of the carbon, probably later in 1994 before entering the rivers. Our observation is consistent with that of Schell(1983) who found $\delta^{13}C$ values in coregonines sampled in October and November that were consistent with continued feeding on marine carbon into the fall. In **1994,** the salinity in the Prudhoe Bay area decreased anomalously to low values in late summer when it more typically increases. This may have lengthened the time that these fish spent in the estuary since the variable that drives them back into the rivers, salinity, became more benign. They could have stayed longer and fed more in late 1994 than is typical. This may have allowed them to change their isotopic composition, otherwise the late 1994 **and early** 1995 **values** of younger cohorts would have been more similar than determined here (compare adjacent stippled and black box and whiskers in Fig. 6).

Our study suggests that, because of the lower trophic position suggested by their $\delta^{15}N$ (Fig. 5), broad whitefish may be able to store **energy in a "poor feeding condition" while other** species could not. Potentially, measurements of natural stable isotope abundance of fishes in an extreme condition year such as experienced in the Prudhoe Bay region in 1991 could provide evidence of an alternative **hypothesis:** that broad whitefish shifted feeding to

alternate food sources which would in turn cause a shift to different isotopic values because of the change in source of carbon and nitrogen. For example, Fechhelm et al. (1995, 1996) tracked the early and late summer condition of individual cohorts of broad whitefish and Arctic cisco in time. Through this analysis they were able to detect inconsistencies between species and among years in summer energy accumulation. For example, they noted that in the summer of 1991, 75% of Arctic cisco cohorts lost lipid reserves (Fechhelm et al. 1996) while all the broad whitefish cohorts gained lipid reserves (Fechhelm et al. 1995). Fechelm et al. (1996) noted that 1991 was a very "fresh" year in the Sagavanirktok delta and that Dolly Varden, Arctic flounder, and four-horn sculpin also exhibited poor condition. They postulated that poor feeding conditions existed throughout the area.

We have shown that anadromous/amphidromous fish have a certain isotopic signature, while marine and freshwater fishes have another confirming the freshwater-marine isotopic dichotomy and utilization of ^{13}C-depleted carbon reported by Schell(1983). Within the anadromous/amphidromous group, we can show shifts in trophic level with increase in size, presumably because as fish grow they are more capable of searching further and accepting different (larger) prey. Natural stable isotope abundance is a technique that could assess changes in the migrational patterns of these fishes, such as changing time of seaward migration to later in life as seen in Dolly Varden. We have also shown that fish at a given size in one year might show a different signature in another year, possibly due to environmental gradients that differed in the two years that enabled those fish to feed in different areas or on different prey. This is especially relevant in the Alaskan Arctic where fishes display widely varying life history strategies for seasonal feeding and migration to cope with a dynamic and harsh Arctic environment.

Though considerable, environmental impact studies on North Slope fishes have shown little detrimental effect and have contributed considerably to advances in understanding fish life histories in the central Alaskan Beaufort Sea (Wilson and Gallaway 1997). Stable isotope analysis may be an important tool in advancing this knowledge further. Natural stable isotope abundance data provide additional understanding of the feeding ecology of important subsistence and commercial fish, and provide a *useful* tool for analyzing effects of nearshore development in Arctic fishes.

Acknowledgments

References Cited

Bamett, Bruce A. 1994. Carbon and nitrogen isotope ratios of caribou tissues, vascular plants, and lichens from northern Alaska. M.S. Thesis, University of Alaska Fairbanks, Fairbanks, Alaska.

Cabana, G. and J. B. Rasmussen, 1994. Modeling food chain structure and contaminant bioaccumulation using stable nitrogen isotopes. Nature 372:255-257.

Craig, P. C. and P. McCart. 1976. Fish use of near-shore coastal waters in the western Arctic: Emphasis on anadromous species. In: D. W. Hood and D. C. Burrell (eds.) Assessment of the arctic marine environment: Selected topics. Institute of Marine Science, University of Alaska, Fairbanks, Alaska. I?. 361-388.

Craig, P. C., W. R. Griffiths, S. R. Johnson, and D. M. Schell. 1984. Trophic dynamics in an Arctic lagoon. In: P. W. Barnes, D. M. Schell, and E. Reimnitz (eds.) The Alaskan Beaufort Sea, Ecosystems and Environments. Academic Press, Orlando. P. 347-380.

Craig, P. C. 1984. Fish use of coastal waters of the Beaufort Sea: a review. Trans. Am. Fish. Soc. 113:265-282.

Craig, P. C. 1989. An introduction to anadromous fishes of the Alaskan Arctic. Biol. Pap. Univ. Alaska 24:27-54.

DeNiro, M. J. and S. Epstein. 1977. Mechanism of carbon isotope fractionation associated with lipid synthesis. Science 197:261-263.

Fechhelm, R. G., W. B. Griffiths, W. J. Wilson, B. J. Gallaway, and J. D. Bryan. 1995. Intra- and interseasonal changes in the relative condition and proximate composition of broad whitefish from the Prudhoe Bay region of Alaska. Trans. Amer. Fish. Soc. 124:508-5 19.

Fechhelm, R. G., W. B. Griffiths, L. R. Martin, and B. J. Gallaway. 1996. Intra- and interseasonal variation in the relative condition and proximate composition of Arctic ciscoes from the Prudhoe Bay region of Alaska. Trans. Amer. Fish. Soc. 125:600-612.

France, R. 1995. Stable nitrogen isotopes in fish: literature synthesis on the influence of ecotonal coupling. Estuar. Coast. Shelf Sci. 41:737-742.

Fry, B. 1988. Food web structure on the Georges Bank from stable C, N, and S isotopic compositions. Limnol. Oceanogr. 33:1182-1190.

Fry, B. and E. B. Sherr. 1984. $\delta^{13}C$ measurements as indicators of carbon flow in marine and freshwater ecosystems. Contr. Mar. Sci. 27: 13-47.

Gallaway, B. J., W. R. Griffiths, I?. C. Craig, W. J. Gazey, and J. W. Hernericks. 1983. An assessment of Colville River delta stock of Arctic cisco (*Coregonus autumnalis*) - migrants from Canada? Biological Papers of the University of Alaska 21:4-23.

Gallaway, B. J., W. J. Gazey, J. M. Colonell, A. W. Niedoroda, and C. J. Herlugson. 1991. The Endicott development project - preliminary assessment of impacts from the first major offshore oil development in the Alaskan Arctic. Am. Fish. Soc. Symp. 11:42-81.

Gallaway, B. J., R. G. Fechelm, W. R. Griffiths and J. G. Cole. 1997. Population dynamics of broad whitefish in the Prudhoe Bay region, Alaska. *In:* J. Reynolds (ed.) Fish Ecology in Arctic North America. Amer. Fish. Soc. Symp. 19. Bethesda, Maryland. P. 194-207.

Hesslein, R. H., M. J. Capel, D. E. Fox, and K. A. Hallard. 1991. Stable isotopes of sulfur, carbon, and nitrogen as indicators of trophic level and fish migration in the lower Mackenzie River basin, Canada. Can. J. Fish. Aquat. Sci. 48:2258-65.

Hesslein, R. H., K. A. Hallard, and P. Ramlal. 1993. Replacement of sulfur, carbon, and nitrogen in tissue of growing broad whitefish (*Coregonus nasus*) in response to a **change in diet traced by $\delta^{34}S$, $\delta^{13}C$, and $\delta^{15}N$. Can.** J. **Fish.** Aquat. Sci. 50:2071-2076.

Hobson, K. A. and H. E. Welch. 1992. Determination of trophic relationships within a high Arctic marine food web using $\delta^{13}C$ and $\delta^{15}N$ analysis. **Mar. Ecol. Prog.** Scr. 84:9-18.

Kiriluk, R M., M. R. Servos, D. M. Whittle, G. **Cabana, J. B. Rasmussen.** 1995. Using ratios **of** stable **nitrogen and carbon isotopes to characterize the** biomagnification **of DDE,** mirex, and PCB in a Lake Ontario pelagic food web. Can. J. Fish. Aquat. Sci. 52:2660-2674.

Kline , T. C. Jr., J. J. Goering, and R. J. Piorkowski. 1997a. The effect of salmon carcasses on Alaskan freshwaters. *In:* A. M. Milner and M. W. Oswood (eds.) Freshwaters of Alaska: Ecological Syntheses. Springer Verlag, New York, P. 179-204.

Kline, T. C. 1997b. Confirming forage fish food web dependencies in the Prince William Sound ecosystem using natural stable isotope tracers. *In:* B. Baxter (ed.) Proceedings of the International Symposium on the Role of Forage Fishes in Marine **Ecosystems, Anchorage, Alaska. Alaska Sea Grant College Program (IN PRESS).**

Kling, G. W., B. Fry, and W. J. O'Brien. **1992.** Stable isotopes and plankton trophic structure in arctic lakes. Ecology 73:561-566.

McConnaughey, T. and C. P. McRoy. **1979. Food-web structure and the** fractionation **of** carbon isotopes in the Bering Sea. Mar. Biol. 53:257-262.

McPhail, J. D. and C. C. Lindsey. 1970. Freshwater Fishes of Northwestern Canada and Alaska. Fish. Res. Bd. of Can. Bull. 173. Ottawa. 381pp.

Minagawa, **M.,** and E. Wada. **1984.** Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between δ^{15}N and animal age. Geochim. Cosmochim. Acta 48:1135-1140.

Owens, N. J. P. 1987. Natural variations in ^{15}N in the marine environment. Adv. Mar. Biol. 24:389-451.

Schell, D. M. 1983. Carbon-13 and carbon-14 abundances in Alaskan aquatic organisms: delayed production from peat in Arctic food webs. Science 219:1068-1071.

Schell, D. M. and P. J. Zieman. 1989. Natural carbon isotope tracers in Arctic aquatic food webs. *In* P. W. Rundel, J. R. Ehleringer and K. A. Nagy (eds.) Stable Isotopes in Ecological Research. Springer-Verlag, New York, p.230-25 1.

Wada, E., H. Mizutani, and M. Minagawa. 1991. The use of stable isotopes for food web analysis. Crit. Rev. Food. Sci. Nutr. 30:361-371.

Wilson, **W. J. and B. J.** Gallaway. **1997.** Synthesis **in applied fish ecology:** twenty years **of** studies on effects of causeway development on fish populations in the Prudhoe Bay region, Alaska. *In:* J. Reynolds (ed.) Fish Ecology in Arctic North America. Amer. **Fish.** Soc. Symp. **19. Bethesda,** Maryland. **P. 326-339.**

Table 1. Percent estuarine carbon computed from mean $\delta^{13}C'_{TL}$ values in Fig. 6 using formula (6) with -28 $\pm$ 1.0 and -22 $\pm$ 0.5 as the end members. The accuracy of the estimate based on the $\delta^{13}C'_{TL}$ range of marine fishes of $\pm$ 8.3 % accounts for values $>$ 100%.

Species Sampling year Sampling period		Arctic cisco				Broad whitefish			
		1994		1995		1994		1995	
		Early	Late	Early	Late	Early	Late	Early	Late
Year class	Age								
1990	4 to 5	98	102	95	101	88	98	95	109
1991	3 to 4	92	103	97	96	94	91	97	101
1992	2 to 3	95	*85*	*91*	*95*	92	*92*	*91*	*101*
1993	1 to 2		*80*	*88*	*86*	87	86	90	91
1994	0 to 1			*73*	*76*		55	80	106

Figure 1. Fish and hydrographic monitoring stations (diamonds) in the Prudhoe Bay region (1994 and 1995), (a); and freshwater circles and marine (square) fish sampling stations in the Ikpikpuk River region including Teshekpuk Lake (1992) and Chipp River (1994 and 1995), (b).
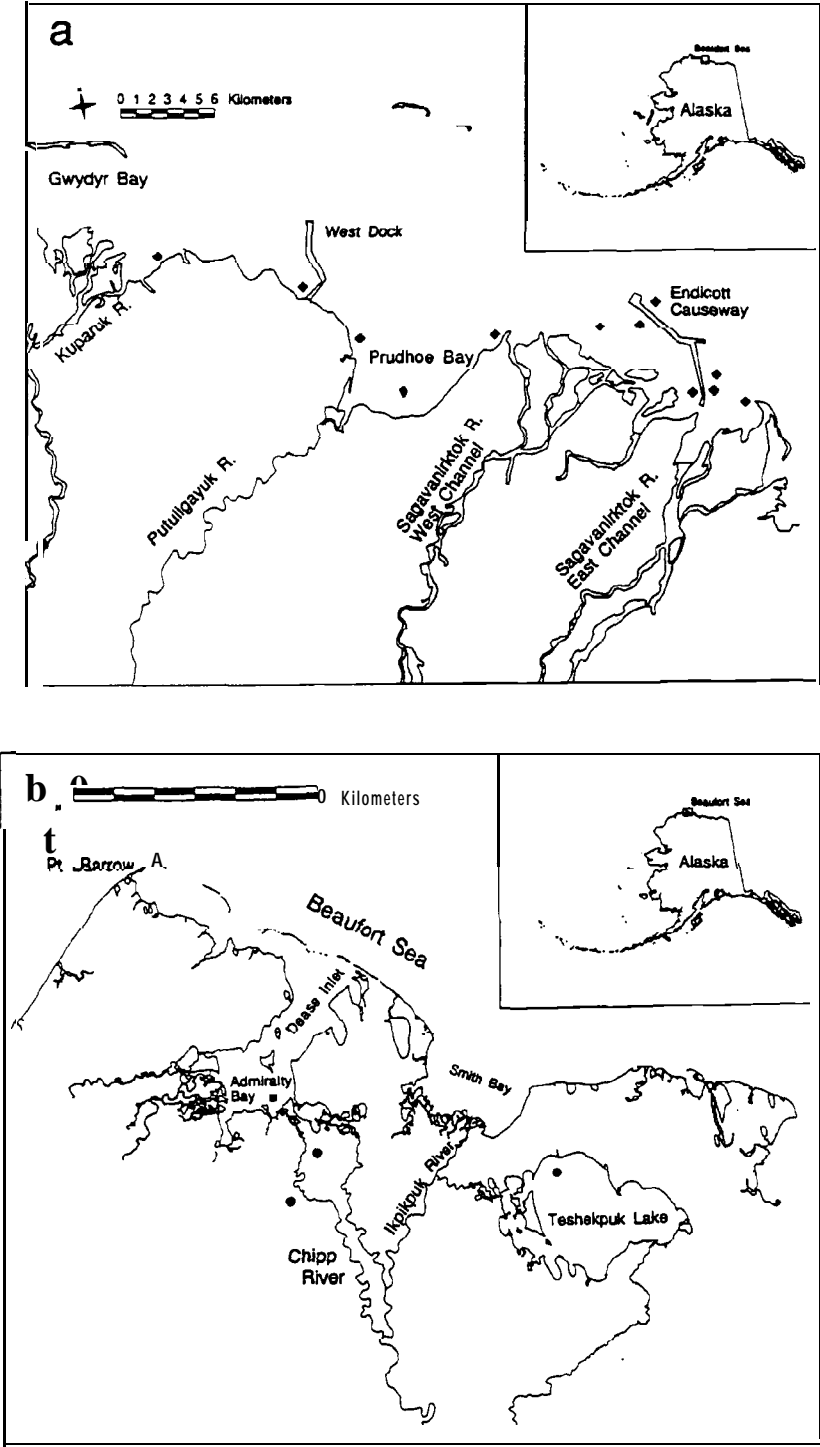
Figure 2. Determination of TL (trophic level, upper axis label) from $\delta^{15}N$ with variability indicated by computer-fitted (Deltagraph Pro 3.0, Deltapoint Inc.) box and whisker plots. Fresh water resident fishes shown in the upper panel [lake trout LKTR, N = 2 (*Salvelinus namycush*); northern pike NOPK, N = 2 (*Esox lucius*); longnose sucker LNSK (*Catostomus catostomus*), N = 16; Arctic Grayling ARGR, N = 22 (*Thymallus arcticus*); burbot BRBT, N = 12 (*Lota lota*); and ninespine stickleback NSPS, N = 25 (*Pungitius pungitius*)] were collected from the Alaskan Arctic Coastal Plain in 1992 and 1994 while marine fishes [fourhorn sculpin FHSC (*Myoxocephalus quadricornis*), N = 22 and Arctic flounder ARFL (*Liopsetta glacialis*), N = 19]shown in the lower panel were collected from the Alaskan Arctic Coastal Plain in 1994. TL, CR, and PB after species codes refer to the sampling locations, respectively, Teshekpuk Lake, Chipp River, and Prudhoe Bay. The whiskers indicate the 10 and 90 percentiles. The 25, 50 and 75 percentiles are indicated by the boxes, whereas the mean value is the shown as a symbol.
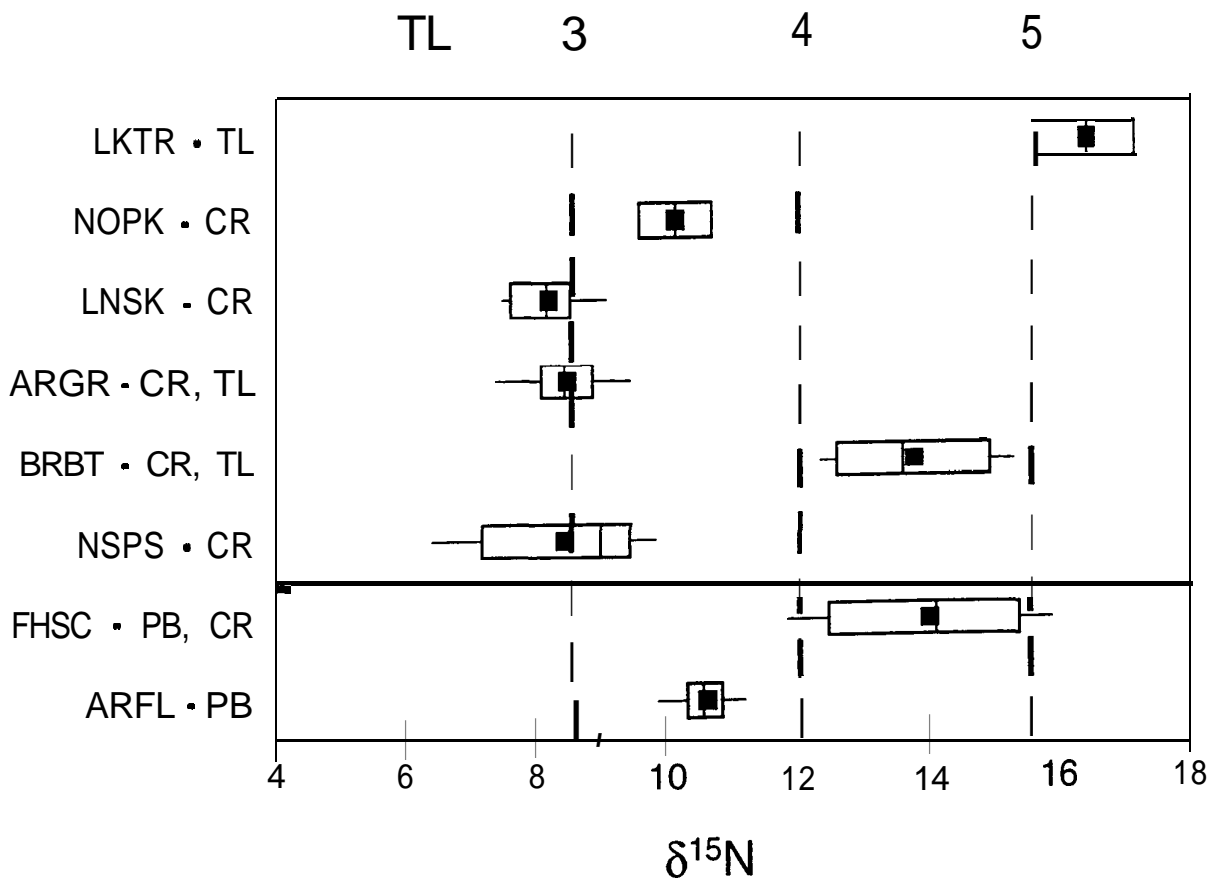
Figure 3. Dichotomyin $\delta^{13}C'$ (a) and $\delta^{13}C'_{TL}$ (b), shown as box and whisker plots, between two marine and five freshwater fishes as in Fig. 1. Variation in $\delta^{13}C'$ among freshwater species due to differences in trophic level shown in (a) removed in (b).
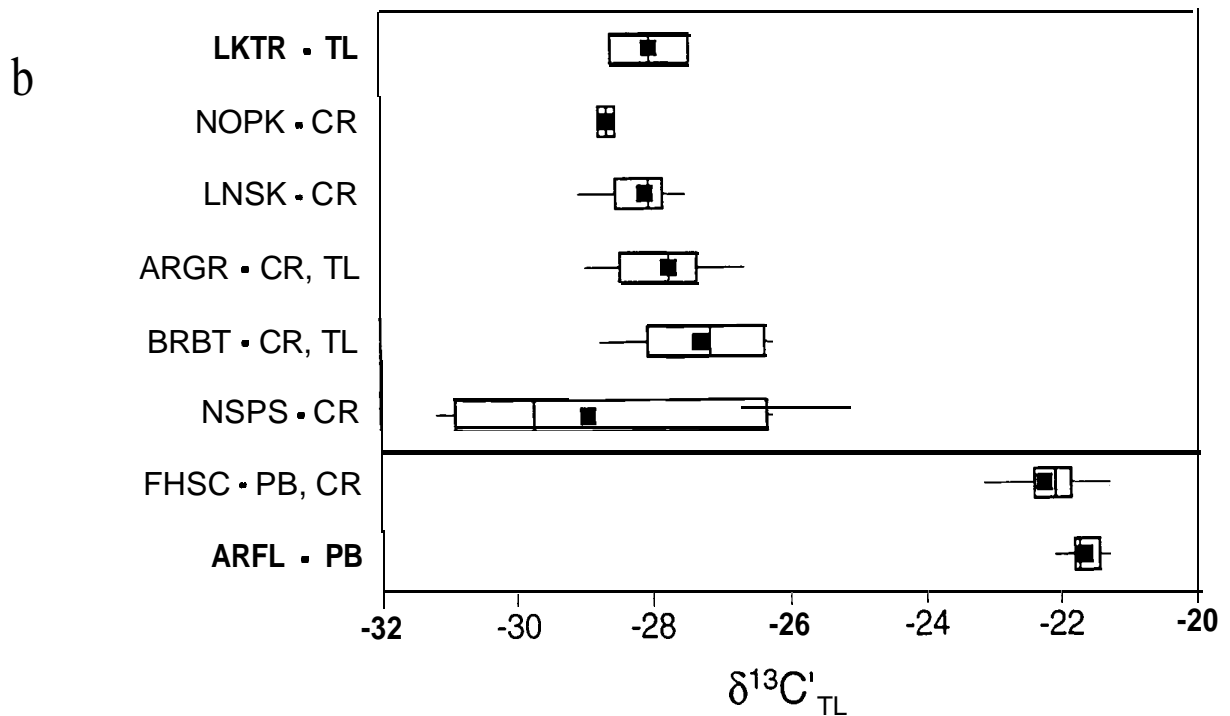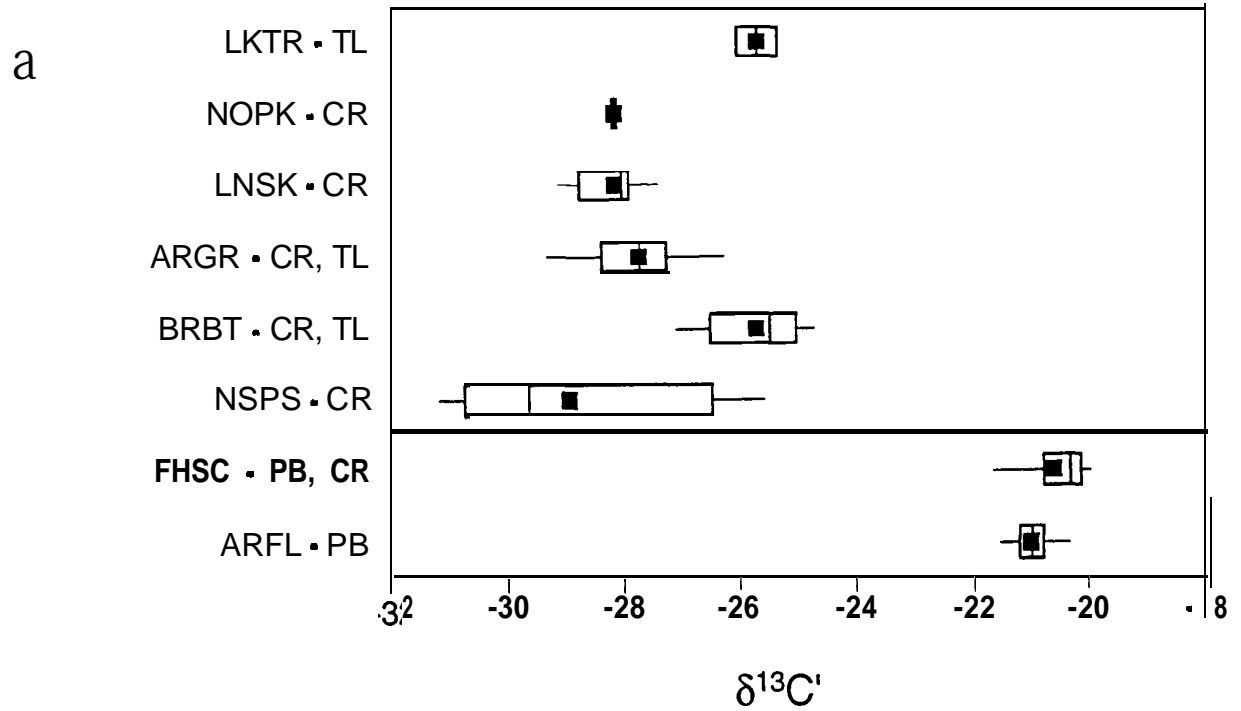
Figure 4. $\delta^{13}C'_{TL}$ shifts as a function of length of four North Slope salmonid fishes that are anadromous or amphidromous (Dolly Varden chat-r, N = 46 from 1994, triangles, dotted Line; least cisco, N = 57 from 1994, squares, alternating long and short dashed line; Arctic cisco, N = 148 from 1994 and 5, crosses, dashed line; and broad whitefish, N = 181 from 1994 and 5, circle, solid line) sampled in the Sagavanirktok River delta suggest species-dependent change in carbon source (M = marine, F = freshwater, T = transitional) during life history. Second order polynomial regressions computer-fitted (Deltagraph Pro 3.0, Deltapoint, Inc.) to data. The delayed shift in Dolly Varden charr is consistent with this species' life history pattern (Craig 1989).
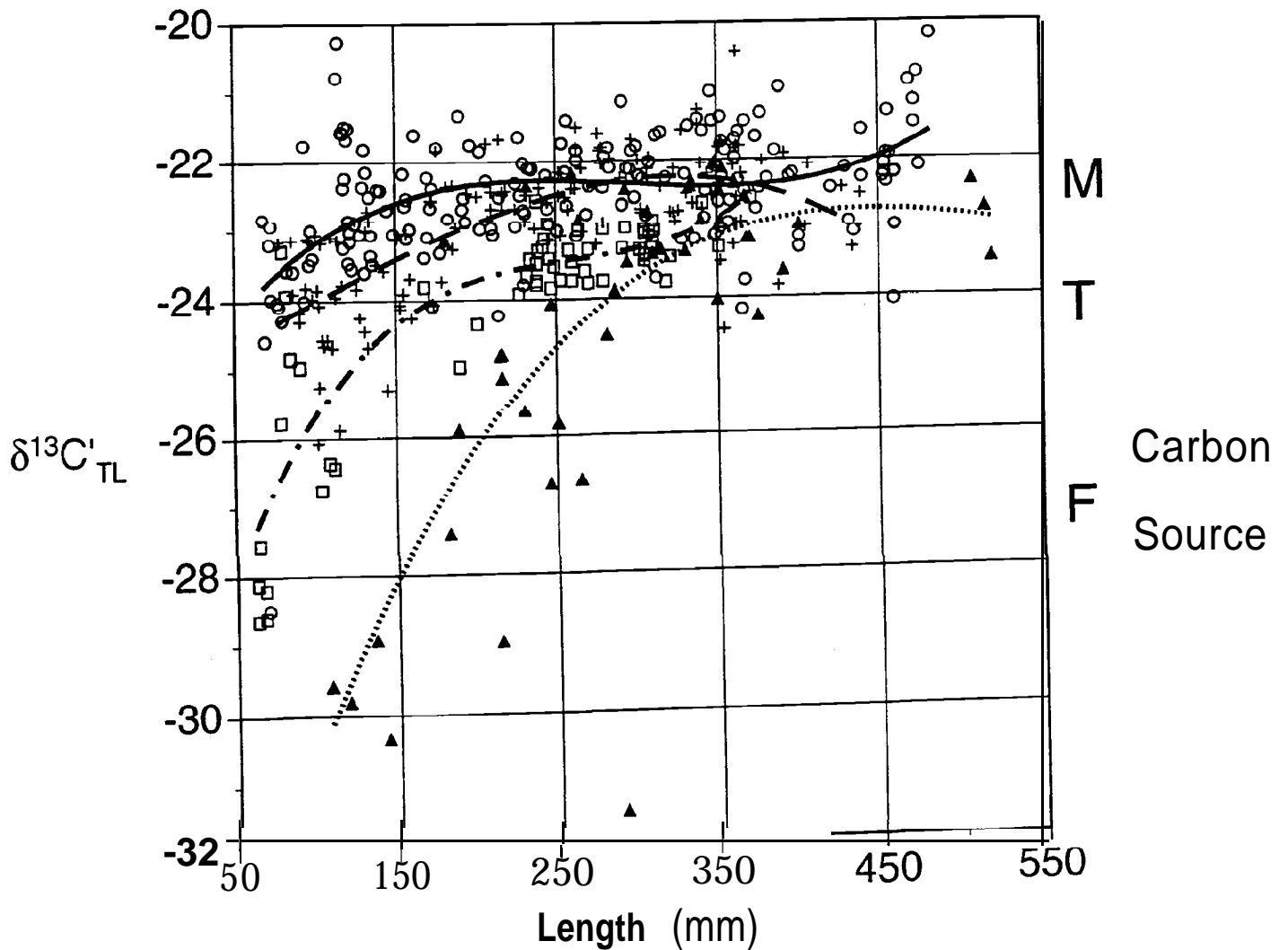
Figure 5. Shifts in $\delta^{15}N$ as a function of length four North Slope salmonid fishes that are anadromous or amphidromous (Dolly Varden charr, N = 46, triangles, solid line; least cisco, N = 57, crosses, dashed line; Arctic cisco, N = 148, circles, dotted line; and broad whitefish, N = 181, squares, alternating long and short dashed line) sampled in the Sagavanirktok River delta suggest species-dependent differences in relative trophic level as well as increases during life history. Regression lines are second-order computer-fit to the data as in Fig. 4.
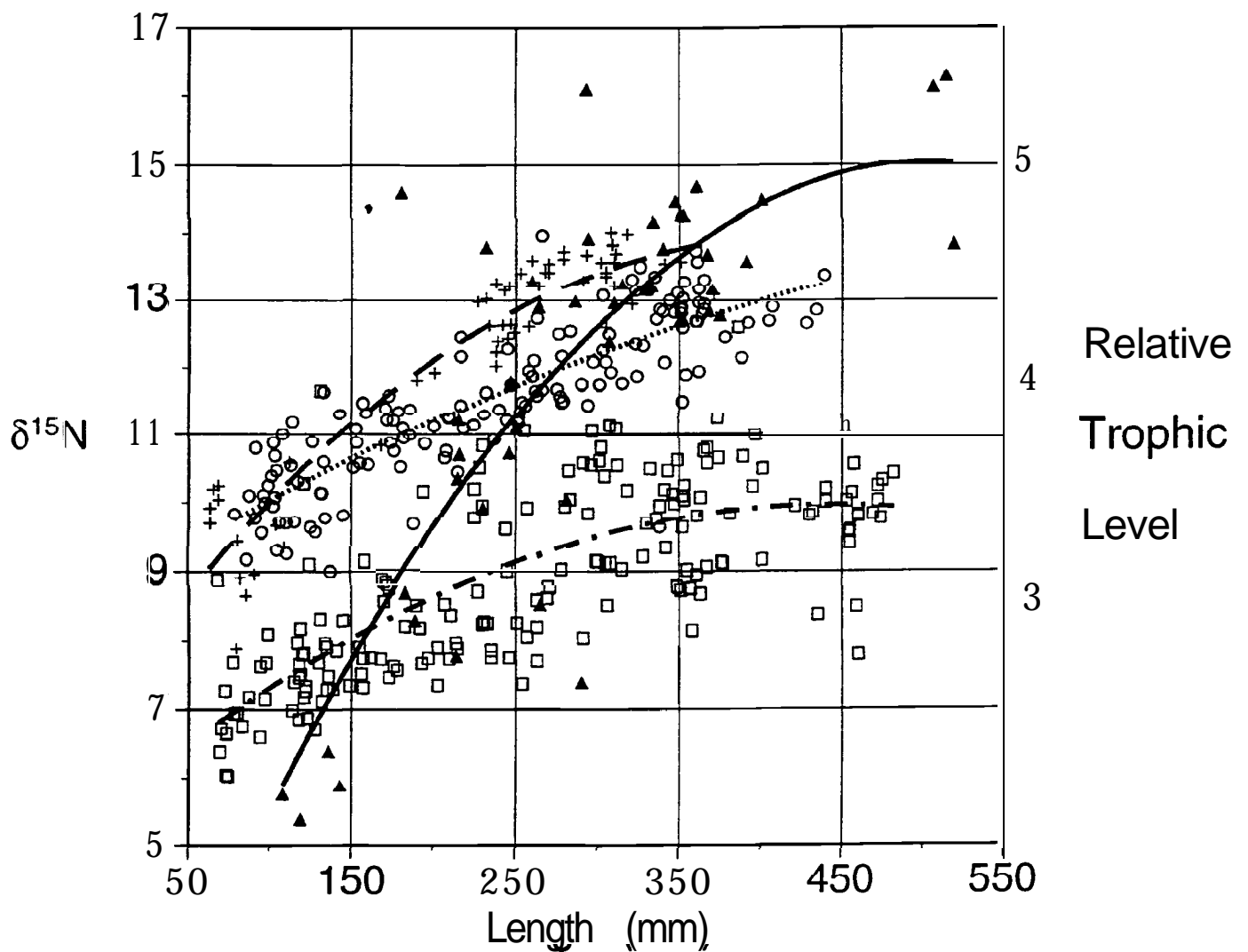
Figure 6. Carbon (upper panels) and nitrogen (lower panels) isotopic shifts of cohorts (year of birth on X axes) of Arctic cisco (a) and broad whitefish (b) during four-sample-period time series [24 June to 23 July, 1994 (white); 11 to 22 August, 1994 (stippled); 23 June to 4 July, 1995 (black); and 14 to 20 August, 1995 (cross-hatched)] shown as box and whisker plots (the five horizontal lines display the 10th, 25th, 50th, 75th, and 90th percentiles) while outliers are shown as symbols. Outliers and percentiles omitted by computer programming (Statview 4.5, Abacus Concepts, Inc.) for box and whiskers with small N as appropriate.

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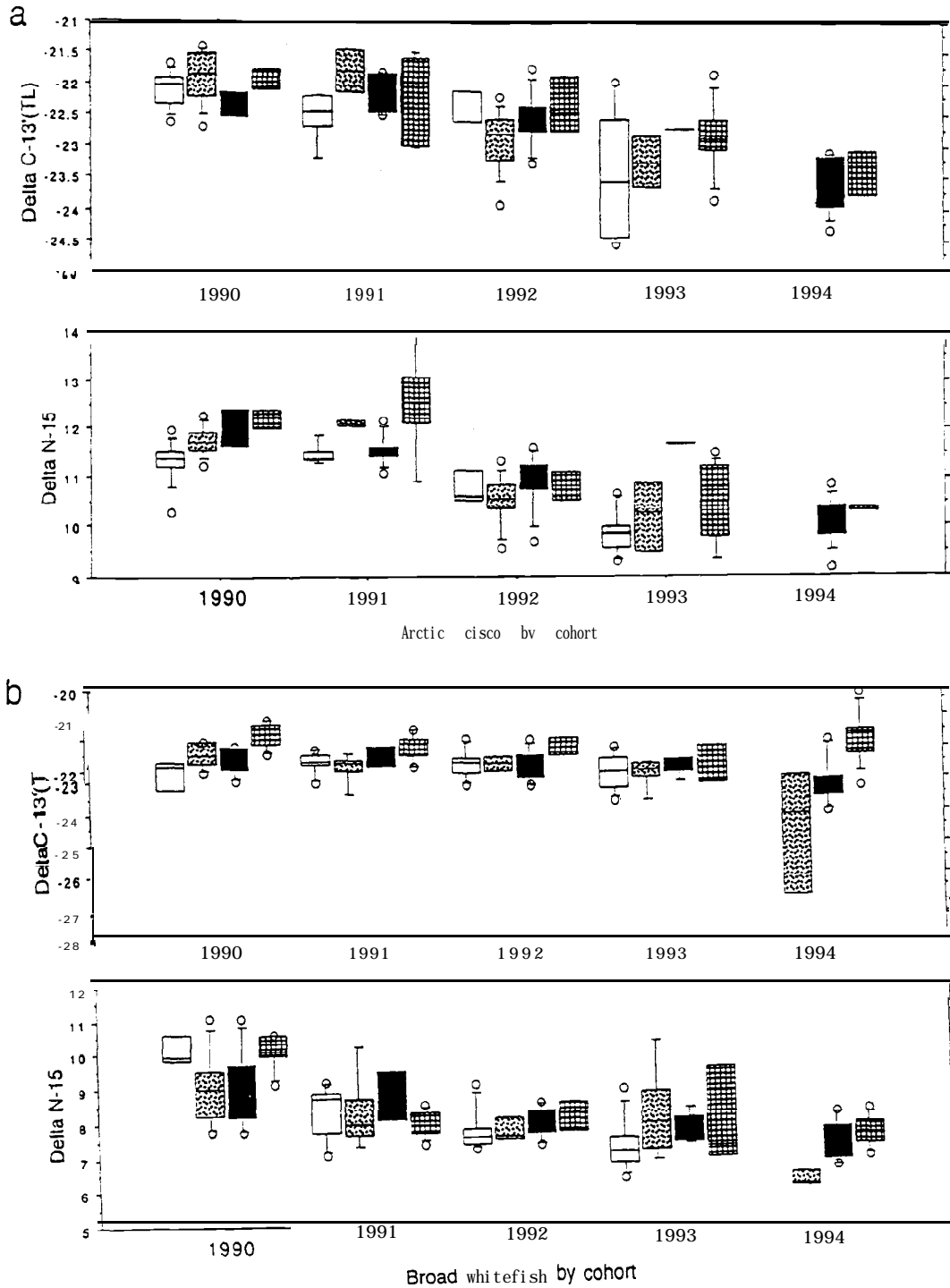
The Department **of the** Interior **Mission**

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management **Service** Mission

As a bureau of the Department of the Interior, the Minerals Management Service's **(MMS)** primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf **(OCS),** collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the Offshore Minerals Management Program administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty** Management Program meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS **strives** to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic