AN ABSTRACT OF THE THESIS OF

John Seigle for the degree of Master of Science in Fisheries Science presented on December 19, 2003.

Title: Determination of Marine Migratory Behavior and its Relationship to Selected Physical Traits for Least Cisco (*Coregonus sardinella*) of the Western Arctic Coastal Plain, Alaska.

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M. Jesse Ford

With increased resource development on the western Arctic coastal plain of Alaska (especially within the oil extraction industry) it is important to understand the basic life history attributes of whitefish stocks in the region in order to ensure appropriate management. These fish are a crucial part of subsistence harvests for native Alaskans. Multiple forms of the whitefish least cisco (*Coregonus sardinella*) have been described based on both appearance and life history traits. Two major forms of least cisco have been mentioned in the literature: a larger *normal* amphidromous form with fork lengths of approximately 420 mm and a *dwarf* lake resident form with lengths up to 230 mm. However, there is considerable evidence for additional forms and life history strategies of least cisco. I investigated the relationship between migratory behavior and selected physical traits of least cisco in six lakes and one brackish lagoon in the western Arctic coastal plain of Alaska. I used electron microprobe technology to determine the levels of Sr and Ca in the otoliths of 258 least cisco in order to resolve their marine migratory life history. I also investigated the relationship between migratory behavior and the numbers of gill rakers, lateral line scales, anal rays and dorsal rays as well as condition factor. The vast majority of least cisco captured in these sites were *normal* in form, yet only ~12% of all samples yielded any sign of sea-run behavior. Evidence for migratory behavior was low even for sites within close proximity to brackish waters. Fish exhibiting marine migratory behavior tended to make their first migrations to sea before age three (mean = 2.6 years), although fish in one coastal site (Joeb's) averaged over 5 years of age at first marine visit. There was some evidence of higher condition factors for fish with sea-run migratory experience. There were significant differences in lateral line and dorsal ray numbers among sites but none for anal rays or gill rakers. Variability in all of these characters was high, and fish from coastal sites tended to have greater variability than those from inland sites. Only dorsal rays showed significant differences in meristic traits between sea-run and resident least cisco. These results suggest that least cisco exhibit high variability in physical traits. Also, least cisco appear to be flexible in their use of the marine environment, even within similar forms in the same lake. Some of the most basic life history characteristics of least cisco remain uncertain. With increased resource extraction occurring on the western Arctic coastal plain of Alaska, it is important to continue to investigate these and other life history strategies so as to ensure a sustainable fishery for native inhabitants of the region.

# Determination of Marine Migratory Behavior and its Relationship to Selected Physical Traits for Least Cisco (*Coregonus sardinella*) of the Western Arctic Coastal Plain, Alaska.

by

John C. Seigle

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John C. Seigle, Author

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**Introduction**

Fish of the coastal plain of Arctic Alaska are fundamental to the diet and culture of the native inhabitants of the region. Although caribou and other mammals such as wolverine, fox and the bowhead whale all play important roles in the culture of native Alaskans, it is fish that make up the bulk of subsistence harvests (Wolfe 2000). These species include not only the much sought after broad whitefish (*Coregonus nasus*) and burbot (*Lota lota*), whose liver is coveted as a delicacy, but also lake trout (*Salvelinus namaycush*), arctic cisco (*Coregonus autumnalis*) and least cisco (*Coregonus sardinella*). Iñupiat communities are not simply augmenting their diet with these fish; they depend heavily upon them for their existence.

While there have been a number of studies and surveys that investigated fish populations and movements on the coastal plain of Arctic Alaska (Craig 1989, Moulton et al. 1997, Morris 2000), there are still many holes in our understanding of the basic life history strategies for several species. However, it is not for lack of interest that these species go unstudied. Indeed, the sheer vastness of this remote landscape, the complexity of the innumerable lake and river systems therein, along with the harsh weather conditions of the region have conspired to limit basic scientific research in the region (Ford and Bedford 1987).

The least cisco (*Coregonus sardinella*) is a perfect example of a species of the region for which we lack significant life history data. Although it is by many accounts among the most prevalent fish along most drainages and near-shore waters of the coastal plain of northern Alaska (Craig 1984, 1989 Philo et al. 1993 a, 1993b, Moulton et al. 1997), only a handful of studies have been conducted on this species. As a result, there are confusing and sometimes conflicting accounts for some of the simplest life history attributes of this fish.

Multiple forms of least cisco have been described over the years. The most common forms mentioned are the *dwarf* form and the significantly larger *normal* form (McPhail and Lindsey 1970, Mann and McCart 1981). It is often stated in these reports that the *normal* least cisco is an amphidromous form which spends its summers in brackish coastal waters, while the smaller *dwarf* form spends its entire life in freshwater. Furthermore, larger least cisco caught in the brackish waters of the Arctic Alaskan coast in the spring and summers are implied to be akin to *normal* fish found in freshwater environments of the region. As *dwarf* forms have not been described in brackish water, this theory has been largely accepted.

The purpose of this study was to determine the possibility of reliably categorizing least cisco as amphidromous or freshwater resident based on physical characteristics. In this thesis I examine use of the marine environment for each least cisco by analyzing otolith microchemistry. I then examine body condition as well as numbers of lateral line scales, dorsal rays, anal rays and gill rakers in order to determine whether relationships exist between those characteristics and migratory behavior in least cisco.

## Background

### *Human inhabitants*

Iñupiat inhabitants of the North Slope Borough in Alaska annually make numerous trips via snow machine or boat to remote regions of their tundra environment to hunt and fish from their traditional subsistence camps (personal observation). Residents of the Barrow area, located at the northernmost tip of the state (Fig. 1), routinely travel 100-200 km to camps situated near large lakes or alongside major tributaries where subsistence fishing opportunities are readily available. These camps normally consist of one or more shelters, and also act as staging areas for excursions to the numerous river and lake systems nearby for hunting caribou, wolverine, fox and other mammals important to the diet and cultural fiber of native communities. Indeed, subsistence hunting and fishing is a way of life, not just a hobby, for native cultures of this Arctic region.

With an increase in population growth comes an increase in resource exploitation. Although the literature on the effects of fishing pressure on northern fish stocks is sparse, deleterious impacts of over-fishing on whitefish populations has been documented (Clark and Bernard 1992). Of equal or greater concern are the pressures exerted on fish of the North Slope through habitat change due to the continued search for oil and the development of resource extraction industries (Fechhelm et al. 1994, Galloway and Fechhelm 2000).

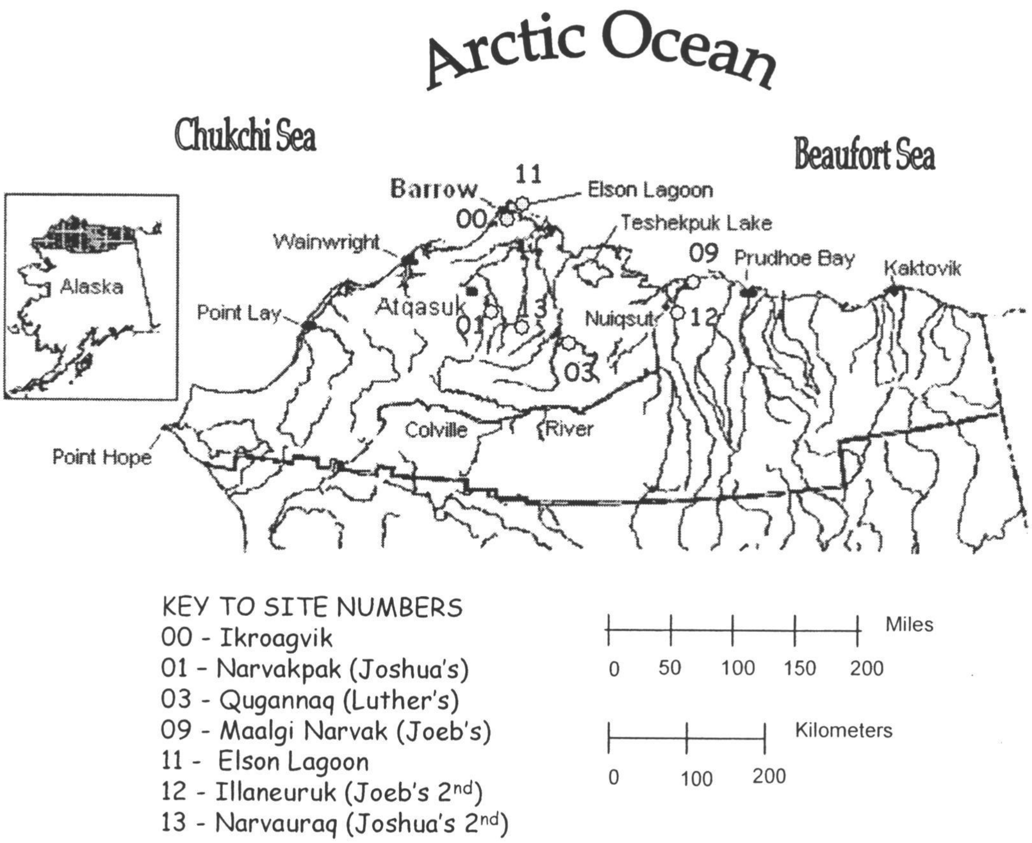



Figure 1. Map of the North Slope Borough of Alaska, including sites in this study. Also listed are major towns and villages of the region as well as major drainages including the Colville River.

In recent years a number of surveys have been conducted to look at the effects on fish populations of gravel causeways which extend from land into the near-shore waters of the Arctic Ocean (Environmental Protection Agency (EPA) 1988, National Oceanic and Atmospheric Association (NOAA) 1988, BP exploration (Alaska) Inc. 1989, Fechhelm et al. 1994). These causeways, which lie between the Colville River Delta and McKenzie River, are constructed to take advantage of offshore oil and natural gas reserves. Much of the concern is over the fact that these causeways affect near-shore water circulation and salinity and may actually hinder coastal migration of migratory fish species, in particular, whitefish. This region has been documented as a major summer dispersal area for least cisco (Craig 1984).

Other factors associated with oil extraction such as infrastructure development, population growth and road construction have increased throughout the National Petroleum Reserve- Alaska (NPRA). This area encompasses a tremendous amount of the land area of the North Slope Borough west of the Colville River and is currently undergoing aggressive oil exploration and development. The distributions of a number of fish species important to the people of the region fall within this area of concern (Craig 1989).

***Study area***

The study area extends from Barrow, Alaska southward approximately 150 km to sites southeast of Atqasuk (Fig. 1), and approximately 250 km eastward from Barrow to sites in the Nuiqsut area near the Colville River Delta. The area is largely composed of a lowland tundra ecosystem. The landscape is riddled with countless small bodies of water ranging in size from puddles, to ponds, to lakes which extend in all directions as far as the eye can see. During summer months visitors to the region can endure seemingly limitless swarms of mosquitoes, view herds of caribou in the thousands, and check numerous birds and wildflowers off their life-lists. In winter the landscape appears barren and bleak with frozen bodies of water often indecipherable from snow-covered land. Caribou are still prevalent though, as are many other fur bearing animals such as wolverine, arctic fox, and polar bear.

The region receives less than 15 cm of precipitation annually and average temperatures range from about 10° C in summer to -29° C in winter (Ford and Bedford 1987). For the more than nine months of Arctic winter, the entire coastal plain is blanketed with snow and ice. At Barrow, the sun disappears below the horizon on November 18$^{th}$ and is in complete darkness until January 24$^{th}$. In summer, from June to August, the ice breaks up and snow melts as the days grow gradually longer until constant daylight occurs when the sun does not set from May 10$^{th}$ until August 2$^{nd}$.

Most of the lakes of the region are thermokarst or thaw lakes (Young 1989). These lakes were formed over time by the continual freeze/thaw process of water which accumulated in depressions in the earth. As subsurface water freezes it expands. When it melts it takes up less space and thus the land above it sinks. Over time these bodies of water grow larger and larger. The majority of these lakes are actually shallow ponds

( < 4 meters) and probably freeze to the bottom during winter, thus rendering them void of fish life (Craig 1989). Deeper lakes freeze only a meter or two down from the surface and thus can support fish life throughout the long winter. Generally lakes of the region are oligotrophic in nature (Power 1997) but many still support substantial fish populations ranging from extremely hardy fish like the Alaska blackfish (*Dallia pectoralis*), to plankton eaters like the nine-spine stickleback (*Pungitius pungitius*) and large predators like the lake trout (*Salvelinus namaycush*) and northern pike (*Esox lucius*).

### *Least cisco physical characteristics*

Least cisco is a coregonid, a sub-family of the salmonids. This species was first described from preserved samples in 1848 by the Italian taxonomist Valenciennes from samples collected in Siberian streams (McPhail and Lindsey 1970). It is found in freshwater streams and lakes of the northern latitudes of Asia, Europe and North America (McPhail and Lindsey 1970, Scott and Crossman 1973, George et al. 2001). Taxonomic publications have suggested the presence of two major forms of least cisco based on length at age (McPhail and Lindsey 1970, Scott and Crossman 1973). The first is a *dwarf* lake resident form reaching lengths up to 23 cm. The second is a *normal* marine migratory form up to 42 cm in length. The normal form is also said to be more dorsally spotted (McPhail and Lindsey 1970). The least cisco is a long lived species with individuals as old as 28 years of age described (Philo et al. 1993a). Least cisco spawn in early to late fall, with females depositing eggs over sand or gravel, where they are fertilized by the males. The eggs hatch out under the ice in early spring.

The few studies that have been conducted on least cisco illustrate how confusing the life history of this species can be. The dwarf form of least cisco matures anywhere from three to five years of age depending on the study area (Mann and McCart 1981, Philo et al. 1993a, Moulton et al. 1997). The normal form has generally been described as maturing later, from five to seven years of age (Philo et al. 1993a, 1993b, Mann and McCart 1981). There is some evidence that sea-going males mature later than females (Philo et al. 1993b, Moulton et al. 1997, Mann and McCart 1981). There tends to be a positive relationship between both fecundity and somatic weight (Moulton et al. 1997) and fecundity and length (Clark and Bernard 1992).

Two early studies conducted in Lake Ikroagvik near Point Barrow, Alaska provided one of the first documentations of least cisco life history age and growth (Cohen 1954, Wohlschlag 1954). In fact, Cohen claimed that these were the first age and growth studies of freshwater fish ever conducted in the Alaskan Arctic. Cohen found that amphidromous populations of least cisco were noticeably different in body shape. He also noted that marine fish were smaller at a given age than the freshwater least cisco. One must note however, that he was basing age on scale increments which have been shown to become less accurate as an aging tool as the fish gets older (Beamish and McFarlane 1987). Similarly, Cohen differentiated between marine and freshwater populations in freshwater lakes by examining scale growth patterns of known lagoon fish to fish captured in lakes. Large lagoon fish and a few large fish from Ikroagvik had wider, clearer circuli in their scales than *dwarf* fish found in the same lake. The scales of *dwarf* least cisco were characterized by very closely packed circuli.

Wohlschlag (1954) suggested that lagoon fish (i.e. amphidromous least cisco) were "somewhat thinner" than Ikroagvik fish (i.e. freshwater resident least cisco) of the same length, but he did not say anything about the age of these fish. Both authors suggested that marine migratory least cisco were slightly smaller than the freshwater resident fish. However, the smaller fish in this case was not the *dwarf* form as defined by subsequent studies involving least cisco (Mann 1974, Philo et al. 1993a). Rather, these fish were simply at the smaller end of the size spectrum at age for what would later come to be known as *normal*.

The existence of *dwarf* and *normal* forms of least cisco living sympatrically was reported for lakes of the Yukon Territory (Mann 1974, Mann and McCart 1981). Unfortunately, Mann found that it was difficult to distinguish mature *dwarfs* from immature *normal* forms on the basis of external appearance alone (1974). Contrary to Cohen's work, Mann found that the migratory forms had the fastest growth of all populations he sampled. Mann (1974) also reported the existence of anadromous (fish that were captured in brackish waters), freshwater migratory (fish appeared suddenly in large numbers in nets during sampling period after long period of absence in certain sites), and freshwater non-migratory (lake appeared to have no suitable outflow for migration) forms of least cisco.

Further complicating the matter, a "Jumbo Spotted" form of least cisco was also described in the southern Yukon Territory (Lindsey and Kratt 1982). This was seemingly a unique form of least cisco and was by far the largest form yet described (fork length up to 452 mm). This form had not been observed in surrounding tributaries and thus it was considered a lake resident form.

In addition to age and length, other physical attributes of least cisco have been noted (refer to Table 1 for summary). It has generally been noted that the larger normal form is heavily spotted dorsally while the smaller *dwarf* form is unspotted (McPhail and Lindsey 1970, Mann and McCart 1981). Mann (1974) and Mann and McCart's (1981) reports were the most extensive, reporting numbers of gill rakers, lateral lines and pyloric cecae and vertebrae. These authors found significant differences between *dwarf* and *normal* forms for gill raker and lateral line scale counts, with the *normal* form having higher counts than the *dwarf* form fish (Table 1). Lindsey and Kratt's (1982) "Jumbo Spotted" form had gill raker counts higher than those reported by Mann and McCart (1981), but consistent with the range of values reported by McPhail and Lindsey (1970).

Table 1. Summary of findings on least cisco from Alaska and northwestern Canada (1954-1997).

| Study | N | Forms Described | Max Fork Length (mm) | Fork Length at Maturity (mm) | Age at First Maturity | Max Age (yrs.) | Sea Going? | Spawning Frequency | Spotted? | Gill Raker # Range | Lateral Line # Range |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cohen (1954)/Wohlschlag (1954) | 1019 | larger lake resident | 385 | ? | ? | 11 | no | ? | ? | ? | ? |
| | 153 | small marine migratory | 345 | ? | ? | 12 | yes[1] | ? | ? | ? | ? |
| | 116 | dwarf lake resident | 320 | ? | ? | 10 | no | ? | ? | ? | ? |
| Philo et al. (1993a)/Moulton (1997) | 122 | brackish water migratory | 400 | m=245, f=223 | m=7, f=6 | m=26, f=28 | yes[2] | biannual[5] | ? | ? | ? |
| Philo et al. (1993b) | 156 | normal | 407 | m=258, f=250 | m=5, f=5 | m=27, f=25 | ? | ? | ? | ? | ? |
| | 117 | intermediate | 325 | m=173, f=163 | m=6, f=6 | m=20, f=17 | ? | ? | ? | ? | ? |
| | 181 | dwarf | 213 | m=136, f=135 | m=5, f=5 | m=15, f=18 | ? | ? | ? | ? | ? |
| McPhail and Lindsey (1970) | ? | small unspotted | 230 | ? | ? | 5 or 6 | no | ? | no | 41-47 | ? |
| | ? | larger (usually spotted) | 420 | ? | ? | 5 or 6 | usually[3] | ? | yes | 48-53 | ? |
| Mann and McCart (1981) | 265 | dwarf | 135 | 85 | m=3, f=3 | 14 | ? | annual[6] | no | 39-46 | 78-83 |
| | 246 | normal | 344 | 205 | m=7, fe=6 | 23 | ? | annual[6] | yes | 40-48 | 81-91 |
| Lindsey and Kratt (1982) | ? | jumbo | 452 | ? | ? | ? | doubtful[4] | ? | yes | 48-52 | ? |

m = male, f = female, ? = unknown

[1] Determined from comparison of freshwater and marine samples with similar scale banding patterns

[2] Samples were captured in marine waters

[3] Did not specifically state how this was determined

[4] Based on samples from closed lakes and lack of evidence for out-migration in open lakes

[5] Determined from analysis of age class structure of mature fish

[6] The authors did not state how they came to this determination

***Migratory behavior***

To date there have been no studies to validate marine migratory behavior in least cisco captured in freshwater environments. Most descriptions of least cisco have inferred migratory behavior from size (McPhail and Lindsey 1970), or a combination of factors such as growth, morphology, or similarity to known sea-run forms (Cohen 1954, Mann and McCart 1974, Philo et al. 1993b). In each case it is the larger, *normal* form that has been suggested to travel to sea. However, it is dangerous to assume that all least cisco falling into the category of *normal* form fish go to sea, as some studies have concluded that larger forms can be freshwater residents (Mann 1974, Lindsey and Kratt 1982). *Normal* and *Jumbo-Spotted* forms of least cisco in these studies were either landlocked or had never been viewed amongst runs of migratory fish exiting or entering these lakes. At the same time, no study has produced evidence of a *dwarf* form least cisco in the marine environment.

Otoliths have been a useful tool in determining the migratory behavior of fish. Analysis of the chemical composition of otoliths along the built-in time line created by daily and annual ring deposition can be an important instrument in determining where a fish has spent its time (Radtke 1989, Secor et al. 1995). A number of studies have examined the microchemistry of otoliths through techniques such as wavelength dispersive electron microprobe analysis (Rieman et al. 1994, Radtke 1995, Radtke et al. 1996), scanning proton microprobe analysis (Babaluk et al. 1997, Howland et al. 2001), micro-PIXE analysis (Limburg et al. 2001), solution-based ICP-MS (Fowler et al. 1994a) and laser ablation ICP-MS (Fowler et al. 1994b).

The underlying theme in utilizing these various methods of microchemical analysis of otoliths is that the otolith is a storage facility for time specific records of environmental history (Campana et al. 1997, Radtke 1989). Trace elements found in the mostly calcium carbonate ($CaCO_3$) matrix of otoliths act as markers of the environment in which these fish live at any given time (Campana et al. 1997, Secor et al. 1995). The trace element strontium (Sr) has been of particular interest to researchers interested in migratory behavior of anadromous fishes. The ionic form of Sr, like calcium (Ca), has a plus-two charge. Furthermore, Sr has a similar ionic radius to that of Ca. For these reasons Sr readily substitutes for Ca in the $CaCO_3$ matrix of otoliths (Secor et al. 1995, Farrel and Campana 1996).

It is important to note that Sr is found in much higher concentrations in sea-water than in freshwater (Rosenthal et al. 1970, Kalish 1990) and many studies have shown a positive correlation between Sr in the environment and that found in the otolith (Rosenthal et al. 1970, Kalish 1989, Ingram and Sloan 1992, C. Zimmerman, unpublished data). Thus, determining elemental content of otoliths at a series of points along transects from the otolith's core to its marginal edge can be an important instrument in determining where a fish has spent its time.

By analyzing the ratio of the Sr to Ca along otoliths of Arctic char (*Salvelinus alpinus*) and inconnu (*Stenodus leucichthys*), it was possible to determine the migratory status of these fish (Radtke 1995, Howland et al. 2001). Analysis of Sr:Ca in arctic char otoliths yielded information that, when coupled with annulus structures inherent to otoliths, demonstrated the usefulness of this method in relating microchemical data and age data (Radtke 1995). Babaluk et al. (1997) found evidence of non-migratory behavior in Arctic Char by using scanning proton microprobe analysis. Howland et al. (2001) used scanning proton microprobe analysis on otoliths of inconnu (*Stenodus leucichthys*) to determine that both migratory and resident populations existed in the Mackenzie River system. This method allows researchers to determine not only migratory status of the fish being analyzed, but also the age at first sea-run and frequency of sea migrations.

A number of other factors such as temperature, diet, growth, and stress have been shown to influence Sr uptake by otoliths. However, it is the amount of Sr in water that has the greatest effect on levels of Sr found in otoliths (Secor et al. 1995, Farrell and Campana 1996). This method is therefore extremely useful in estimating marine migratory behavior of fish.

***Objectives of study***

The aim of this study was to investigate selected life history traits of least cisco in several freshwater lakes and one brackish water lagoon of the northern coastal plain of Arctic Alaska. The specific goals were to:

1.) Analyze microchemistry of otoliths to determine migratory status of least cisco by site.

2.) Couple microchemical data with age data to determine age at first sea-run for migratory fish.

3.) Use morphological and meristic data in concert with microchemical data to determine whether selected physical traits of least cisco could be used as an indicator of sea-run behavior.

## Materials and Methods

### *Site selection and description*

Locations and sampling dates for each site are given in Table A-1 (App. A). Samples were taken from six lakes and one brackish water lagoon over the course of three field seasons (summer 2000 and 2001, fall 2001). Four of the six lakes are known as subsistence sites located at or near Iñupiat fishing camps (Joshua's, Joshua's 2$^{nd}$, Luther's, and Joeb's in Fig. 1). These sites normally are fished by only one or two families. The remaining sites (Ikroagvik and Joeb's 2nd) are also traditional subsistence fishing sites, but are fished by numerous citizens of the greater Barrow and Nuiqsut areas respectively. Two lakes, Ikroagvik and Joeb's, were situated within 10 km of saline waters. A third site, Joeb's 2$^{nd}$, was located southeast of Nuiqsut, approximately 50 km from the Colville Delta. This lake has an outlet which drains into the Colville River within 10 km. These three sites are designated as *coastal* sites. Three other sites (Joshua's, Joshua's 2$^{nd}$ and Luther's) were located to the south and east of Barrow, between 100 and 150 km from the marine environment. Helicopter reconnaissance revealed that each of these sites had outlets which flowed to other creeks and/or lakes, but it was unclear if or where these sites linked to streams flowing seaward. These sites are referred to here as *inland* sites.

In most cases sample sites were chosen with counsel from expert Iñupiat whitefish fisherman who collaborated on this project on many levels, including opening their subsistence camps to fishing for this study. These sites are known by our native collaborators to support populations of least cisco. In the case of Ikroagvik Lake, which is located just outside of Barrow, Alaska, biologists from the North Slope Borough Wildlife Department and the Alaska Department of Fish and Game encouraged us to study the site, aided in locating fishing areas, and provided additional fish for use in this study.

In addition to the sampling effort that took place in 2000 and 2001, nine sets of otoliths were donated by the North Slope Borough Wildlife Department from least cisco obtained in a 1991 survey at Teshekpuk Lake, an 810 $km^2$ body of water located between Barrow and Prudhoe Bay. We also obtained least cisco from Elson Lagoon near Barrow, Alaska to ensure the capture of known sea-run fish for comparative analysis with fish caught in freshwater lakes.

***Limnology***

The deepest area of each lake was located by taking a series of sonar readings in the vicinity of areas that appeared to be deep as determined both from changes in water transparency when viewed from above during aerial reconnaissance and from information gained from counsel with our Inupiat collaborators. At the deepest area, GPS coordinates, air temperature (°C), and maximum water depth (to nearest 0.1m), were recorded. Water temperature, $O_2$ saturation, $O_2$ concentration , conductivity, specific conductance, and salinity were determined at one meter from the water's surface using a YSI-85 multi-meter.

Next, a Van Dorn water sampler was lowered to gather a water sample from a depth of one meter. This water was used to fill a one-liter bottle. A final Van Dorn sample was then obtained and stored in the chamber for transport to the field lab.

In the field lab, water samples were prepared for cation analysis in a clean environment within a water chemistry tent. A graduated cylinder was filled with 100 ml of water from the Van Dorn spigot and transferred to a labeled and pre-acidified Nalgene® bottle for unfiltered cation analysis. All samples were kept cold in the field and sent by courier to Oregon State University for further processing.

Water samples were analyzed for major cations (Ca, Mg, Na, K) and Sr at the Central Analytical Laboratory in the Department of Crop and Soil Science at Oregon State University. Values were reported in parts per million (ppm). A ratio of Sr to Ca (Sr:Ca) was calculated for each sample for comparison with Sr:Ca ratios in otoliths.

***Fishing- Summer 2000 and 2001***

Summer sampling was done from early July to mid-August from a 12-foot inflatable zodiac boat with a four hp Johnson motor. Appropriate sampling locations at each site were determined in counsel with our native collaborators based on historically successful fishing endeavors at those sites. At each sampling location 80-foot gill nets were placed with weighted sand bags attached at several points along the bottom length of the nets and floats attached along several points of the top portion of the nets to maintain their vertical position in the water column. The nets were of composite twine/nylon construction with a mesh size ranging from 2.0 inches to 4.5 inches. (It should be noted that two multi-panel nets with mesh sizes ranging from ¾ inch to 5 inches were added to the fall 2001fishing season (See Table A-2, App. A. for net descriptions). This allowed for the capture of a range of sizes for least cisco. GPS coordinates and "time in", "time out", and number of fish captured were recorded (See Table A-3 App. A. for catch per unit effort information). Fish were stored in coolers and returned to shore for data processing. If fishing was successful, the net was left in place and a new "time in" was recorded. If fishing was deemed unsuccessful for a given location, nets were moved to a more promising location.

***Fishing- Fall 2001***

Five of the original six sites were fished during the sampling period from October 20 – November 20, 2001. The sampling effort took place under ice after freeze-up. Again, Iñupiat collaborators guided the research team to traditionally successful fishing areas at or near their fishing camps. The one exception was Ikroagvik Lake, which was fished with the assistance of personnel from North Slope Borough Wildlife and the Alaska Department of Fish and Game. Access to all sites was gained by dog-sled or snow-machines from staging areas in Barrow, Atqasuk or Nuiqsut.

Once at the sampling location, a 4 hp gas powered auger with a 12 inch bit was used to drill holes through the ice (up to one meter in thickness) at approximately two meter intervals along a transect that ran the length of a gill net. The first hole was made larger by cutting out six to eight adjacent holes with the auger. Metal chipping wedges were used to clean up the rough edges of ice around the hole so as not to catch or tear the nets upon retrieval.

Before placing a net, a 50m rope was attached to a metal weight and lowered into the large first hole making sure to keep one end of the rope above ice. A second worker stood at the next ice-hole three to four meters away and submerged a four meter length of wood (2 in. x 2 in.) with a metal hook attached at one end for use in hooking the weighted rope under the ice. Once hooked, a bight of the rope was pulled up through the second hole so that the working and standing ends of rope remained under ice. The first worker then took hold of the bight end of rope at the second hole while the other worker moved to the third hole and reached with the hooking device back towards the second hole. This process was repeated until reaching the final hole for that transect. At this point the line ran completely under the ice, emerging only from the first and last holes. The gill net was then tied to the emerging end of the submerged rope at the first hole. A worker standing at the last hole pulled on the long weighted end of rope such that the entire net was now pulled under the ice through the larger first hole. Care was taken to insure that a bit of rope attached to the other end of the net remained above ice at the entry hole while the far end of the net still had the long rope attached. At this point, both ends of the net were attached by rope to sticks embedded in ice at the surface of each terminal hole, making sure not to allow the top portion of the net to stick to the bottom of the ice as it rested vertically in the water column. A "time in" and GPS location was recorded.

At the end of the sampling period (typically 18-24 hours), nets were retrieved at the large entry hole, making sure not to pull the long rope attached to the far end completely beneath the ice. The "time out" was noted, the fish were removed and numbers captured recorded. To return the net to the water, a worker at the far end hole simply pulled on the long rope until the net was slid back into position under the ice as before.

### *Fish processing methods*

All processing from the summer seasons of 2000 and 2001 was completed in the field. Fall 2001 samples were placed in individually labeled bags directly after removal from the gill nets. As these fish quickly froze, in-field processing was difficult. Thus, the fall samples were shipped by courier from Barrow in coolers to the laboratory in Corvallis, Oregon where they were kept at -20° C for later processing. The exception was Ikroagvik Lake for which fall samples were processed in a laboratory of the Barrow Arctic Science Consortium (BASC). A sub-sample of Ikroagvik fish were shipped to the laboratory in Corvallis for taxonomic reference while the remaining Ikroagvik fish were retained by Alaska Department of Fish and Game personnel.

Each fish was weighed to the nearest gram with a 2000-gram electronic top-loading scale. This scale was calibrated daily with a one-kilogram calibration weight. Standard, fork, and total lengths were measured to the nearest mm for each fish, and sex was determined. Whole stomachs were removed and stored in 70% ethanol for summer samples and frozen at -20° C for fall samples and archived for future reference. Liver and gonad weight were recorded along with state of maturity for all fish for future reference. Otoliths were removed and each pair stored in one well of a 96-well tray. Gill tags were tied in place and labeled with a fish specific ID code. Whole fish were placed in labeled zip lock bags and stored frozen at -20° C. Subsets of least cisco in this study received additional processing as part of a larger investigation of contaminants in arctic fish, and were shipped whole to labs for further processing.

### *Meristic measurements and condition factor*

The meristic traits measured were lateral line number, gill raker number, anal ray number and dorsal ray number. All counts were made on the left side of the fish. Each meristic trait was counted two times during one counting session. If the counts differed, a third count was taken and the average of the three was used as the value for that trait. If agreement was reached on a particular trait after two counts, a third count was not taken.

During summer sampling, meristic measurements were made in the field. At times it was difficult to quickly and accurately count gill rakers in the field. In these situations the first arch on the left gill raker was removed and stored in 70% ethanol and shipped to Oregon State University. Gill raker counts were performed back in the lab on unstained samples using a dissecting microscope at 4-10 x magnification.

For fall 2001 Ikroagvik Lake least cisco, meristic counts were made in the laboratory at the Barrow Arctic Science Consortium (BASC). All other fall meristic counts were made in the Corvallis laboratory at the same time as other fish processing measurements. The exception to this rule was gill rakers. The first arch gill rakers for fall 2001 samples were removed from frozen samples and placed in 20 ml vials and kept frozen at -20° C for counting at a later date. These samples were later removed from their 20 ml vials, thawed, and counted unstained under a dissecting microscope at 4-10 x magnification.

Some gill raker samples from Ikroagvik Lake were damaged during attempts at preservation. Some gill rakers became brittle while frozen and later broke off when handled during counting. As a result there was some doubt as to the accuracy of counts for this trait. Statistical results on gill rakers are consequently reported both with and without Ikroagvik samples included.

Body condition for each fish was calculated from fork length (mm) and weights (g) according to Fultons' method $[K=(W/L^3)*X]$ where K refers to condition, W refers to the weight in grams, L is the fork length (mm) and X is an arbitrary scaling coefficient, in this case 100,000 (Anderson and Gutreuter 1983).

***Otolith preparation***

Saggital otoliths were removed and cleaned with deionized water and placed in storage in 96-well trays. Standard microscope slides were labeled with fish-specific identification codes. A small square of broken glass from a standard microscope slide was glued to the labeled slide near one end using Crystal Bond 509 adhesive heated to melting over a hot plate. Each left side saggital otolith was removed from storage and glued to the surface of the small square of glass, sulcal side up.

Each preparation was sequentially ground in the saggital plane to near the core region on increasing sandpaper grits of 400, 600, 1200 and then fine polished with .05 micron aluminum polishing powder diluted in deionized water to remove scratches on the surface of the otoliths. The preparations were then cleaned in distilled/deionized water. The samples were then flipped over by melting the Crystal Bond over the hotplate and carefully turning the sample with forceps. The otoliths were then ground to their core from the other side. The surface was cleaned thoroughly with distilled/de-ionized water to remove any remaining aluminum powder or other debris. The samples were aged to the nearest year by counting alternating hyaline and opaque regions using a compound light microscope with transmitted light at 100 x total magnification.

***Electron microprobe analysis***

Each labeled slide was again heated over a hot plate. The small squares of glass upon which samples sat were removed and placed onto a petro-graphic slide. Transferring the preparations in this manner had the advantage of keeping the very brittle otoliths from being handled directly. Depending on otolith size, between 6 and 15 otoliths were placed on each petro-graphic slide. Using a compound light microscope fitted with a numbered stage, (x,y) coordinates of the core of each otolith were recorded so that it could be located easily on the electron microprobe. The entire slide was coated with a 400 Å carbon layer in a vacuum in order to increase conductivity of the electron beam on the otoliths.

Two petrographic slides per microprobe run were mounted on a Cameca SX-50 wavelength dispersive microprobe. Transects were chosen from the core to the edge of each otolith. Thirty-five to forty equidistant points were sampled for 40 seconds with a 15kV, 50nA, 7μm beam following the methods of Toole and Nielsen (1992). Standards for Sr and Ca were strontiantite ($SrCO_3$ – USNM R10065) and calcite ($CaCO_3$ – USNM 136321) respectively. Sr and Ca were sampled simultaneously with the TAP and PET crystals respectively.

***Anomolous otolith***

The distal portion of one otolith (00-11-LC-05, App. D, pg. 126) displayed lower than normal Sr:Ca ratios that corresponded with a visibly obvious change in otolith structure. Increments appeared wavy and blurry and resembled descriptions of vaterite inclusions given in Howland et al. (2001) and Brown and Severin (1999). Such inclusions are polymorphs of calcium carbonate and seem to prevent incorporation of trace metals into the otolith's chemical matrix (Gauldie 1996, Brown and Severin 1999). The second otolith from this fish was probed and yielded the same result for Sr:Ca over time. However, the first seven Sr:Ca points for both otoliths corresponded to an area of the otoliths that appeared normal (i.e. not blurry and wavy). This portion of the Sr:Ca results gave a signal typical of sea-run fish before giving way to the blurred portion of the otolith with anomalously low Sr:Ca signals. This otolith is included in the overall analysis.

***Data analysis***

***-data acquisition***

A ratio of Sr to Ca (A%) was taken for each sampling point on each otolith. Data were displayed in Excel ® line graphs as a ratio of Sr to Ca along the sampling transect. Fish were classified as sea-run if they had at least one point per otolith with Sr:Ca higher than $2.0 \times 10^{-3}$ as long as that point did not occur in the core region. This was to avoid any confusion with maternal influence, as the Sr:Ca in this region is normally a reflection of the environment in which the mother was living at the time of egg production. This value was chosen as a cutoff between resident ($< 2.0 \times 10^{-3}$) and marine migratory ($\geq 2.0 \times 10^{-3}$). Other studies indicated that the freshwater phase Sr:Ca in otoliths was below $2.0 \times 10^{-3}$ (Kalish 1990, Limburg 1995 for Shad, Radtke 1995, 1996 for Arctic Char). Secor (1995) showed experimentally that salinity accounted for most variation in Sr:Ca when those values were between $2.0 \times 10^{-3}$ and $4.2 \times 10^{-3}$, corresponding to a range of salinities in that study of between 5 and 30 ppt.

***-quality assurance of electron microprobe data***

Examination of Sr:Ca plots in Excel ® line graphs revealed occasional unusual data points (e.g. one extremely high or low Sr:Ca point relative to the points around it). Each profile in Appendix A was examined for unusual data points. Electron microprobe analysis yielded data reported as both the weight percentage (W%) and molar percentage (A%) for each of four elements (O, C, Ca, Sr). The total W% for the four elements should approach 100% for each sampling point. If the percentages for a point were below 96% the reading was considered to be incorrect and its Sr:Ca value was replaced with a value determined from the average of all freshwater phase Sr:Ca points for that otolith. Those points are noted by circles in Appendix C.

These low readings for W% were uncommon and were the result of an unusually low Ca W% for those points probably due to one or more of the following:

1.) Incomplete burns as a result of the electron beam being out of focus for that sampling point.

2.) Interference from a bit of glue which accidentally became affixed to the otolith surface in some spots.

3.) Beam position over a pit or fissure in the otolith surface, putting the beam out of focus for that point.

4.) Vaterite replacement in the otolith which causes the chemical composition of the otolith to be affected, thus limiting uptake of certain elements.

*-seasonality of growth in otoliths*

Examination of the outer edge of growth for otoliths in this study showed that the increments at the edges were hyaline (light bands under transmitted light) as opposed to opaque (dark bands under transmitted light) (Appendix D). This was true for fish caught in summer and in fall, and thus it was assumed for the purposes of aging that hyaline bands were representative of summer growth and opaque bands were associated with winter growth (see also Discussion).

***-age adjusted otolith microchemistry***

For fish determined to have visited the marine environment, Sr:Ca profiles were plotted against age using Sigma Plot ® in order to show the relationship between sample points along a transect as it related to age. These age adjusted profiles (Appendix D) consist of vertical bars that represent the core region (cross hatched bands), summer (hyaline bands) and winter (opaque bands) growth of each otolith. Adjacent hyaline and opaque bands represent one year of growth. Displays were created in Sigma Plot ®.

***Statistical analysis***

Independent classification of sea-run status was achieved by using Statgraphics® cluster analysis on untransformed data in which groups were formed based on average and maximum Sr:Ca for each otolith. A Euclidean distance measure was used and grouping was achieved through the Group Average Method as in McCune and Grace (2002).

Box and whisker plots were generated using Sigma Plot ®. Site-specific differences in meristic counts and condition factors among sites were compared using one-way ANOVA from Statgraphics® statistical software. In cases where the assumptions of ANOVA were invalid, the non-parametric Kruskal-Wallis test was performed using S-plus® statistical software to determine differences in traits among sites. If a p-value for this test was less than 0.05 it was deemed significant, and pair-wise site comparisons were then made for that trait using the Wilcoxon rank sum test with a Bonferroni corrected p-value (p = alpha 0.05 / 7 sites = 0.007). If p-values fell below 0.007, then the sites were considered to be significantly different from one another for that trait.

Values for meristic counts and condition factors of freshwater resident least cisco were compared to sea-run least cisco using simple two-sample comparisons (T-tests) for the difference in means of each count. When the assumptions of T-tests were violated, the Wilcoxon rank sum test was performed. In either case, p-values less than 0.05 were deemed to indicate a statistically significant difference for a given trait.

Logistic regression analysis was performed in order to determine if a combination of meristic traits could predict the odds of a fish being sea-run (1) versus resident (0). A full model was fitted with each of four meristic traits. Meristic traits with p-values greater than 0.05 were dropped and the model was re-analyzed without that trait. This process was repeated until the p-values for explanatory variables were all less than 0.05. The resulting *reduced* model was compared to the *full* model through a drop-in-deviance test in which the change in deviance between the *full* and *reduced* was calculated. A new p-value was determined based on the chi-square distribution with drop in degrees of freedom (d.f.) resulting from the difference between d.f. for the *full* and *reduced* models. If the drop in deviance p-value was large, then the *reduced* model was accepted as adequate in explaining the binary response (Ramsey and Schafer 1997).

**Results**

***Lake water and otolith chemistry***

The range of unfiltered lake water Sr:Ca ratios averaged over multiple years varied between 0.00126 and 0.0042, while the mean for Elson Lagoon was an order of magnitude higher (0.034) (Table 2). Lake water Sr:Ca was positively related to the average of the freshwater phase Sr:Ca in least cisco otoliths, although this relationship is only moderate ($R^2 = 0.5763$, $p = 0.08$, Fig. 2). Adding a point corresponding to the mean Elson Lagoon water Sr:Ca and the associated mean saltwater phase Sr:Ca in the otoliths of those fish to the regression increases the positive correlation for the slope of this regression dramatically ($R^2 = 0.9742$, $p < 0.01$). This is because the Sr:Ca for salt water and the average salt water phase Sr:Ca for Elson Lagoon fish are each an order of magnitude greater than the respective lake values.

***Classification of Sr:Ca profiles***

Sr:Ca profiles of otoliths for all least cisco in this study are given in Appendix C. Comparison of visual classification with classification using cluster analysis gave similar results. Visual classification of 249 fish from the seven study sites plus nine donated fish from Teshekpuk (total n=258) revealed sea-run signals in 30 fish or 11.6% of samples. This percentage also included nine fish from Elson lagoon which were known sea-run fish. Results from cluster analysis yielded four distinct groups (Fig. 3). The first cluster, consisting of 228 fish, corresponded precisely with what had been visually described as freshwater resident fish. The remaining fish (n=30) were

Table 2. Mean unfiltered Sr:Ca values for water and otoliths. Mean freshwater phase Sr:Ca in otoliths represent the mean of all electron microprobe sample points for each site *below* $2 \times 10^{-3}$. Both freshwater phase and saltwater phase values of Sr:Ca in otoliths are given for Elson Lagoon. The first is the mean of all values *below* $2 \times 10^{-3}$ and the second is the mean of values *above* $2 \times 10^{-3}$ for those otoliths. Note that the mean freshwater phase for Elson Lagoon otoliths is the same as that for Ikroagvik Lake located less than 10 km away.

| Freshwater Sites | Mean Sr:Ca in freshwater (Value x 10-3) | Mean freshwater phase Sr:Ca in otoliths (Values x 10-3) [SD] |
|---|---|---|
| Ikroagvik | 2.38 | 0.98 [0.20] |
| Joshua's | 1.29 | 0.59 [0.13] |
| Joshua's 2nd | 1.98 | 0.69 [0.16] |
| Luther's | 1.26 | 0.54 [0.13] |
| Joeb's | 4.20 | 0.94 [0.30] |
| Joeb's 2nd | 2.26 | 0.61 [0.16] |
| Saltwater Site | Mean Sr:Ca in sea-water (Value x 10-3) | Mean freshwater phase / saltwater phase Sr:Ca in otoliths (Values x 10-3) [SD] |
| Elson Lagoon | 33.6 | 0.98 [0.52] / 2.82 [0.60] |

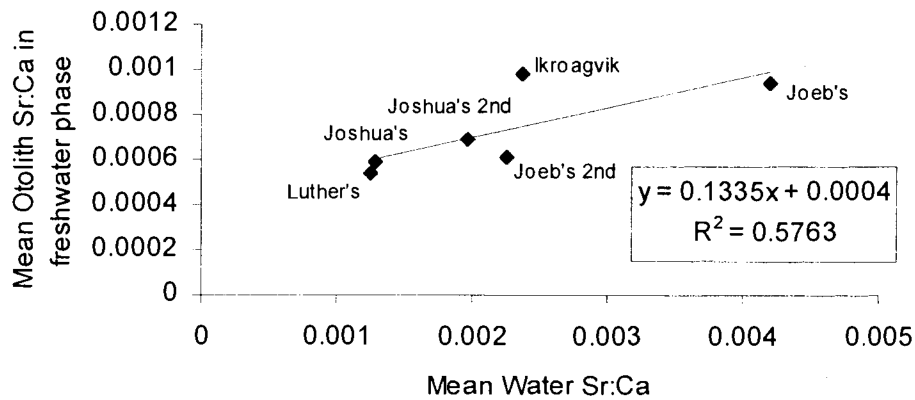



Figure 2. The relationship between least cisco mean freshwater phase Sr:Ca (mean of all values < 2.0 x 10) and unfiltered lake water mean Sr:Ca ($R^2$ = 0.5763, p = 0.08).

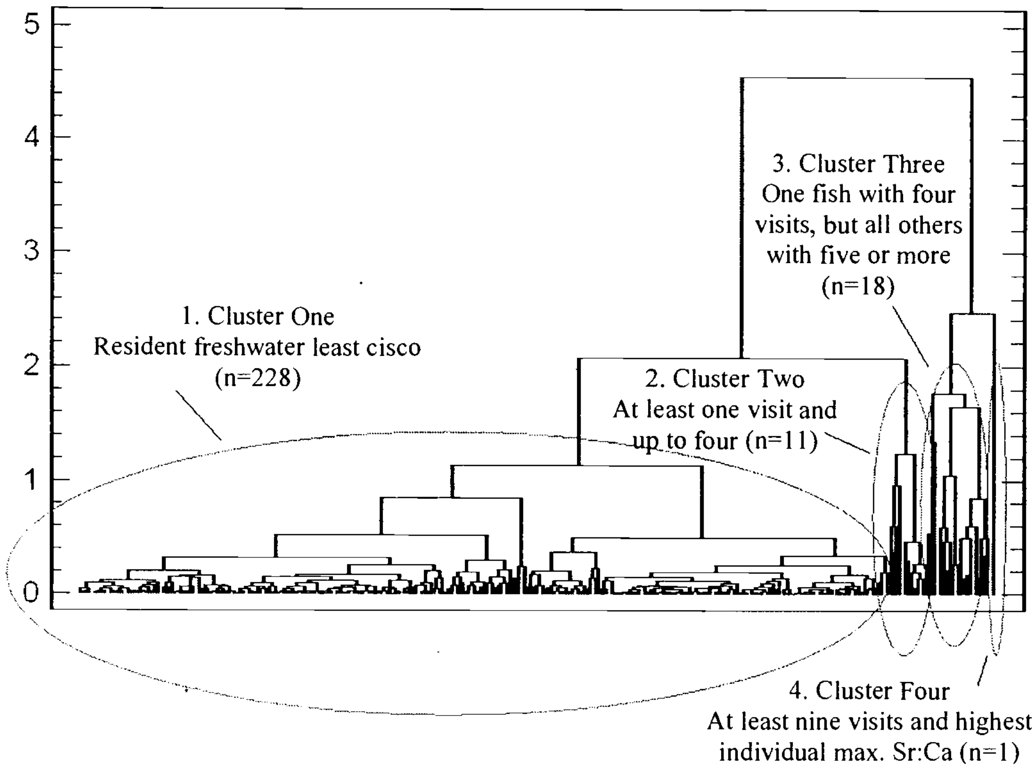



Figure 3. Cluster analysis (Group Average Method, Euclidean) of Sr:Ca in all least cisco. Factors used in analysis are mean Sr:Ca value and maximum Sr:Ca value. Clusters are divided into four groups based on individual visual inspection of Sr:Ca profiles for each otolith. Includes nine samples donated from 1991 Teshekpuk Lake survey.

spread among the remaining three clusters, corresponding with fish that had been visually classified as sea-run. Cluster two consisted of 11 fish that had been to sea at least once and up to four times according to visual inspection (e.g. 01-09-LC-11 Fall and 01-09-LC-05, respectively). Cluster three consisted of one fish that visually appears to have traveled to sea at least four times (e.g. 00-00-LC-02), as well as 17 others that appear to have made at least five sea voyages. Cluster four consisted of only one fish. This fish was from Teshekpuk, went to sea at least nine times, and had the highest individual maximum Sr:Ca ($5.73 \times 10^{-3}$) (fish 002-015).

The location and percentage of sea-run fish is shown by site in Figure 4. Fish from coastal sites showed the most sea-run activity. Even so, Ikroagvik fish, which accounted for almost half of all samples (n=120), yielded only ten fish with sea-run signals. Joeb's site is classified as a perched lake according to the Alaska Dept. of Fish and Game (W. Morris pers. comm. 2001; guidelines for classification as stated in Moulton and George 2000) and had six of twenty-six fish with sea-run profiles. Joeb's 2nd site had only one of sixteen fish displaying sea-run profiles. As expected, all 9 fish caught in Elson Lagoon showed sea-run signals.

Inland sites showed very little sea-run activity. Joshua's two subsistence camps and Luther's camp, all south and east of Atqasuk (aggregate n = 78) produced only two sea-run fish. A number of fish had high Sr:Ca in their core (e.g. 01-00-LC-121 Fall),

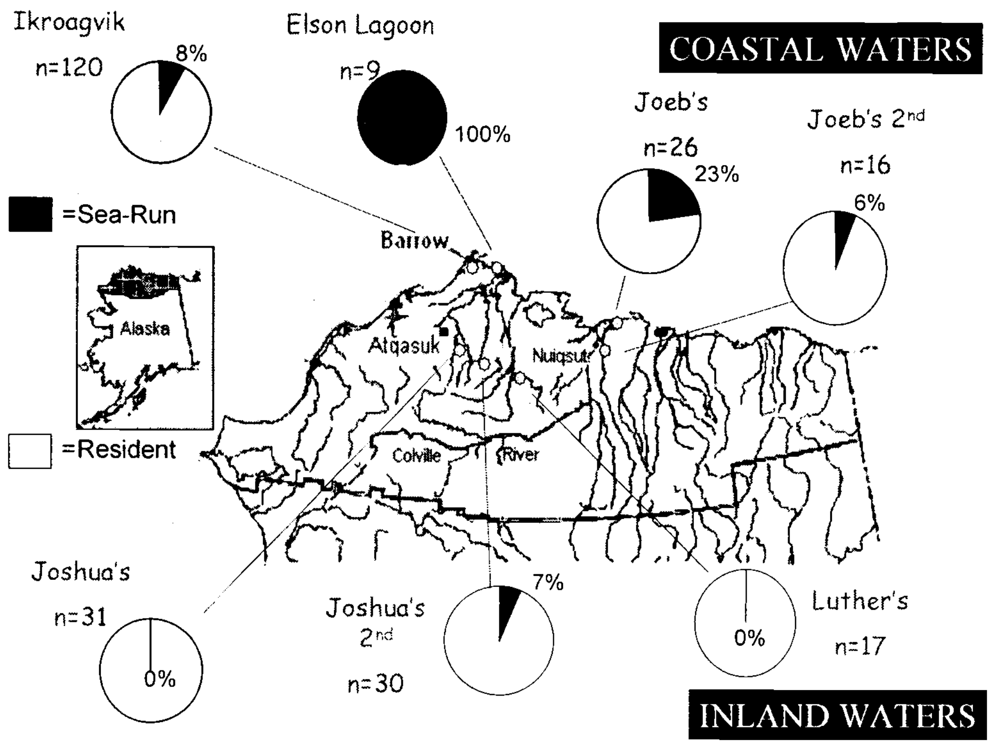



Figure 4. Percentage of least cisco otolith Sr:Ca profiles displaying evidence of sea-run behavior by lake.

representing maternal influence with respect to Sr incorporated from the yolk sac. The nutrients within the yolk sac are derived from the mother. Thus, these samples are indicative of a mother of amphidromous behavior. Such maternal influences are noted in Appendix C profiles.

### *Age at first sea-run*

For general characteristics of sea-run fish, refer to Appendix A (Table A-5). Age adjusted Sr:Ca profiles of sea-going fish are given in Appendix D. Least cisco in this study ranged from 2 to 19 years of age and the distribution of age for these fish was roughly normal (Fig. 5a). Age distribution was not necessarily normal at each site, however (Fig. 5b [a-g]). For the 28 sea-going fish we acquired, plus the two sea-going Teshekpuk fish, mean age of first excursion was 2.6 years (Fig. 6). There are differences in age of first sea-run by site. Elson Lagoon fish made their first marine excursions earliest (1.22 years, n=9). At Ikroagvik, sea-run fish went to sea for the first time at a mean age of 2.4 years (n=10). The six sea-run fish from Joeb's, the perched site at the mouth of the Colville River, went to sea for the first time at a mean age of 5.33. All other sites had only one or two sea-run fish per lake. In all, half of sea-run least cisco went to sea for the first time by age one, though this value is heavily biased by Elson lagoon fish. All sea-run least cisco went to sea for the first time by age seven (Fig. 7).

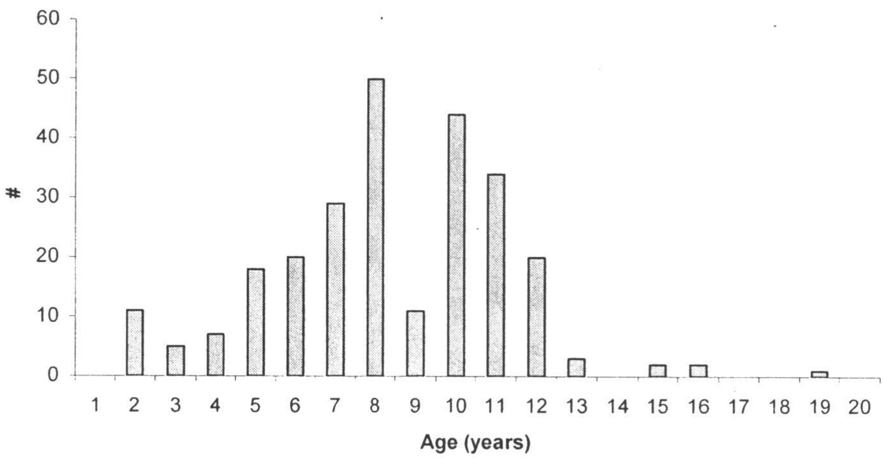



Figure 5a. Age frequency distribution for all least cisco combined for all sites (n=249).

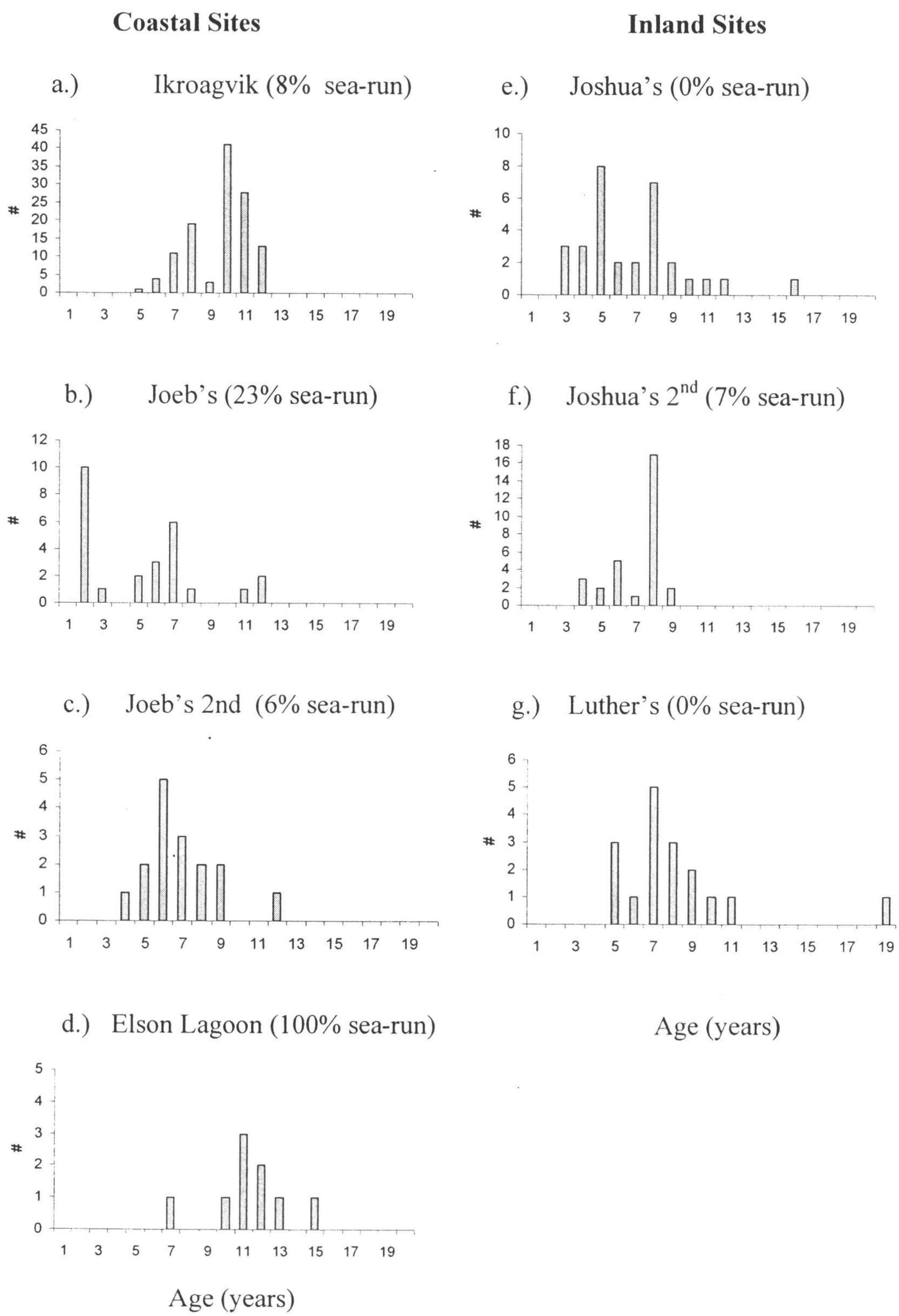



Figure 5b[a-g]. Age frequency distribution of least cisco by site for all sampling seasons combined. Sites are divided into two groups: Coastal and Inland.

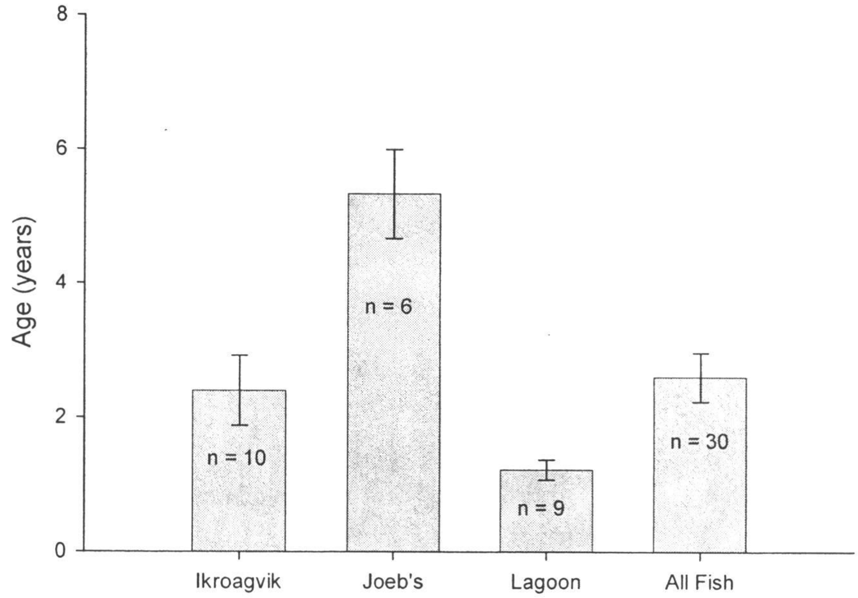



Figure 6. Mean age at first sea-run for least cisco classified as having visited the marine environment at some point in their life history (bars represent S.E.). Data are summarized by site for coastal lakes only. Three additional fish from our catch (01-13-LC-21 Fall and 01-13-LC-33 Fall from Joshua's 2$^{nd}$ and 01-12-LC-12 from Joeb's 2$^{nd}$) plus two additional fish from the Teshekpuk study (002-002 and 002-015) embarked on marine excursions. These five fish were included in the "All Fish" category.

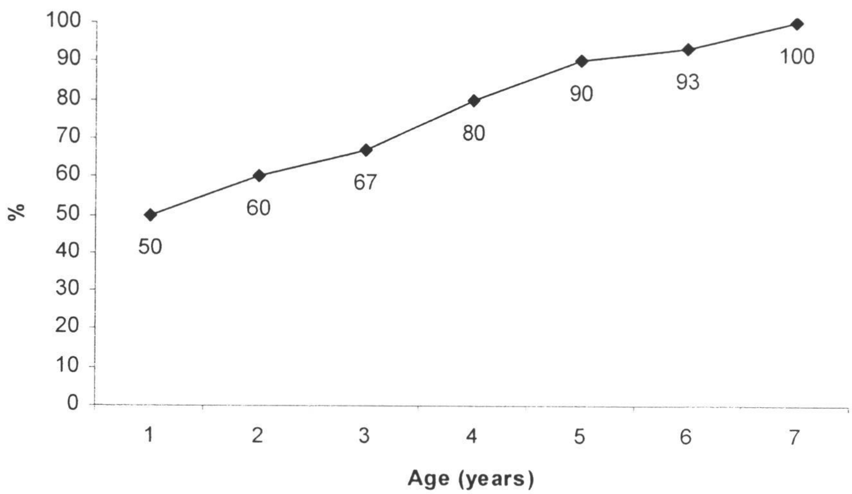



Figure 7. Percentage of all least cisco classified as sea-run (n=30) that went to sea for the first time by a given age. Includes Teshekpuk samples from 1991 survey.

***Teshekpuk samples***

Of the nine donated otoliths examined for Sr:Ca, only eight had age and length data (t791-001 is missing length data). Plotting these eight remaining fish against the von Bertalanfy curves generated by Philo et al. 1993b for least cisco in Lake Teshekpuk, it appears four fish are clear *dwarf* (001-014, 001-016, 002-006, and 002-012), two are *intermediate* between *dwarf* and *normal* (002-002, 002-005), and two are clear *normals* (001-007 and 002-015). Only two fish (002-002 *normal* and 002-015 *intermediate*) were sea-run. While all four *dwarf* fish appear to be resident, so too do one of the *normal* and one of the *intermediate* fish. (see App. B. for raw data, App. C and D for profiles).

***Growth and condition***

All least cisco were plotted over a von Bertalanfy growth curve (Fig. 8). This plot shows that fish fell into a range of length at age similar to least cisco from previous work (Philo et al. 1993a,b, Mann 1974). When length/age data are plotted over growth curves indicative of the three forms of least cisco described in Philo et al. (1993b) (see Fig. 9), the clear lack of *dwarf* form least cisco captured in this study becomes evident (n=1). The vast majority of fish in the current study appeared to fall into the category of *normal* or *intermediate* forms when overlain upon the Philo et al. growth curves.

Distribution of condition factor for least cisco by site can be seen in Figure 10. Condition factors ranged from 0.1947 to 1.677 (Table 3) and were significantly

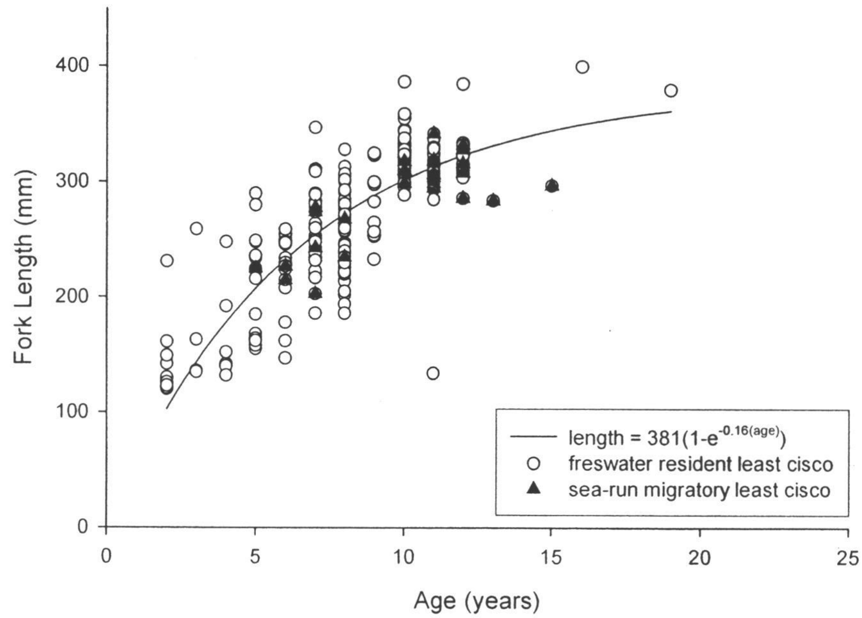



Figure 8. Von Bertalanfy growth curve for all least cisco in this study (n=249).

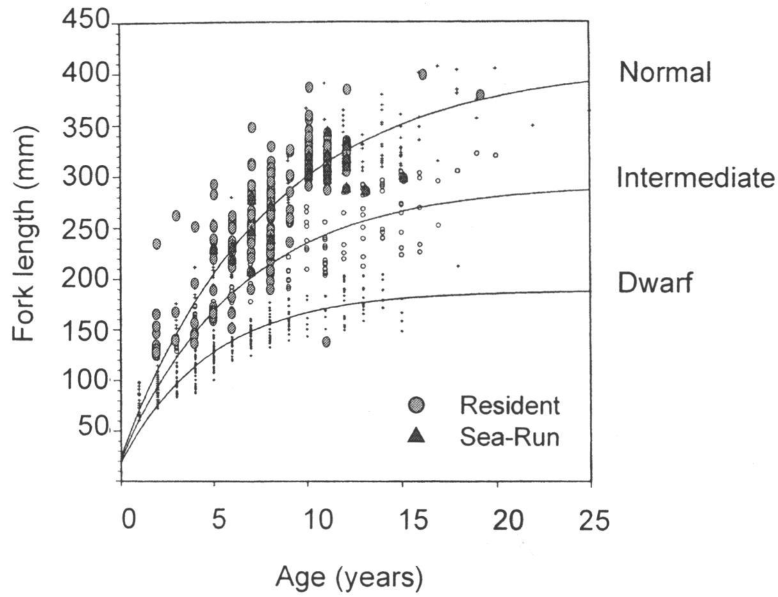



Figure 9. Least cisco in this study (n=249) plotted vs. three von Bertalanfy growth curves described in Philo et al. 1993b (includes their data).

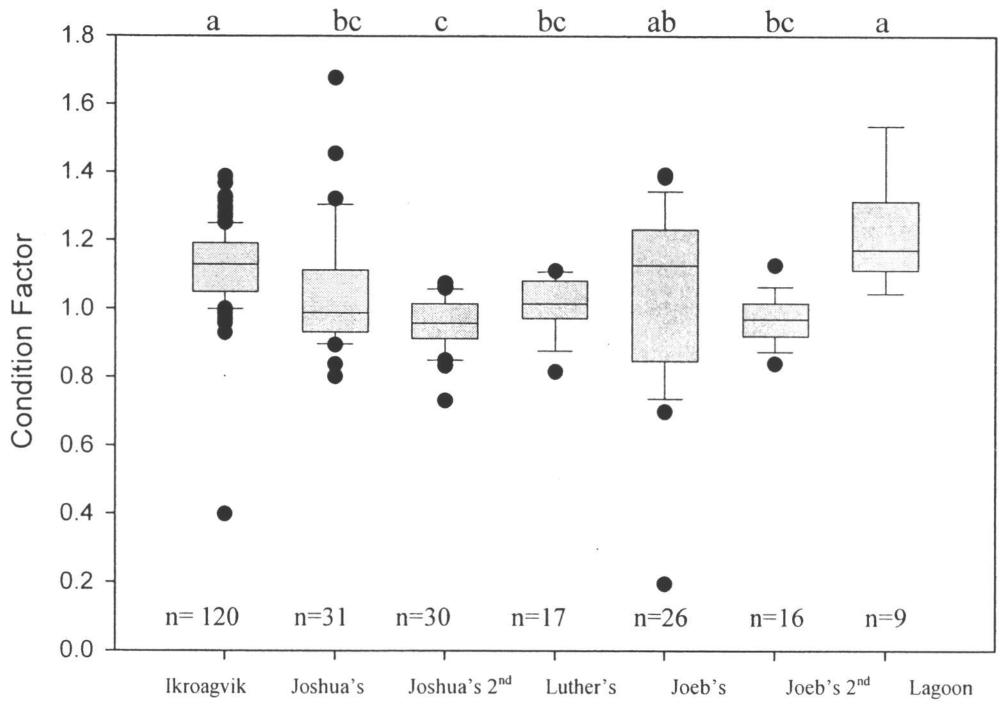



Figure 10. Condition factor for least cisco by site. Based on the methods of Fulton [K= $(W/L^3)*X$] where K refers to condition, W refers to weight in grams, L is fork length in mm and X is an arbitrary scaling coefficient (Anderson and Gutreuter 1983). Letters (a-d) above distributions refer to homogenous groups.

Table 3. Summary statistics for least cisco condition factor by site and Kruskal-Wallis rank sum test results for differences amongst sites. Homogonous groups (a,b,c) were determined through Bonferroni corrected p-values from all pair wise comparisons using Wilcoxon rank sum tests.

| Site | n | min | max | mean | sd | homogeneous groups |
|---|---|---|---|---|---|---|
| Ikroagvik | 120 | 0.399 | 1.387 | 1.121 | 0.118 | a |
| Joshua's | 31 | 0.802 | 1.677 | 1.044 | 0.184 | bc |
| Joshua's 2nd | 30 | 0.731 | 1.075 | 0.958 | 0.077 | c |
| Luther's | 17 | 0.816 | 1.111 | 1.01 | 0.081 | bc |
| Joeb's | 26 | 0.195 | 1.393 | 1.055 | 0.268 | ab |
| Joeb's 2nd | 16 | 0.84 | 1.128 | 0.97 | 0.071 | bc |
| Elson Lagoon | 9 | 1.045 | 1.537 | 1.222 | 0.152 | a |
| Kruskal-Wallis Rank Sum Test | | | | | | |
| | n = 249 | df = 6 | chi-square = 76.7443 | | p-value = 0.000 | |

different among sites (Kruskal-Wallis rank sum test, $p < 0.01$, Table 3). Fish from Elson Lagoon and Ikroagvik had significantly higher condition factors than fish from all other sites but Joeb's, which was also a coastal site. However, condition factors for fish in Joeb's site were not significantly different from fish in any other site but one of the inland sites, Joshua's $2^{nd}$. Condition factors for fish in Joshua's $2^{nd}$ site were significantly different from those in three coastal sites: Ikroagvik, Elson Lagoon and Joeb's.

Distribution of condition factors for sea-run vs. freshwater resident least cisco is given in Figure 11. A two sample comparison yielded a significant difference between the two groups (Wilcoxon rank sum test, $p = 0.002$, Table 4). On average, the condition factor for sea-run fish was higher than for resident least cisco, although there is much overlap in their respective distributions.

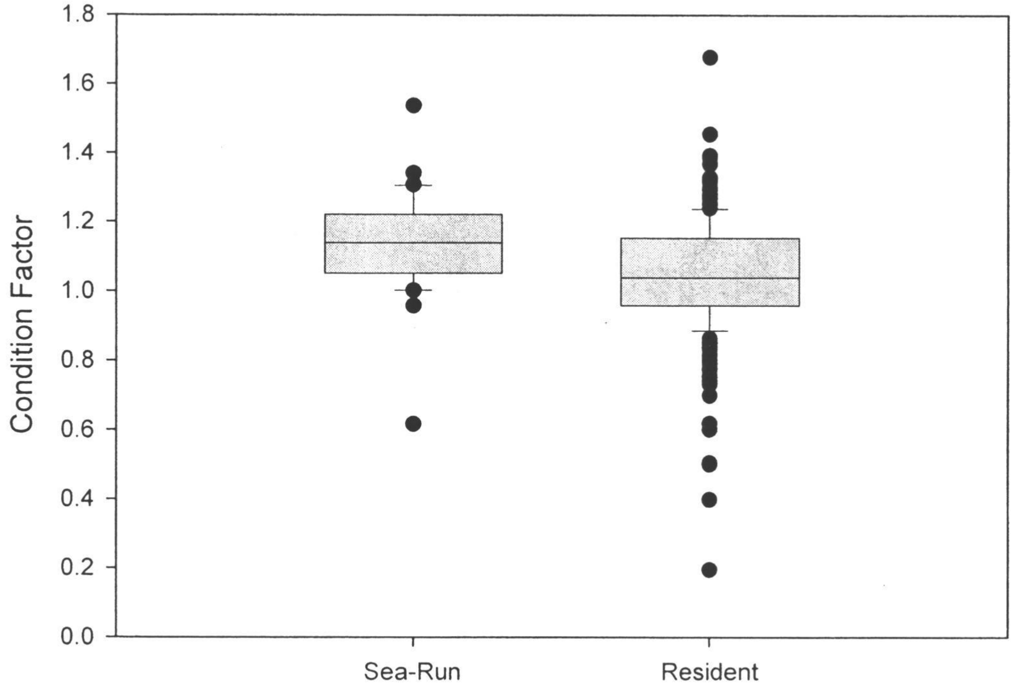



Figure 11. Condition factor for sea-run vs. resident least cisco, including Teshekpuk samples. Based on the methods of Fulton [$K=(W/L^3)*X$] (Anderson and Gutreuter 1983)where K refers to condition, W refers to weight in grams, L is fork length in mm and X is an arbitrary scaling coefficient (100,000).

Table 4. Summary statistics and Wilcoxon rank sum test for comparison of condition factor in sea-run vs. resident least cisco in all study sites (n=249).

| | Sea-Run Fish | Freshwater Resident Fish |
|---|---|---|
| Observations | 28 | 221 |
| Average | 1.164 | 1.06 |
| Median | 1.144 | 1.047 |
| Standard Deviation | 0.117 | 0.158 |
| Minimum | 0.958 | 0.195 |
| Maximum | 1.537 | 1.677 |
| | | |
| Wilcoxon Rank Sum Test | | |
| z-statistic | 3.7474 | |
| Two sided p-value | 0.0002 | |

*Meristics*

Fish in the inland sites tended not to differ from one another with respect to meristic traits, while coastal sites showed more variability (Table 5). Lateral line scale number in least cisco from all sites ranged from 74-108 (Table 6). Significant differences were found in the mean lateral line scale number among lakes (One-Way ANOVA, $p < 0.05$, Table 7). Generally speaking, fish from Elson Lagoon and Joeb's (two coastal sites) had lower counts than other sites (Fig. 12). Multiple range tests confirmed that mean lateral line scale numbers for Joeb's site (coastal) and Elson Lagoon were significantly different from all but each other's sites. Ikroagvik (coastal) was significantly different from four of six other sites, similar only to Joeb's 2$^{nd}$ (coastal) and Luther's site (inland). The three inland sites (Joshua's two sites and Luther's) were not significantly different from one another with respect to mean lateral line number (Table 8).

Dorsal ray counts for least cisco in all sites ranged from 10-14 (Table 6). Significant differences were found in the mean dorsal ray number for least cisco among lakes (One-Way ANOVA, $p < 0.01$, Table 7). Least cisco from Joeb's two sites (coastal) were different from fish from Ikroagvik (coastal) and Joshua's two sites (inland)(Tables 5, 8). Fish from Luther's and Elson Lagoon were not significantly different from any of the other sites with respect to mean dorsal ray number (Table 8).

Anal ray numbers ranged from 11-16 (Table 6). Significant differences in mean anal rays were not found among sites (ANOVA $p < 0.199$, Table 7).

Table 5. Summary of meristic features of least cisco that are significantly different between sites. Values are judged significant at the .05 level. (LL = lateral line, DR = dorsal rays, AR = Anal Rays, GR = Gill Rakers)

| | Site | COASTAL SITES: Ikroagvik | COASTAL SITES: Elson Lagoon | COASTAL SITES: Joeb's | COASTAL SITES: Joeb's 2nd | INLAND SITES: Joshua's | INLAND SITES: Joshua's 2nd | INLAND SITES: Luther's |
|---|---|---|---|---|---|---|---|---|
| COASTAL SITES | Ikroagvik | | | | | | | |
| | Elson Lagoon | LL | | | | | | |
| | Joeb's | LL, DR | - | | | | | |
| | Joeb's 2nd | DR | LL | LL | | | | |
| INLAND SITES | Joshua's | LL | LL | LL, DR | DR | | | |
| | Joshua's 2nd | LL | LL | LL, DR | DR | - | | |
| | Luther's | - | LL | LL | DR | - | - | |

Table 6. Summary statistics for meristics of least cisco from all sites. Two sample comparison of means for resident versus sea-run fish.

| | Anal Ray<br>Resident / Sea-Run | Dorsal Ray<br>Resident / Sea-Run | Lateral Line<br>Resident / Sea-Run | Gill Raker with Ikroagvik<br>Resident / Sea-Run | Gill Raker w/o Ikroagvik 2000<br>Resident / Sea-Run | Gill Raker without Ikroagvik<br>Resident / Sea-Run |
|---|---|---|---|---|---|---|
| Observations [n] | 182 / 25 | 184 / 25 | 181 / 25 | 155 / 19 | 109 / 16 | 84 / 12 |
| Average | 13.46 / 13.64 | 12.07 / 12.56 | 91.8 / 89.52 | 40.51 / 40.84 | 41.49 / 41.875 | 41.94 / 42.08 |
| Median | 13.5 / 14 | 12.0 / 12.0 | 92 / 91 | 41 / 41 | 42 / 41.5 | 42 / 41.5 |
| Standard Deviation | 0.914 / 0.995 | 0.899 / 1.474 | 5.75 / 5.84 | 2.86 / 3.24 | 2.058 / 2.247 | 1.79 / 2.54 |
| Minimum | 11.0 / 12.0 | 10.0 / 10.0 | 74 / 77 | 32 / 34 | 37 / 39 | 37 / 39 |
| Maximum | 16.0 / 15.0 | 14.0 / 18.0 | 108 / 97 | 47 / 46 | 47 / 46 | 47 / 46 |
| 95% C.I. | [-0.567, 0.210] | [0.131, -1.11] | [-0.142, 1.667] | [-1.726, 1.06] | [-1.492, 0.714] | [-1.301, 1.015] |
| t-statistic | -0.906 | -1.619 | 1.856 | -0.4708 | -0.698 | -0.245 |
| Two sided p-value | 0.3662 | 0.05 | 0.07 | 0.6384 | 0.487 | 0.807 |

Table 7. Summary of One-Way ANOVA for least cisco meristic data between and within sites.

| Variable: | Anal Ray | Dorsal Ray | Lateral Line | Gill Raker with Ikroagvik | Gill Raker minus Ikroagvik 2000 | Gill Raker minus all Ikroagvik |
|---|---|---|---|---|---|---|
| Observations [n] | 207 | 209 | 206 | 174 | 125 | 96 |
| # of levels | 7 | 7 | 7 | 7 | 7 | 6 |
| Sum of squares | | | | | | |
| between (df) | 7.29195 (6) | 23.5775 (6) | 1269.35 (6) | 432.087 (6) | 78.7103 (6) | 4.90394 (5) |
| within (df) | 168.399 (200) | 181.934 (202) | 5612.03 (199) | 1021.04 (167) | 456.378 (118) | 330.929 (90) |
| total (df) | 175.691 (206) | 205.512 (208) | 6881.38 (205) | 1453.13 (173) | 535.088 (124) | 335.833 (95) |
| f-ratio | 1.44 | 4.36 | 7.5 | 11.78 | 3.39 | 0.27 |
| p-value | 0.1997 | 0.0004 | 0.0000 | 0.0000 | 0.0040 | 0.9301 |

Table 8. Summary of homogenous groups from ANOVA for meristic traits by site. Like group letters (a,b,c, or d) under each trait refer to no statistical difference between sites for that trait based on Fisher's least significant differences (LSD) test.

| | Anal Ray | Dorsal Ray | Lateral Line | Gill Raker (all) | Gill Raker (w/o Ikroagvik 2000) | Gill Raker (w/o Ikroagvik) |
|---|---|---|---|---|---|---|
| Site | n / mean/ group | n / mean/ group | n / mean/ group | n / mean/ group | n / mean/ group | n / mean/ group |
| Ikroagvik | 85 / 13.34 / a | 86 / 12.05 / a | 86 / 90.71 / b | 78 /38.81 / a | 29 / 40.14 / a | - |
| Joshua's | 30 / 13.33 / a | 30 / 11.67 / a | 30 / 93.63 / c | 23 / 41.87 / b | 23 / 41.87 / b | 23 / 41.87 / a |
| Joshua's 2nd | 30 / 13.73 / a | 30 / 11.93 / a | 29 / 95.35 / c | 26 / 42.12 / b | 26 / 42.12 / b | 26 / 42.12 /a |
| Luther's | 13 / 13.54 / a | 13 / 12.23 /a,b | 11 / 94.00 / b,c | 13 / 41.69 / b | 13 / 41.69 / b | 13 / 41.69 / a |
| Joeb's | 25 / 13.48 / a | 26 / 12.58 / b | 26 / 88.08 / a | 15 / 41.93 / b | 15 / 41.93 / b | 15 / 41.93 / a |
| Joeb's 2nd | 15 / 13.8 / a | 15 / 12.93 / b | 15 / 92.07 / b,c | 12 / 41.75 / b | 12 / 41.75 / b | 12 / 41.75 / a |
| Elson Lagoon | 9 / 13.89 / a | 9 / 12.33 / a,b | 9 / 86.00 / a | 7 / 42.57 / b | 7 / 42.57 / b | 7 / 42.57 / a |

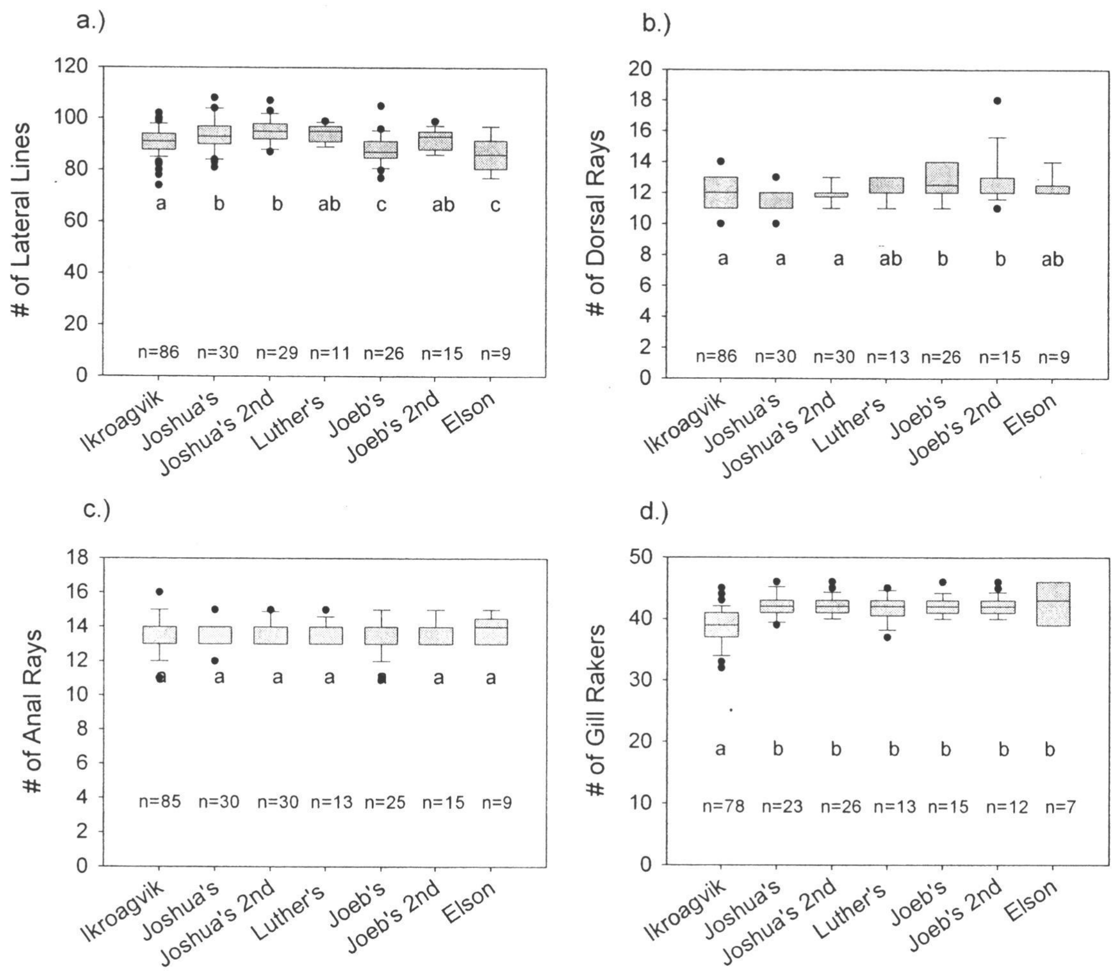



Figure 12 (a-d). Frequency distribution of meristic traits by site for all least cisco in this study. Box and whisker plots display 5th percentile, 1st quartile, median, 3rd quartile, 95th percentile and outliers. Like group letters (a,b,c, or d) under each trait refer to no statistical difference between sites for that trait based on Fisher's least significant differences (LSD) test.

Gill rakers ranged from 32 in Ikroagvik to a high of 47 in several sites. Significant differences were found among sites if Ikroagvik fish were included in the analysis (ANOVA $p < 0.05$, Table 7), due to differences between Ikroagvik and several other lakes (Table 8). However, there were difficulties in obtaining accurate counts for gill rakers for some of the Ikroagvik fish (see methods). Table 7 includes ANOVA results with Ikroagvik samples included and with one or both years removed. In the absence of gill raker data from Ikroagvik, differences among other sites were not found.

### *Meristics for sea-run vs. resident least cisco*

Because the number of sea-run fish was so small (n=28 without Teshekpuk samples for which no meristics are available), these samples were pooled across sites. Analysis of individual meristic traits for comparison of sea-run fish versus resident fish was not significant for anal rays (two-sided T-test, $p = 0.37$) or (marginally) lateral lines ($p = 0.07$) (Table 6). There was also no difference between sea-run or resident fish for gill rakers regardless of whether different levels of Ikroagvik samples were included ($p = 0.638$, $p = 0.487$, $p = 0.807$). Only dorsal ray number was significantly different between sea-run and resident least cisco ($p < 0.05$). Distributions are given in Fig. 13.

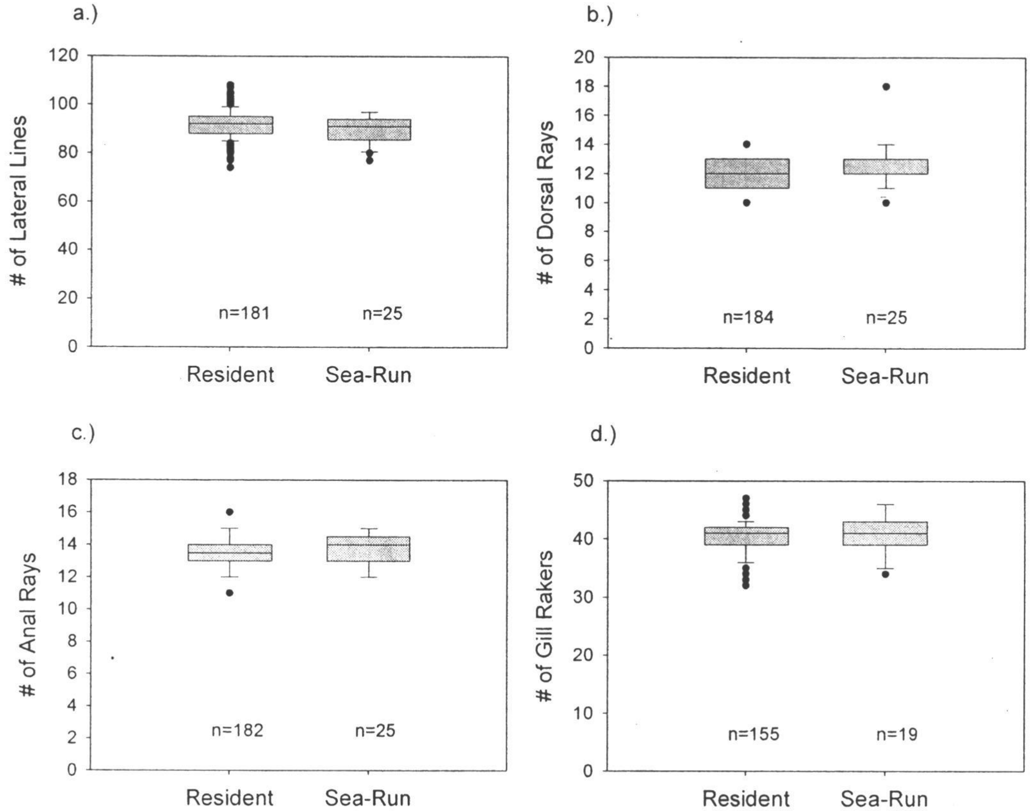



Figure 13 (a-d). Frequency distribution of meristic traits for resident versus sea-run least cisco. Box and whisker plots display 5th percentile, 1st quartile, median, 3rd quartile, 95th percentile and outliers.

***Combination of meristics for predicting sea-run behavior***

The binary logistic regression analysis with all meristic traits resulted in the *full* model:

$$\text{logit} = 1.032 - 0.257(\text{Anal Ray \#}) + 0.633(\text{Dorsal Ray \#}) + 0.09(\text{Gill Raker \#}) - 0.123(\text{Lateral Line \#})$$

Since the P-values for gill rakers and anal rays were > 0.05, those values were dropped resulting in the *reduced* model:

$$\text{logit} = 1.034 + 0.547(\text{Dorsal Ray \#}) - 0.11(\text{Lateral Line \#})$$

Results of a drop-in-deviance test comparing the *full* versus *reduced* model were insignificant (0.867, df = 2, P-value > .25) suggesting that the reduced model was sufficient in explaining the odds of sea-run behavior. The model suggests that a one unit increase in lateral line scales results in the odds of a fish being sea-run to decrease by 1.1 times, after accounting for dorsal rays. Conversely, a one unit increase in dorsal rays results in the odds of a fish being sea-run to increase by 1.7 times, after accounting for lateral line scales. A Chi-Square Goodness of Fit Test suggested that this was a good model (P-value = 0.91) but the percentage of deviance explained by this model was low (10.6 %) (Table 9).

Table 9. Logistic regression models for full and reduced models of meristic traits as predictors of the odds of least cisco being sea-run or resident.

***Full Model***

| Variable | Est. | Analysis of Deviance | Model d.f. | P-Value | chi-square test | d. f. | p-val | Goodness of Fit p-val. |
|---|---|---|---|---|---|---|---|---|
| Constant | 1.032 | 12.79 | 4 | 0.0123 | | | | 0.402 |
| AR | -0.227 | | | | 0.47 | 1 | 0.4912 | |
| DR | 0.633 | | | | 4.81 | 1 | 0.028 | |
| GR | 0.09 | | | | 0.696 | 1 | 0.4039 | |
| LL | -0.122 | | | | 6.8 | 1 | 0.0087 | |

*% of deviance explained by model = 10.7869*

***Reduced Model***

| Variable | Est. | Analysis of Deviance | Model d.f. | P-Value | chi-square test | d. f. | p-val | Goodness of Fit p-val. |
|---|---|---|---|---|---|---|---|---|
| Constant | 1.034 | 11.925 | 2 | 0.0026 | | | | 0.906 |
| DR | 0.55 | | | | 5.6 | 1 | 0.017 | |
| LATLINE | -0.11 | | | | 6.1 | 1 | 0.0135 | |

*% of deviance explained by model = 10.057*

## Discussion

### *Interpretation of elevated otolith Sr:Ca*

Many factors other than salinity have been shown to affect Sr levels in otoliths, including diet (Limburg 1995, Farrell and Campana 1996, Galahar and Kingsford 1996), physiology (Kalish 1989, Sadovy and Severin 1992) stress (Kalish 1992) and temperature (Radtke 1989, Fowler et al. 1995a, b).

Limburg (1995) found that increased Sr in food led to an increase in Sr:Ca in shad otoliths, but the 3-5 fold increase in Sr in outer growth rings was accrued in the time period in which these organisms were living in salt water. Farrell and Compana (1996) determined through laboratory experiment that water contributed 75% of calcium and 88% of strontium to these elements composition in otoliths, although diet did contribute slightly to the overall otolith composition of these elements. Gallahar and Kingsford (1996) found that food supplemented with Sr played a role in uptake of that element, as did temperature, but the factor most important to Sr uptake by otoliths in this study was the concentration of Sr in the surrounding water.

Seasonal changes in the physiology of fish related to growth rates and reproductive cycles have also been linked to changes in the uptake of Sr (Kalish 1989, Sadovy and Severin 1992). Kalish (1992) determined that increased stress led to higher Sr:Ca in Australian salmon. Radtke (1989) found an inverse relationship between temperature and Sr:Ca for *Fundulus heteroclitus* but suggested that water chemistry was the primary influence of otolith Sr:Ca in char (1995). The evidence for a temperature / Sr relationship was absent in Australian salmon and Rock Blackfish (Kalish 1989, Gallahar and Kingsford 1996). Fowler et al. (1995a, b) determined through use of solution-based ICPMS and laser ablation ICPMS that temperature, salinity, growth rates and ontogenetic effects influenced Sr uptake by otoliths.

It is clear that numerous factors influence Sr uptake in otoliths to some degree. However, experimentation has shown that water chemistry is by far the factor most important to levels of Sr incorporated into otoliths (Secor et al. 1995, Fowler et al. 1995a,b, Farrell and Campana 1996). In all studies where water chemistry was investigated, increased salinity in water was accompanied by increased Sr incorporated into otoliths and thus increased Sr:Ca. There is considerable scientific evidence suggesting that the variability of Sr:Ca in otoliths along a fish's built-in time line reflects the environment in which that fish was living at any given point in time.

***Strontium in water***

Although factors influencing Sr uptake have yet to be validated for least cisco, it is reasonable to expect that otolith Sr levels are primarily dependent upon water chemistry. In our region, Sr concentrations were considerably higher in Elson Lagoon than in freshwater sites. Rosenthal et al. found that Sr was found at levels 114 times greater in salt water than in freshwater (1970). Elson Lagoon water had Sr concentrations of up to 250 times greater than in freshwater sites. All subsequent discussion of sea-run classified fish is based on the assumption that values in Sr:Ca over time $> 2.0 \times 10^{-3}$ are a result of exposure to high salinity water.

***Patterns of Sr:Ca ratios in otoliths***
***-freshwater resident least cisco***

Most otolith transects in this study displayed low baseline levels of Sr:Ca from birth to death (i.e.- 00-00-LC-01, appendix C). The spread around the mean in Sr:Ca over time for these nearly flat-line fish is on the order of 10-15% (as opposed to ~50% for lagoon fish such as 00-11-LC-02) and is probably due to factors affecting fish growth on a seasonal basis such as temperature and physiology (Radtke 1989, Secor et al. 1995).

Baseline values of Sr:Ca are remarkably similar for least cisco within sites but differ slightly among sites. For instance, baseline levels of Sr:Ca in profiles of fish from Joeb's site are somewhat higher than baseline levels in Luther's site (App. C). The positive relationship between Sr:Ca concentration in water and the mean baseline freshwater phase Sr:Ca in otoliths (Fig. 2) suggests that even slight changes in salinity are responsible for a difference in baseline Sr:Ca in otoliths across sites.

***-marine migratory least cisco***

Analysis of Sr:Ca profiles in the otoliths of sea-run least cisco from Elson Lagoon revealed patterns consistent with those of sea-run Arctic char (Radtke 1995, Radtke et al. 1996). An example of this can be seen with fish 00-11-LC-01 (App. D). There is a period of low level baseline Sr:Ca ($\sim 1 \times 10^{-3}$) near the otolith's core, followed by a large increase in levels of Sr:Ca ($> 2 \times 10^{-3}$), followed by a return to levels of Sr:Ca closer to initial baseline values sometime after year one. This general pattern is repeated several times over the life history of this fish and is consistent with a life history involving some length of time spent in freshwater, with periodic movement to salt water and back again. Otolith profiles for known sea-run fish from Elson Lagoon are similar to those for putative sea-run fish from freshwater lakes in this study (App. D).

An interesting feature of almost all sea-run fish in this study occurs just after a given marine excursion. Following these marine visits, ratios tend to drop considerably, indicative of the movement of that fish back to freshwater (Refer to fish 00-11-LC-02, App. D). However, these values often remain at levels above $2 \times 10^{-3}$, which was earlier described as the baseline value for classification of a seaward migration. So if these values (sample points 17, 20, 24 for instance) are representative of return trips to freshwater, why don't Sr:Ca values for these points return to baseline levels consistent with the pre-migration early life history of this fish? Several factors could be involved.

First, it is possible that there are resolution issues due to the equal spacing of points along a sampling transect which might miss the true low point of Sr:Ca troughs between marine migratory events. In contrast, placing the beam on transition zones between strict saltwater and freshwater growth might cause multiple migratory periods and their associated Sr:Ca information to be combined during analysis (Kalish 1989). Both of these resolution issues could be addressed by simply adding more sampling points in the area between the current sample points.

However, another explanation for this phenomenon is that fish may not be returning to freshwater to over-winter beyond their initial migration to sea. Wyborn Nungasuk, a subsistence fisherman living in Atqasuk, has reported that his family caught least cisco in brackish waters near Point Barrow in winters past (Nungasuk pers. comm. 2002), suggesting that some least cisco (i.e. Elson Lagoon fish) might spend one or more years entirely in brackish waters. Limburg (2001), using whole otolith imaging μPIXE technology, suggested that some populations of anadromous brown trout (*Salmo trutta*) in the Baltic Sea actually lacked a freshwater stage based on analysis of Sr:Ca patterns. Limburg also suggested that fish with no previous freshwater experience can apparently recruit to freshwater streams for spawning. In many cases the Sr:Ca of the last sample points near the otolith's edge in sea-run least cisco appeared to be lower than "freshwater" Sr:Ca troughs following a sea-run. Perhaps some least cisco are displaying a similar life history flexibility to Limburg's fish, where several years are spent at sea before recruitment to freshwater for spawning (i.e. 00-00-LC-12, App. D).

A third possible explanation is that least cisco are indeed returning to freshwater, but their Sr:Ca values do not return to levels below $2 \times 10^{-3}$ immediately because Sr remains in the blood for some extended length of time post marine migration. Under this premise, higher levels of Sr remain available for incorporation into the otolith's chemical matrix even after a return to freshwater (Halden et al. 1996, Howland et al. 2001). Evidence for this is suggested by the plot for Teshekpuk fish # 002-002 (App. D). This fish was only three years of age and went to sea at age two. Since sixteen sample points were taken during the one plus year from its single marine migration until death, it is unlikely that much relevant life history information was missed by the probe during this time. This fish was caught in a freshwater site in the summer approximately 30 river kilometers from the nearest estuary, yet the last four values of Sr:Ca are still higher than pre-migration baseline values. Similarly, fish # 01-11-LC-02 (App. D) has several sample points that are interpreted here as freshwater periods (points 17, 20, 22, 24, 26, 28, 30) directly following a marine excursion. However, when a migratory fish returned to freshwater for some extended period of time beyond a single migratory excursion (as with fish 01-00-LC-127 Fall, App. D) Sr:Ca would indeed return to pre-migration baseline freshwater levels.

***Otolith Structure***
***-hyaline and opaque zones of otoliths***

An interesting feature of otoliths is that physical features of the otolith change according to the season of growth. Generally alternating pairs of light (hyaline) and dark (opaque) rings grow in correspondence with seasons of fast and slow growth respectively. It is thought that opaque zones obtain their appearance due to the presence of more protein relative to calcium in the chemical matrix with lower ratios in the hyaline regions (Casselman 1982, Kalish 1989). By combining each light and dark ring, one year of growth is accounted for. As such, the otolith is a powerful tool for use in the aging of fish.

However, in the past there has been a great deal of confusion regarding the terminology related to otolith growth bands (Beckman and Wilson 1995). This is due in part to confusion over the meaning of hyaline and opaque, what these bands represent, and lack of direct evidence for when the components of the annuli are formed for a given fish species (Beckman and Wilson 1995). In addition, further confusion is introduced when researchers fail to state the light conditions under which samples are viewed (i.e. transmitted or reflected light). For these reasons it is important to relate the marginal otolith increment to the season(s) in which a fish species is captured (marginal incremental analysis) in order to relate the timing of opaque and hyaline band formation on otoliths (Beckman and Wilson 1995).

In this study fish were captured between July and November. Under transmitted light, the lighter hyaline band was found at the edge of otoliths suggesting that this is the band corresponding to summer growth. Under this premise, the darker opaque band represents winter growth. Since least cisco are thought to hatch sometime in late winter or early spring under ice (a period associated with opaque growth), it was determined that this band should be used as the marker for annuli.

Other studies on Arctic species report that the opaque zone is the zone of summer growth (Radtke 1995, Radtke et al. 1996, Howland 2001). However, Radtke calls lighter bands opaque zones in his 1995 study and hyaline in the 1996 study. It is clear that hyaline and opaque zones were determined in the 1996 study using transmitted light, but it is not clear whether reflected or transmitted light was used in the 1995 study.

In this study the hyaline bands are much narrower than opaque bands. Putting zone coloration aside for a moment, the narrower band of growth has usually been associated with slow winter growth. However, in this study the narrower hyaline band appeared at the outer margin during summer and early fall. Moreover, least cisco in these sites live in an environment which experiences 8-9 months of winter per year. In laboratory experiments, otoliths have been shown to continue to grow considerably beyond the period at which feeding diminishes or ceases (Moksness et al. 1995). So even though it might be expected that least cisco do not feed much in winter (Kuznetsova 1993), the extreme length of winter in the Arctic provides a long period in which otoliths likely continue to grow and might explain why opaque bands are wider than hyaline bands.

***-relationship of Sr:Ca to hyaline and opaque zones***

Annual bands consisting of hyaline and opaque zones, coupled with the visible burn marks corresponding to sample points from the electron microprobe, allowed for age adjusted migratory profiles for sea-run fish in this study (App. D). However, there seems to be no consistent pattern of peaks in Sr:Ca as they relate to seasonal data for least cisco. For example, in the case of fish # 00-11-LC-03 (App. D) it can be seen that there are peaks in Sr:Ca in hyaline zones (points # 25, 31, 33, 40), opaque zones (point # 21) and on the border between these zones (points # 28). For fish # 002-002 Teshekpuk, all the Sr:Ca points indicative of a marine visit occur in the opaque zone (App D), as do most of the peaks for the other sea-run Teshekpuk fish (# 002-015). Conversely, the majority of Sr:Ca peaks for fish # 00-00-LC-12 occur in the hyaline zone (App D., pg. 115). It has been assumed that summer (hyaline) growth periods are the likely period for migrations because it is the only time that ice does not completely freeze connecting streams (Power 1997). Thus it is seems odd that Sr:Ca would occur in so many growth regions.

It is conceivable that there is some physiological lag time in when Sr is taken up by the otolith. If Sr remains in the blood stream for an extended period beyond migration to sea as theorized by Halden (1996), then it is possible that it could be taken up by the otolith during the formation of both hyaline and opaque bands. Another possibility is that opaque and hyaline zones are formed simultaneously at different points on the same otolith (Beckman et al. 1991). If this is the case with least cisco, it would be possible to see a peak in Sr:Ca in the hyaline zone in one year and in a simultaneously formed opaque zone on another part of the otolith. It is clear that more work needs to be done in order to validate the season or seasons of increment and annuli formation in least cisco.

***Patterns of migration across the study area***

Perhaps the most astonishing feature of these results is that so few fish appear to display any marine migratory behavior. It is reasonable to think that few sea-run fish would have been captured in summer, but the proportion of sea-run individuals did not increase markedly in the fall season (Table A-4). Further, of those fish that did visit the sea there is great variability in when and with what frequency the marine environment is used (App. D). This suggests that least cisco in this study are indeed flexible in their migration strategies.

Although less than 12% of the least cisco analyzed went to sea in this study (n = 28, not including two Teshekpuk fish), the majority of sea-going least cisco were from lakes previously categorized as coastal (Fig. 4) with only two fish from inland sites apparently visiting the sea. Coastal fish certainly have an advantage over inland fish in terms of shorter distances to the marine environment. Inland fish, in addition to having a longer trip to the sea, also have more small streams to navigate before entering large tributaries en route to brackish waters. However, broad whitefish from the same inland sites regularly visit marine environment (J. Ford and M. Terwilliger unpublished data).

*-frequency*

Migrations to sea might be expected to be associated with spawning years, in which case this would be reflected in the Sr:Ca of the otoliths. Moulton et al. (1997) suggested that least cisco spawn on a two year cycle and that they probably do not mature until seven or eight years of age. If they are not spawning annually then it would not necessarily benefit least cisco to make annual sea migrations. However, the majority of Elson Lagoon fish appeared to make approximately annual migrations to higher salinity water. It could be that these are a separate population of coastal least cisco who spend most of their life in brackish waters, as suggested by Nungasuk (pers. comm. 2002). The Sr:Ca profiles for these fish suggest that they tend to be more frequent in their marine migratory forays than Ikroagvik fish, and especially fish in

Joeb's site (see Fig. 6 and App. D). It would be interesting to see if fish caught in Elson Lagoon are mature at an earlier age since they are traveling to sea at or near age one.

***-timing***

Craig (1989) suggested that sea-run least cisco initially visit the marine environment within the first three summers of their life. Similar results were found here, as 20 of 30 fish in this study (and Teshekpuk samples) went to sea by age one or two. Almost half (9 of 20) were from Elson Lagoon. Ikroagvik, which is less than 10 km from the ocean, had four fish that did not go to sea until age four or five. It is difficult to make statements about the significance of these values because so few fish actually display sea-run Sr:Ca profiles.

On the other hand, it is interesting that of the six migratory least cisco from Joeb's site, not one was younger than six years of age at the time of their first marine excursion (Table 5), even though this site is at the very seaward end of the Colville River Delta and is actually adjacent to the Beaufort Sea. This site has been categorized as a perched lake by Alaska Department of Fish and Game (W. Morris, pers. comm. 2003). There is what appears to be an ephemeral stream leading from this lake, but ultimately this becomes a false outlet which dead ends only a few meters from the lake itself. Therefore it would appear that there is no persistent outlet to accommodate travel between marine and freshwater environments.

However, spring ice jams on the Colville River can cause widespread flooding. As spring temperatures begin to rise, tributaries of larger rivers such as the Colville swell from snowmelt runoff of the Brooks Range to the south. As the icy surface of the Colville melts, the raging waters carry a mélange of woody debris and large chunks of ice which jam rivers, leading to widespread flooding. Descriptions of the area from our Iñupiat collaborators suggest that in the late spring many areas of the North Slope can resemble one large floodplain (Feb. 2000 and Oct. 2002 interviews with native elders). They are quick to point out that there is great inter-annual variability in timing and degree of this flooding. At this particular perched lake, it is reasonable to suppose that resident fish simply may not have had access to the marine environment for years at a time. It is just as reasonable to suppose that fish from other sites find their way into Joeb's site during floods and then are trapped for years at a time once flood waters recede.

This scenario of events allows for the possibility that least cisco from any lake might spend much of their early life history in a closed lake system before spring floods allow for out-migration. Just as likely is a scenario in which they end up in another lake because flood waters recede before they can return to their site of origin. Regardless, the data from Joeb's site (App. D) show that least cisco are capable of making their first sea voyage at a relatively old age.

Alternatively, it is possible that the late migration is related to maturity for some populations. Moulton et al. (1997) showed that least cisco in Dease Inlet, 30 miles southeast of Barrow, reach maturity at age 7. A mature pre-spawning individual of this age, whose pre-spawning metabolic needs could not be met simply by remaining in nutrient poor freshwaters, might time its visits to the marine environment in spawning years. In order to better evaluate this concept, it would be important in the future to relate age at first maturity for populations of least cisco in these sites with the Sr:Ca data in their otoliths.

Nonetheless, more than half the fish in this study were seven years of age or older (Fig. 5). This is the oldest age at first visit for marine migratory fish in this study and the age at which they are theorized to reach maturity, yet only two fish appear to have waited this long to visit the sea at this age (see Table A-5). Although all fish classified as sea-run did so for the first time by age seven, in most cases they made their original visit within the first three years of life (Fig. 7). An examination of age/length data (Fig. 8) illustrates the preponderance of fish over three years of age, and even seven years, are without evidence of migratory behavior. It seems likely that if the majority of least cisco were going to travel, they would have already done so at some point prior to age 7.

***Growth and migratory behavior***
***-least cisco growth forms***

Almost all least cisco in these study sites would be classified as *normal* form fish by previous standards (e.g.- Philo et al. 1993b) (see Fig. 9). There are a number of possibilities that might explain why normal form fish were so prevalent in this study.

First it is possible that we simply missed smaller form least cisco because of net bias during the summer sampling seasons. Mesh size for gill nets used in these seasons was two inches or higher. In the fall 2001 season a multi-panel net was also used, with mesh sizes of 0.75", 1" and 1.75". However, only one clear *dwarf* least cisco was caught (01-09-LC-22 Fall, App. C). Thus, it appears that *dwarf* least cisco either: (1) did not exist sympatrically in these study sites, (2) were facultatively avoiding *normal* form least cisco, (3) or were using a different niche from *normal* form fish.

Little can be said of the *dwarf* form fish in this study since only one clear example was captured. Yet, this fish, together with the *dwarf* form fish from the donated Teshekpuk samples, were all freshwater residents. Nonetheless, with such a small sample size it is difficult to definitively say whether all dwarf least cisco are resident. On the other hand, the large number of normal form fish captured allows for the generalization that least cisco cannot be classified as sea-run based on size alone. Even some of the largest and oldest fish in this study (Fig. 8) did not yield Sr:Ca values typical of sea-run fish.

If most *normal* form least cisco in these study sites really are not traveling to sea at any point in their life history, then early descriptions of least cisco life history relating fish size to marine experience do not hold true (i.e. McPhail and Lindsey 1970). The discussion of form and factors influencing these forms has long been a feature in whitefish research (Svärdson 1949, Loch 1974, Todd et al. 1981, Lindsey 1981, Lu and Bernatchez 1998). In the past, *normal* form least cisco were thought to be sea-going because they were observed either directly in the marine environment or migrating in rivers and assumed to be sea-going (Cohen 1954, Mann 1974, Philo et al. 1993a). At the same time larger form least cisco (i.e. *Jumbo* form) have been shown to be lake residents (Lindsey and Kratt 1981, Cohen 1954). The tendency for coregonid species, including least cisco, to display significant variation in appearance and behavior has led to their being classified as the "coregonid problem" (Svärdson 1949) or the "*Coregonus* complex" (McPhail and Lindsey).

One possible explanation for the apparent lack of sea-run migrations in many *normal* form least cisco may relate to the ability of coregonids to display rather significant plasticity in phenotype from one generation to the next. Experiments have shown that hybridization between forms produces viable offspring (Lu and Bernatchez 1998). Furthermore, the environment has been shown to have a significant effect on various morphological features in coregonids transferred from one site to another (Todd et al. 1981, Shields and Underhill 1993). Thus, it is possible that many more than two forms of least cisco are present in the coastal lakes and streams of northern Alaska and that there are many life history strategies for this species.

A second explanation for apparently freshwater resident *normal* forms might be the use of near-shore brackish waters as opposed to full strength saline waters (Craig 1984, 1989, Power 1997). The near-shore environment is less harsh in terms of salinity due to freshwater inputs from land. By remaining near shore, least cisco could engage in "hit and run" feeding sessions where they minimize the length of time in which they inhabit salt water. Facultative anadromy has been suggested for both inconnu (*Stenodus leucichthys*) in the Mackenzie River (Howland et al. 2001) and Baltic Sea brown trout (Limburg et al. 2001. Perhaps least cisco are taking advantage of brackish coastal waters in an even more refined manner on the order of hours to a few days. Under this model, a short stay in saline water may not be reflected in the otoliths of least cisco. Even if the otolith did capture the environmental fingerprint of their brief stay in marine waters, the temporal resolution in this study might be insufficient to reveal it.

***-maternal influence on dwarf least cisco***

Finally, it should be noted that the one clear dwarf form fish caught in this study (01-09-LC-22 Fall, App. D) and one of the donated dwarf samples (001-016, App. D) appear to give at least slight evidence of sea-run maternal influence. Perhaps these fish are the result of a union between a *dwarf* male and *normal* female. This has been shown to occur in whitefish, although with reduced viability in offspring (Lu and Bernatchez 1998). The alternative hypothesis is that some *dwarf* form fish are capable of sea-run migrations, but these two fish have yet to make that migration. These results suggest the importance of further investigations on the *dwarf* life history form.

***Condition factor***

Sea-run fish had statistically higher condition factors than fish classified as resident (Fig. 11, Table 4). Interestingly, fish in the three most coastal sites (Elson, Ikroagvik, Joeb's) had the highest median condition factors (Figure 10) suggesting that fish in coastal sites have a slight advantage in growth over inland fish. It is possible that for these fish the benefits of marine migrations outweigh the costs. It could be that fish making marine forays benefit from greater food availability in near-shore saline waters (Gross 1987). Radtke et al. (1996) found that sea-run char had higher condition factors than resident char, although in this case condition factors were 8-10 times those of resident fish. Sea-run least cisco in this study did not display the same degree of increased condition factor over resident fish. It appears that the benefits of migration are not as significant for least cisco as for char (in terms of body condition), perhaps suggesting another explanation for why so few least cisco appear to be migratory. Furthermore, although these data suggest a statistical difference between condition factors for the sea-run and resident fish (Table 4), the distributions of these values overlap so much as to suggest little practical difference (Fig. 11). In the case of Radtke et al. (1996) it appears that higher growth in char was occurring pre-migration and that there was no increase in growth post-migration. It was theorized that increased pre-migration growth in char could be the major factor contributing to the option of migration since there would be the advantage of significantly increased growth over increased mortality associated with the migration to sea. However, resident fish in their study would be analogous to dwarf least cisco, of which only one occurred in the current study. Future analysis of least cisco life history should focus on this relationship between pre-migration growth and migratory behavior.

*Meristics*

It was hypothesized that least cisco with marine migratory behavior might be able to be differentiated from those of resident behavior based on various meristic features. Variation has always been at the heart of the problem in differentiating between forms of whitefish (Svärdson 1949). Furthermore, it is not unusual to find individual fish of one species which possess physical characteristics of another, thus creating confusing situations in which fish which are thought to be the same species are actually different species and vise versa (Politov 2000). Gill rakers have traditionally been the best differentiator of various forms/species of whitefish throughout the northern hemisphere (Lindsey 1981, Todd et al. 1981). Thus it was surprising that results from this study suggested no difference between gill rakers for least cisco of sea-run behavior vs. those of resident behavior (Table 6). Furthermore, no significant differences could be found in gill rakers of least cisco by site except possibly for Ikroagvik (Table 7). Due to poor preservation of some of gill raker samples, these counts may not be reliable.

Loch (1974) proposed that there is a relationship between gill-raker length and niche, although whether this was environmentally induced due to abrasion from eating harder food (snails and clams as opposed to zooplankton) or whether it was a result of natural selection was unclear. Since in this present study there were no differences in gill raker numbers and since all but one fish in this study were considered n*ormal* form (Fig. 9), perhaps all of these fish are adapted to similar niches (i.e. food types). Lindsey (1981) suggested that variation in *C. clupeaformis* between sites occurred due to the presence or absence of ciscos in a particular site. Broad whitefish (*Coregonus nasus*) were present in all freshwater sites in this study. Similiarity in gill raker number for least cisco between sites could be related to their occupation of the same niche relative to *C. nasus* in each site, regardless of their migratory nature. Perhaps future research could relate diet and gill raker length to sea-run behavior. However, the current results suggest that gill rakers are a poor predictor of sea-run behavior.

Although gill rakers did not differ by site or migratory strategy, other meristic traits did. Fish from the inland sites were similar to one another with respect to meristic traits, but differed from those in coastal sites in lateral line number and dorsal ray (see Table 5). Svärdson (1952) discussed the importance of lateral line scale in differentiation of forms in coregonids. Perhaps inland fish are distinct from more coastal sites due to their lack of interaction with coastal fish.

Fish in coastal sites showed greater variability in meristic traits (Table 5). Loch (1974) showed that *C. clupeaformis* showed variation in a number of meristic traits upon introduction into new lakes. Perhaps coastal fish display greater variation in traits between sites due to their apparent greater proclivity for migration to different environments.

The only trait with significant differences in sea-run versus resident fish, other than condition factor, is number of dorsal rays. Dorsal fin *height* had been described in the past as significantly different in progeny versus parent fish when those progeny were transplanted and allowed to develop in a new environment (Loch 1974, Todd et al. 1981), although no significant differences in *number* of dorsal rays were found. As dorsal rays in whitefish have been discussed very little, the implications of this finding are not clear.

While meristic differences exist between sea-run and resident least cisco, it is also clear that there is a great deal of plasticity. Logistic regression results imply that a combination of dorsal ray number and lateral line scale number might be used to predict the odds of a fish being sea-run. However, the percentage of variance explained by this model (Table 7) is so low that this combination of variables also seems unlikely to be a good predictor of sea-run behavior.

Various factors have been shown to affect meristic traits. Svärdson (1952) suggested that temperature readily affected growth and subsequently lateral line scale number in transplanted coregonids, whereas Svärdson (1952) and Loch (1974) stated that gill raker number was more a result of genetic inheritance. Conversely, it has been suggested that environmental conditions (i.e. temperature, $O_2$, other stress) during development plays a physiological role in determining numbers of this trait (Todd et al. 1981, Lindsey 1981). A more detailed examination of meristic traits may be able to differentiate between sea-run and resident least cisco. However, this study suggests that there is simply a tremendous amount of variability inherit to least cisco in this region as has been the case with the entire coregonus "complex".

**Conclusion**

Least cisco on the coastal plain of northern Alaska are complex in their life history strategies and appearance. In the past, multiple forms have been described with significant differences in size as it relates to age. Although marine migratory behavior has not previously been thoroughly investigated in this species, it has been assumed that larger *normal* forms take advantage of brackish waters during the summer while *dwarf* forms remain in freshwater throughout the year. Results from this study do not support that idea.

A large percentage of fish in this study reach sizes consistent with *normal* form least cisco. However, less than 12% of least cisco in this study made at least some use of the marine environment during their life history. Thus, it appears unlikely that we can infer migratory behavior based on size alone.

Those fish that do go to sea tend to go at an early age. However, a number of factors may influence migration. These include, but are probably not limited to the availability of outlets and the relationship between maturity (or spawning years) and migrations to sea. Furthermore, it is possible that certain populations of least cisco display a life history which is completely at odds with previous theories of migratory behavior. It should be considered that certain populations might spend a tremendous amount of their life in salt water and could even over-winter there.

Body condition was significantly better in sea-run fish relative to freshwater residents, although differences were small and there is much overlap in distributions for these two groups. This implies that there is a benefit to migratory behavior although this benefit may be minimal for least cisco.

Traditionally useful meristic features such as gill rakers and lateral line scales were not helpful in differentiating between sea-run and resident least cisco. However, dorsal ray numbers were slightly different between sea-run and resident least cisco. This difference could be a function of low sample size for sea-run fish or a bias in the number of fish by site who go to sea. Meristic traits of inland fish appeared to be less variable than fish from coastal sites where marine migratory behavior was more prevalent. More thorough investigations of meristic features are needed. At this time, making determinations of sea-run behavior for least cisco based on physical features such as length, body condition or meristics is not recommended.

There are differences by site for lateral line and dorsal rays of least cisco, and thus it would be interesting to investigate the degree to which genetics (as opposed to the environment) influences meristic traits. Future research would also do well to include a component that captures the exact nature of migration in least cisco, either by use of radio telemetry or PIT-tagging. This would allow for known migratory fish from known freshwater sites to be examined more thoroughly with respect to Sr:Ca in the otoliths. Laboratory growth experiments would also be helpful in validating the effects of increased salinity on Sr uptake in least cisco otoliths. Such studies should also include a component that would help to validate age as well as the season of deposition for opaque and hyaline regions.

With increased industrialization of the western Arctic coastal plain of Alaska, it is important to enhance our basic scientific knowledge of many of the little understood fish species before they are negatively impacted. Least cisco have shown complex life history strategies and thus merit further research. This research would be helpful for local communities constructing management strategies to ensure healthy populations of the fish stocks for future generations.

**Bibliography**

Anderson, R.O. and Gutreuter, S.J. 1983. Length, weight, and associated structural indices. pp: 283-300 In: Fisheries Techniques. Edited by: Nielsen, L.A. and Johson, D.L. for the American Fisheries Society, Southern Printing Company, pp. 468.

Babaluk, J.A., Halden, N.M., Reist, J.D., Kristofferson, A.H., Campbell, J.L. and Teesdale, W.J. 1997. Evidence for non-anadromous behaviour of Arctic Charr (*Salvelinus alpinus*) from Lake Hazen, Ellesmere Island, Northwest Territories, Canada, based on scanning proton microprobe analysis of otolith strontium distribution. Arctic 50:224-233.

Beamish, R. J. and McFarlane, G.A. 1987 in: Age and Growth of Fish. Robert C. Summerfelt and Gordon E. Hall editors. Iowa State University Press, Ames, 1987, pp:544.

Beckman, D.W., Stanley, A.L., Render, J.H., and Wilson, C.A. 1991. Age and growth-rate estimation of sheepshead Archosargus probatocephalus in Louisiana waters using otoliths. Fish. Bull. 89:1-8.

Beckman, D.W. and Wilson, C.A. 1995. Seasonal timing of opaque zone formation in fish otoliths. pp:27-44, In: In: Recent developments in fish otolith research. Edited by: Secor, D.H., Dean J.M., and Compana, S.E., Belle W. Baruch institute for marine biology and coastal research, University of South Carolina Press.

BP Exploration (Alaska) Inc. 1989. Endicott development project causeway issues: An evaluation of the U.S. Environmental Protection Agency position paper *Causeways in the Alaskan Beaufort Sea.* Prepared by BP Exploration (Alaska) Inc. February 1989.

Brown, R. and Severin, K.P., 1999. Elemental distribution within polymorphic inconnu (*Stenodus leucichthys*) otoliths is affected by crystal structure. Can. J. Fish. Aquat. Sci. 56:1898-1903.

Casselman, J.M. 1982. Chemical analysis of the optically different zones in eel otoliths. In: Proc. 198 North American eel conference. Ont. Fish. Tech. Rep. Ser. 4. Loftus, K.H. (ed) Ont. Minist. Nat. Resour. P. 74-82.

Campana, S.E., Thorrold, S.R., Jones, C.M., Günther, D., Tubrett, M., Longerich, H., Jackson, S., Halden, N.M., Kalish, J.M., Piccoli, P., de Pontual, H., Troadec, H., Panfili, J., Secor, D.H., Severin, K.P., Sie, S.H., Thresher, R., Teesdale, W.J., Campbell, J.L. 1997. Comparison of accuracy, precision, and sensitivity in elemental assays of fish otoliths using the electron microprobe, proton-induced X-ray emission, and laser ablation inductively coupled plasma mass spectrometry. Can. J. Fish. Aquat. Sci. 54:2068-2079.

Clark, J.H. and Bernard, D.R. 1992. Fecundity of humpback whitefish and least cisco in the Chatanika River, Alaska. Trans. Amer. Fish. Soc. 121:268-273.

Cohen, D.M. 1954. Age and growth studies on two species of whitefishes from Point Barrow, Alaska. Stanford Ichthyological Bulletin. 4:168-187.

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

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

Environmental Protection Agency (EPA) 1988. Causeways in the Alaskan Beaufort Sea. Prepared by: Brian D. Ross, October 1988.

Farrell, J. and Campana, S.E. 1996. Regulation of calcium and strontium deposition on the otoliths of juvenile tilapia, *Oreochromis niloticus*. Comp. Biochem. Physiol. 115:103-109.

Fechhelm, R.G., Bryan, J.D., Griffiths, W.B., Wilson, W.J. and Gallaway, B.J. 1994. Effect of coastal winds on the summer dispersal of young least cisco (*Coregonus sardinella*) from the Colville River to Prudhoe Bay Alaska: A simulation model. Can. J. Fish. Aquat. Sci. 51:890-899.

Ford, J. and Bedford, B.P. 1987. The hydrology of Alaskan wetlands, U.S.A.; a review. Arct. Alpine Res. 19:209-229.

Fowler, A.J., Campana, S.E., Jones, C.M. and Thorrold, S.R. 1995a. Experimental assessment of the effect of temperature and salinity on elemental composition of otoliths using solution-based ICPMS. Can. J. Fish. Aquat. Sci. 52: 1421-1430.

Fowler, A.J., Campana, S.E., Jones, C.M. and Thorrold, S.R. 1995b. Experimental assessment of the effect of temperature and salinity on elemental composition of otoliths using laser ablation ICPMS. Can. J. Fish. Aquat. Sci. 52: 1431-1441.

Gallahar, N.K. and Kingsford, M.J. 1996. Factors influencing Sr/Ca ratios in otoliths of *Girella elevata*: an experimental investigation. J. Fish Bio. 48:174-186.

Galloway, B.J. and Fechhelm, R.G. 2000. Anadromous and amphidromous fishes. In: The Natural History of an Arctic Oil Field. Joe C. Truett and Stephen R. Johnson editors. Academic Press, New York, pp:422.

Gauldie, R.W. 1996. Effects of temperature and vaterite replacement on the chemistry of metal ions in the otoliths of *Oncorhynchus tshawytscha*. Can. J. Fish. Aquat. Sci. 53:2015-2026.

George, C., Moulton, L., and Johnson, M. 2001. Field Guide: Fish of the North Slope. Prepared by North Slope Borough Department of Wildlife Management. pp. 89.

Gilders, M.A. and Cronin, M.A. 2000. North Slope Oil Field Development. In: The Natural History of an Arctic Oil Field. Joe C. Truett and Stephen R. Johnson editors. Academic Press, New York, pp:422.

Gross, M.T. 1987. Evolution of diadromy in fishes. American Fisheries Society Symposium 1:14-25.

Halden, N.M., Babaluk, J.A., Dristofferson, A.H., Campbell, J.L., Teesdale, W.J., Maxwell, J.A., and Reist, J.D. 1996. Micro-PIXE studies of Sr zoning in Arctic charr otoliths: migratory behavior and stock discrimination. Nuc. Instr. Meth. Phys. Res. B109/110:592-597.

Howland, K.L., Tonn, W.M., Babaluk, J.A., and Tallman, R.F. 2001. Identification of freshwater and anadromous inconnu in the Mackenzie River System by analysis of otolith strontium. Trans. Amer. Fish. Soc. 130:725-741.

Ingram, B.L. and Sloan, D. 1992. Strontium isotopic composition of estuarine sediments as paleosalinity-paleoclimate indicator. Science, 255:68-72.

Kalish, J.M. 1989. Otolith microchemistry: validation of the effects of physiology, age and environment on otolith composition. J. Exp. Mar. Biol. Ecol. 132:151-178.

Kalish, J.M. 1990. Use of otolith microchemstry to distinguish the progeny of sympatric anadromous and non-anadromous salmonids. Fish. Bull. 88:657-666.

Kalish, J.M. 1992. Formation of a stress-induced chemical check in fish otoliths. J. Exp. Mar. Biol. Ecol. 162:265-277.

Kuznetsova, E.N. 1993. Seasonality of growth of least cisco, *Coregonus sardinella*, in brackish water of the Lena River. J. Ichthy. 33(7):1-11.

Limburg, K.E. 1995. Otolith strontium traces environmental history of subyearling American shad Alosa sapidissima. Mar. Ecol. Prog. Ser. 119:25-35.

Limburg, K.E., Landergren, P., Westin, L., Elfman, M. and Kristiansson, P. 2001. Flexible modes of anadromy in Baltic sea trout: making the most of marginal spawning streams. J. Fish Biol. 59:682-695.

Lindsey, C.C. 1981. Stocks are chameleons: Plasticity in gill rakers of Coregonid fishes. Can. J. Fish. Aquat. Sci. 38:1497-1506.

Lindsey, C.C. and Kratt, L.F. 1982. Jumbo spotted form of least cisco *Coregonus sardinella* in lakes of southern Yukon Territory. Can. J. Zool. 60:2783-2786.

Loch, J.S. 1974. Phenotypic variation in the lake whitefish, *Coregonus clupeaformis*, induced by introduction into a new environment. J. Fish. Res. Board Can. 31:55-62.

Lu, G. and Bernatchez, L. 1998. Experimental evidence for reduced hybrid viability between dwarf and normal ecotypes of lake whitefish (*Coregonus clupeaformis* Mitchill). Proc. R. Soc. Lond., Ser. B:Biol. Sci. 265:1025-1030.

Mann, G.J. 1974. Life history types of the least cisco (*Coregonus sardinella*, Vallenciennes) in the Yukon Territory, North Slope and eastern Mackenzie River delta drainages. Arctic Gas Biological Report Series 18. (Also: Master's thesis. University of Alberta, Edmonton, Canada.).

Mann, G.J. and McCart, P.J. 1981. Comparison of sympatric dwarf and normal populations of least cisco (*Coregonus sardinella*) inhabiting Trout Lake, Yukon Territory. Can. J. Fish. Aquat. Sci. 38:240-244.

McCune, B., Grace, J.B., Urban, D.L. 2002 Analysis of Ecological Communities. MjM Software, Glendon Beach, Oregon, USA (www.pcord.com). pp:304.

McPhail, J.D. and Lindsey, C.C. 1970. Freshwater fishes of northwestern Canada and Alaska. Bull. Fish. Res. Board Can. No. 173.

Moksness, E., Rukan, K., Ystanes, L., Folkvord, A., and Johannessen, A. 1995. Comparisons of somatic and otolith growth in North Sea herring (*Clupea herengus L.*) larvae: Evaluation of growth dynamics in mesocosms. pp:119-134, In: Recent developments in fish otolith research. Edited by: Secor, D.H., Dean J.M., and Compana, S.E., Belle W. Baruch institute for marine biology and coastal research, University of South Carolina Press, Columbia.

Moulton, L.L., Philo, L.M. and George, J.C. 1997. Some reproductive characteristics of least ciscoes and humpback whitefish in Dease Inlet, Alaska. Amer. Fish. Soc. Symp. 19:119-126.

Moulton, L.L. and George, J.C. 2000. Freshwater fishes in the Arctic oil-field region and coastal plain of Alaska. pp:327-348 In: The Natural History of an Arctic Oil Field. Joe C. Truett and Stephen R. Johnson editors. Academic Press, New York, pp:422.

National Oceanic and Atmospheric Association (NOAA), 1988. An analysis of the effects of the West Dock Causeway on the nearshore oceanographic processes in the vicinity of Prudhoe Bay. Prepared for the NOAA Ocean Assessments Division by: D.A. Hale and M.J. Hameedi, August 4, 1988, pp:94.

Philo, L.M., George, J.C. and Moulton, L.L. 1993a. The occurrence and description of anadromous fish in the Dease Inlet/Admiralty Bay, Alaska Area 1988-1990. North Slope Borough Dept. of Wildlife Management internal report, pp:150.

Philo, L.M., George, J.C. and Moulton, L.L. 1993b. The occurrence and description of anadromous and freshwater fish in Teshekpuk Lake, Alaska 1990-1992- North Slope Borough Dept. of Wildlife Management internal report, pp:96.

Politov, D.V., Gordon, N. Yu, Afanasiev, K.I., Altukhov, Yu. P. and Bickham, J.W. 2000. Identification of palearctic coregonid fish species using mtDNA and allozyme genetic markers. J. Fish Bio. 57(Sup. A):51-71.

Power, G. 1997. A review of fish ecology in Arctic North America. Amer. Fish. Soc. Symp. 19:13-39, 1997.

Radtke, R.L. 1989. Strontium-Calcium concentration ratios in fish otoliths as environmental indicators. Comp. Biochem. Physiol. 92:189-193.

Radtke, R.L. 1995. Otolith microchemistry of charr – use in life history studies. Nordic. J. Freshw. Res. 71: 392-395.

Radtke, R., Svenning, M., Malone, D., Klementsen, A., Ruzicka, J., and Dariusz, F. 1996. Migrations in an extreme northern population of Arctic charr *Salvelinu alpinus*: insights from otolith microchemistry. Mar. Ecol. Prog. Ser. 136:13-23.

Ramsey, F.L. and Schafer, D.W. 1997. The Statistical Sleuth: A Course in Methods of Data Analysis. Duxbury Press, Belmont CA. pp:742.

Rieman, B.E., Myers, D.L., and Nielsen, R.L. 1994. Use of otolith microchemistry to discriminate *Oncorhynchus nerka* of resident and Anadromous Origin. Can. J. Fish. Aquat. Sci. 51:68-77.

Rosenthal, H.L., Eves, M.M., and Cochran. O.A. 1970. Common strontium concentration of mineralized tissues from marine and sweet water animals. Comp. Biochem. And Phys. 32:445-450.

Sadovy, Y. and Severin, K.P. 1992. Trace elements in biogenic aragonite: correlation of body growth rate and strontium levels in the otoliths of the white grunt, *Haeumulon plumieri* (Pisces: Haemulidae). Bull. Mar. Sci., Vol. 50, pp. 237-257.

Scott, W.B. and Crossman, E.J. 1973. Freshwater fishes of Canada. Fish.Res. Board Can. Bull. 181: 966 p.

Secor, D. H., Henderson-Arzapalo, A., and Piccoli, P.M. 1995. Can otolith microchemistry chart patterns of migration and habitat utilization in anadromous fishes? J. Exp. Mar. Bio. Ecol. 192:15-33.

Shields, B.A. and Underhill, J.C. 1993. Phenotypic plasticity of a transplanted population of dwarf cisco, *Coregonus artedii.* Env. Biol. Fish. 37(1):9-23.

Svärdson, G. 1949. The coregonid problem. I. Some general aspects of the problem. Rep. Inst. Freshwater Res. Drottningholm: 29:89-101.

Svärdson, G. 1952. The coregonid problem IV. The significance of scales and gillrakers. Rep. Inst. Freshwater Res. Drottningholm 33:204-232.

Todd, T.N., Smith, G.R., and Cable, L.E. 1981. Environmental and genectic contributions ot morphological differentiation in ciscoes (Coregoninae) of the Great Lakes. Can. J. Fish. Aquat. Sci. 38-59-67.

Toole, C.L. and Nielsen, R.L. 1992. Effects of microprobe precision on hypotheses related to otolith Sr:Ca ratios. Fish. Bull. 90:421-427.

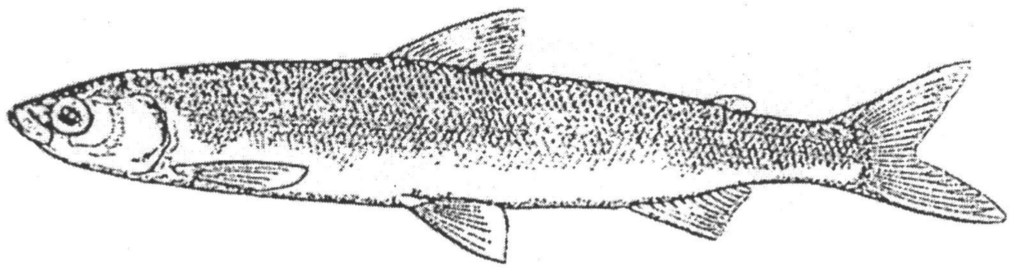
Wohlschlag, D.E. 1954. Growth peculiarities of the cisco, *Coregonus sardinella* (Valenciennes), in the vicinity of Point Barrow, Alaska. Stanford Ichthyological Bulletin. 4:189-209.

Wolfe, R.J. 2000. Subsistence in Alaska: a year 2000 update. Alaska Department of Fish and Game, Division of Subsistence: Juneau Alaska. www.state.ak.us/local/akpages/FISH.GAME/subsist/download/subupd00.pdf

Young, S.B. 1989. To the Arctic: an introduction to the far northern world. John Wiley and Sons, Inc. New York, pp:354.

# APPENDICES

(pp: 81-133)



# Appendix A

(pp: 82-85)

Additional results

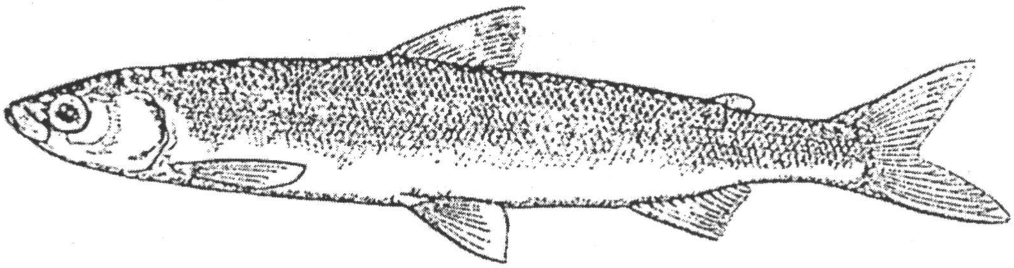


Table A-1. Summary of sampling dates by season and year with location of each site. Refer to Fig. 1 for location of site by number.

| | | | Dates Sampled by Season | | | |
|---|---|---|---|---|---|---|
| Site # | Site Name | Location | Summer 2000 | Fall 2000 | Summer 2001 | Fall 2001 |
| 00 | Ikroagvik | 71° 14.319N 156° 39.298W | 7/20/2000 | Mid October[1] | 8/11/01 - 8/13/01[3] | 10/15/01 - 10/19/01 |
| 01 | Joshua's | 70° 18.884N 156° 21.198W | 7/22/00 - 7/26/00 | NS | 7/31/01 - 8/4/01 | 10/26/01 - 11/03/01 |
| 13 | Joshua's 2nd | 70° 15.282N 156° 07.426W | NS | NS | 8/5/01 - 8/8/01 | 10/27/01 - 11/03/01 |
| 03 | Luther's | 70° 18.136N 155° 23.927W | 7/28/00 - 8/2/00 | NS | 7/22/01 - 7/26/01 | NS |
| 09 | Joeb's | 70° 23.733N 151° 04.353W | 8/12/00 - 8/14/00 | NS | 7/18/01 - 7/21/01 | 11/08/01 - 11/12/01 |
| 12 | Joeb's 2nd | 70° 07.700N 151° 04.520W | NS | NS | 7/14/01 - 7/17/01 | 11/10/01 - 11/11/01 |
| 11 | Elson Lagoon | 71° 15.203 N 156° 40.467 W | 8/26/20 - 8/27/00 [2] | NS | 8/11/01 - 8/12/01 | NS |

[1] A total of 50 fish were donated by employees of the North Slope Borough Wildlife Department and Alaska Department of Fish and Game. Fish were captured at differentlocations over the course of several days in October 2000.
[2] The five fish from this time period were donated by subsistence fishing specialist James Matumeak.
[3] These samples were not analyzed for this study.
NS= Not Sampled

Table A-2. Description of net types used in this study.

| Net # | Mesh Size | Description |
|---|---|---|
| 1 | 3" | composite/ white/ surface floating |
| 2 | 4.5" | composite/ green/ surface floating |
| 3 | 2" | composite/ white/ surface floating |
| 4 | 2.5" | composite/ white/ surface floating |
| 5 | 4" | composite/ white/ surface floating |
| 6 | 3" | composite/ white/ surface floating |
| 7 | 4.5" | composite/ white/ sinking net |
| 8 | 4.5" | composite/ white/ sinking net |
| 9 | 2",3",4",5" | composite/ white/ under ice |
| 10 | 3/4", 1", 1.75" | monofilament/ clear/ under ice |

Table A-3. Catch Per Unit Effort (CPUE) by season for least cisco at all sites. CPUE is expressed as catch per 24 hour period of sampling effort. Note that Fall 2000 samples from Ikroagvik were not included in this table as CPUE data were not collected. For "Net Types", refer to "Net #" in Table 2.

| Site Name | Summer 2000 Hours Fished | Net Types | # of Fish | CPUE | Summer 2001 Hours Fished | Net Types | # of Fish | CPUE | Fall 2001 Hours Fished | Net Types | # of Fish | CPUE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ikroagvik | 24h | 7, 8 | 0 | 0 | ~80h | 6,3,4 | 174[b] | 11.02 | 97h 53min | 9 | 160 | 39.12 |
| Joshua's | 50h 25min | 5,6 | 0 | 0 | 387h 21min | 5,4,2,1, 7,3,6,8 | 0 | 0 | 338h 49min | 5,7,10 | 69 | 4.89 |
| Joshua's 2nd | NS | NS | NS | NS | 181h 1min | 1,2,3,4, 5,6,7 | 0 | 0 | 304h 48min | 7,8,10 | 81 | 6.38 |
| Luther's | 262h 26min | 1,3,5,6 | 7 | 0.64 | 569h 3min | 1,2,3,4, 5,6,7 | 13 | 0.55 | NS | NS | NS | NS |
| Joeb's | 91h 40min | 1,3 | 8 | 2.09 | 513h 1min | 1,2,3,4, 5,6,7,8 | 6 | 0.28 | 115h 37min | 8, 10 | 23 | 4.77 |
| Joeb's 2nd | NS | NS | NS | NS | 354h 17min | 2,7,1,4, 3,6 | 18 | 1.22 | 117h 13min | 7,8 | 0 | 0 |
| Elson Lagoon | ~24h[a] | 4 | 5 | 5.00 | 19h 40min | 3 | 4 | 4.87 | NS | NS | NS | NS |

[a] This is a rough estimate of fishing effort based on information provided from James Matumeak (subsistence specialist)
[b] These fish were captured but remain unanalyzed

Table A-4. Summary of sea-run fish percentages caught in each site by season. Not included in this table are 9 donated fish from Teshekpuk.

| Site | Summer 2000 # probed (% sea-run) | Fall 2001 # probed (% sea-run) | Summer 2001 # probed (% sea-run) | Fall 2001 # probed (% sea-run) | Totals # probed (% sea-run) |
|---|---|---|---|---|---|
| Ikroagvik | - | 50 (6) | - | 70 (6) | 120 (8) |
| Joshua's | - | - | - | 31 (0) | 31 (0) |
| Joshua's 2nd | - | - | - | 30 (7) | 30 (7) |
| Luther's | 3 (0) | - | 14 (0) | - | 17 (0) |
| Joeb's | 5 (60) | - | 6 (16) | 15 (13) | 26 (23) |
| Joeb's 2nd | - | - | 16 (6) | 0 (0) | 16 (6) |
| Elson | 5 (100) | - | 4 (100) | - | 9 (100) |
| Totals | 13 (61) | 50 (6) | 40 (15) | 146 (5) | 249 (11) |

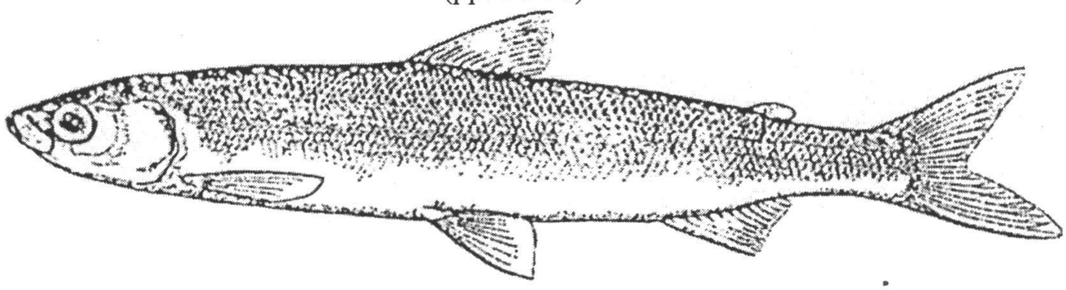
Table A-5. General characteristics of least cisco classified as sea-run fish. Refer to Appendix D for age adjusted Sr:Ca profiles of each fish.

| Site | Fish ID | Appendix D Profile Page # | Length (mm) | Weight (g) | Sex | Age at First Sea-Run | Final Age |
|---|---|---|---|---|---|---|---|
| Ikroagvik | 00-00-LC-02 | 122 | 318 | 366 | female | 4 | 10 |
| Ikroagvik | 00-00-LC-04 | 122 | 319 | 396 | female | 1 | 11 |
| Ikroagvik | 00-00-LC-12 | 122 | 342 | 490 | female | 1 | 11 |
| Ikroagvik | 01-00-LC-09 Fall | 123 | 299 | 296 | male | 1 | 11 |
| Ikroagvik | 01-00-LC-15 Fall | 123 | 295 | 306 | male | 4 | 11 |
| Ikroagvik | 01-00-LC-20 Fall | 123 | 299 | 305 | female | 2 | 10 |
| Ikroagvik | 01-00-LC-27 Fall | 124 | 295 | 270 | male | 5 | 11 |
| Ikroagvik | 01-00-LC-45 Fall | 124 | 286 | 273 | female | 4 | 12 |
| Ikroagvik | 01-00-LC-91 Fall | 124 | 306 | 301 | male | 1 | 11 |
| Ikroagvik | 01-00-LC-127 Fall | 125 | 268 | 214 | male | 1 [2.4] | 8 [10.6] |
| Joshua's 2nd | 01-13-LC-21 Fall | 132 | 235 | 130 | female | 1 | 8 |
| Joshua's 2nd | 01-13-LC-33 Fall | 132 | 227 | 112 | male | 5 [3] | 6 [7] |
| Joeb's | 00-09-LC-01 | 126 | 215 | 118 | female | 4 | 6 |
| Joeb's | 00-09-LC-02 | 126 | 243 | 161 | female | 5 | 7 |
| Joeb's | 00-09-LC-07 | 126 | 225 | 137 | female | 3 | 5 |
| Joeb's | 01-09-LC-05 | 127 | 308 | 382 | male | 7 | 12 |
| Joeb's | 01-09-LC-11 Fall | 127 | 274 | 236 | female | 6 | 7 |
| Joeb's | 01-09-LC-16 Fall | 127 | 203 | 103 | male | 7 [5.33] | 7 [7.33] |
| Joeb's 2nd | 01-12-LC-06 | 131 | 328 | 366 | male | 3 [3] | 12 [12] |
| Elson Lagoon | 00-11-LC-01 | 128 | 278 | 252 | male | 1 | 7 |
| Elson Lagoon | 00-11-LC-02 | 128 | 304 | 313 | female | 1 | 11 |
| Elson Lagoon | 00-11-LC-03 | 128 | 307 | 362 | female | 1 | 11 |
| Elson Lagoon | 00-11-LC-04 | 129 | 318 | 336 | female | 2 | 11 |
| Elson Lagoon | 00-11-LC-05 | 129 | 310 | 384 | female | 1 | 10 |
| Elson Lagoon | 01-11-LC-01 | 129 | 284 | 352 | female | 1 | 13 |
| Elson Lagoon | 01-11-LC-02 | 130 | 332 | 491 | female | 1 | 12 |
| Elson Lagoon | 01-11-LC-03 | 130 | 316 | 358 | female | 2 | 12 |
| Elson Lagoon | 01-11-LC-04 | 130 | 297 | 291 | male | 1 [1.22] | 15 [11.3] |
| *Teshekpuk | 002 - 002 | 133 | 133 | 15 | ** | 1 | 3 |
| *Teshekpuk | 002 - 015 | 133 | 367 | 499 | ** | 1 [1] | 13 [8] |
| | | | | Averages | | 2.6 | 9.8 |

* Denotes North Slope Borough Wildlife Department donated otoliths of least cisco from Summer 1991 Lake Teshekpuk survey (Philo et al. 1993b). ** Denotes an item not reported. Items in brackets refer to the average age for that site.

## Appendix B

(pp. 86-91)



Least Cisco Raw Data

Includes Appendix C page number for reference to graphic profile of Sr:Ca in each fish

Key to Colors and Symbols

| | |
|---|---|
| **** | data unavailable |
| imm | immature and therefore unable to determine sex |
| ^^ | destroyed, unable to count |
| * | count not included in analysis. Count was low due partially destroyed sample |
| + | shaded cell or + sign indicates sea-run fish |
| - | clear cell or - sign indicates resident fish |

| Site | Fish ID | Appendix C Profile Page # | Age | Sex | F.L. (mm) | Weight (g) | Condition Factor | L.L. | AR | DR | GR | Sea Run? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ikroagvik | 00-00-LC-01 | 92 | 9 | m | 323 | 368 | 1.09 | 86 | 13 | 13 | 36 | - |
| Ikroagvik | 00-00-LC-02 | 92 | 10 | f | 318 | 366 | 1.14 | 97 | 13 | 13 | 34 | + |
| Ikroagvik | 00-00-LC-03 | 92 | 10 | f | 320 | 404 | 1.23 | 86 | 13 | 12 | 32 | - |
| Ikroagvik | 00-00-LC-04 | 92 | 11 | f | 319 | 396 | 1.22 | 91 | 13 | 12 | 35 | + |
| Ikroagvik | 00-00-LC-05 | 92 | 10 | m | 322 | 397 | 1.19 | 95 | 13 | 12 | 36 | - |
| Ikroagvik | 00-00-LC-06 | 92 | 10 | f | 305 | 352 | 1.24 | 86 | 12 | 12 | 36 | - |
| Ikroagvik | 00-00-LC-07 | 92 | 10 | f | 323 | 391 | 1.16 | 95 | 12 | 11 | 36 | - |
| Ikroagvik | 00-00-LC-08 | 92 | 11 | f | 331 | 431 | 1.19 | 92 | 13 | 11 | 38 | - |
| Ikroagvik | 00-00-LC-09 | 92 | 10 | m | 305 | 342 | 1.21 | 94 | 12 | 11 | 37 | - |
| Ikroagvik | 00-00-LC-10 | 92 | 10 | m | 307 | 355 | 1.23 | 91 | 12 | 11 | 37 | - |
| Ikroagvik | 00-00-LC-11 | 93 | 10 | f | 332 | 425 | 1.16 | 95 | 12 | 10 | 36 | - |
| Ikroagvik | 00-00-LC-12 | 93 | 11 | f | 342 | 490 | 1.22 | 90 | 12 | 10 | 37 | + |
| Ikroagvik | 00-00-LC-13 | 93 | 10 | f | 345 | 499 | 1.22 | 91 | 12 | 11 | 33 | - |
| Ikroagvik | 00-00-LC-14 | 93 | 10 | f | 334 | 493 | 1.32 | 88 | 12 | 11 | 36 | - |
| Ikroagvik | 00-00-LC-15 | 93 | 10 | f | 355 | 528 | 1.18 | 90 | 12 | 11 | 36 | - |
| Ikroagvik | 00-00-LC-16 | 93 | 10 | m | 387 | 556 | 0.96 | 85 | 12 | 12 | 33 | - |
| Ikroagvik | 00-00-LC-17 | 93 | 11 | f | 330 | 466 | 1.30 | 94 | 12 | 10 | 34 | - |
| Ikroagvik | 00-00-LC-18 | 93 | 10 | f | 359 | 449 | 0.97 | 98 | 12 | 11 | 35 | - |
| Ikroagvik | 00-00-LC-19 | 93 | 11 | f | 328 | 407 | 1.15 | 91 | 12 | 11 | 37 | - |
| Ikroagvik | 00-00-LC-20 | 93 | 10 | f | 344 | 516 | 1.27 | 98 | 11 | 10 | 33 | - |
| Ikroagvik | 00-00-LC-21 | 94 | 10 | m | 338 | 405 | 1.05 | 1001 | 1 | 11 | 36 | - |
| Ikroagvik | 00-00-LC-22 | 94 | 11 | m | 304 | 316 | 1.12 | 88 | 13 | 11 | 37 | - |
| Ikroagvik | 00-00-LC-23 | 94 | 10 | f | 331 | 392 | 1.08 | 83 | 11 | 10 | 38 | - |
| Ikroagvik | 00-00-LC-24 | 94 | 10 | f | 338 | 433 | 1.12 | 98 | 13 | 10 | 39 | - |
| Ikroagvik | 00-00-LC-25 | 94 | 10 | f | 313 | 379 | 1.24 | 97 | 11 | 11 | 34 | - |
| Ikroagvik | 00-00-LC-26 | 94 | 10 | f | 323 | 447.5 | 1.33 | 91 | 14 | 12 | 40 | - |
| Ikroagvik | 00-00-LC-27 | 94 | 10 | f | 338 | 465.3 | 1.20 | 90 | 14 | 11 | 41 | - |
| Ikroagvik | 00-00-LC-28 | 94 | 7 | f | 234 | 132.1 | 1.03 | 74 | 13 | 12 | 33 | - |
| Ikroagvik | 00-00-LC-29 | 94 | 6 | m | 250 | 149.6 | 0.96 | 78 | 14 | 12 | 37 | - |
| Ikroagvik | 00-00-LC-30 | 94 | 10 | f | 300 | 369.1 | 1.37 | 91 | 13 | 11 | 43 | - |
| Ikroagvik | 00-00-LC-31 | 95 | 10 | f | 327 | 419.3 | 1.20 | 88 | 14 | 11 | 39 | - |
| Ikroagvik | 00-00-LC-32 | 95 | 11 | f | 312 | 354.5 | 1.17 | 86 | 12 | 12 | 42 | - |
| Ikroagvik | 00-00-LC-33 | 95 | 10 | m | 306 | 358.4 | 1.25 | 93 | 13 | 12 | 41 | - |
| Ikroagvik | 00-00-LC-34 | 95 | 10 | f | 317 | 369.3 | 1.16 | 90 | 13 | 12 | 42 | - |
| Ikroagvik | 00-00-LC-35 | 95 | 10 | f | 327 | 372.3 | 1.06 | 95 | 14 | 13 | 43 | - |
| Ikroagvik | 00-00-LC-36 | 95 | 10 | f | 319 | 426.9 | 1.32 | 82 | 13 | 12 | 40 | - |
| Ikroagvik | 00-00-LC-37 | 95 | 7 | m | 278 | 258.2 | 1.20 | 85 | 14 | 13 | 40 | - |
| Ikroagvik | 00-00-LC-38 | 95 | 6 | f | 254 | 188.3 | 1.15 | 90 | 14 | 14 | 41 | - |
| Ikroagvik | 00-00-LC-39 | 95 | 7 | m | 347 | 166.5 | 0.40 | 93 | 13 | 12 | 41 | - |
| Ikroagvik | 00-00-LC-40 | 95 | 8 | m | 267 | 195.1 | 1.02 | 90 | 13 | 12 | 40 | - |
| Ikroagvik | 00-00-LC-41 | 96 | 6 | m | 234 | 135.1 | 1.05 | 86 | **** | 13 | ****- | |
| Ikroagvik | 00-00-LC-42 | 96 | 10 | f | 315 | 368.5 | 1.18 | 89 | 13 | 11 | 42 | - |
| Ikroagvik | 00-00-LC-43 | 96 | 10 | m | 309 | 339.7 | 1.15 | 91 | 13 | 13 | 41 | - |
| Ikroagvik | 00-00-LC-44 | 96 | 10 | f | 321 | 389.3 | 1.18 | 99 | 13 | 12 | 41 | - |
| Ikroagvik | 00-00-LC-45 | 96 | 10 | f | 320 | 360.9 | 1.10 | 85 | 15 | 12 | 39 | - |
| Ikroagvik | 00-00-LC-46 | 96 | 6 | f | 246 | 170.9 | 1.15 | 83 | 15 | 12 | 39 | - |
| Ikroagvik | 00-00-LC-47 | 96 | 7 | m | 311 | 320.6 | 1.07 | 89 | 14 | 12 | 44 | - |
| Ikroagvik | 00-00-LC-48 | 96 | 11 | f | 316 | 330.9 | 1.05 | 91 | 14 | 12 | 41 | - |
| Ikroagvik | 00-00-LC-49 | 96 | 9 | m | 299 | 306.6 | 1.15 | 92 | 14 | 13 | 39 | - |
| Ikroagvik | 00-00-LC-50 | 96 | 10 | f | 308 | 339.1 | 1.16 | 94 | 13 | 11 | 43 | - |
| Ikroagvik | 01-00-LC-01 Fall | 97 | 10 | m | 298 | 286 | 1.08 | 98 | 14 | 13 | 42 | - |
| Ikroagvik | 01-00-LC-02 Fall | 97 | 11 | m | 294 | 315 | 1.24 | 89 | 14 | 13 | ****- | |
| Ikroagvik | 01-00-LC-03 Fall | 97 | 11 | f | 330 | 362 | 1.01 | 88 | 14 | 13 | 31* | - |
| Ikroagvik | 01-00-LC-04 Fall | 97 | 11 | f | 325 | 430 | 1.25 | 90 | 15 | 13 | ****- | |
| Ikroagvik | 01-00-LC-06 Fall | 97 | 10 | m | 296 | 283 | 1.09 | 87 | 13 | 13 | 37 | - |
| Ikroagvik | 01-00-LC-08 Fall | 97 | 11 | f | 328 | 379 | 1.07 | 87 | 14 | 13 | ****- | |
| Ikroagvik | 01-00-LC-09 Fall | 97 | 11 | m | 299 | 296 | 1.11 | 90 | 14 | 13 | 42 | + |
| Ikroagvik | 01-00-LC-12 Fall | 97 | 7 | f | 289 | 243 | 1.01 | 93 | 14 | 13 | 39 | - |
| Ikroagvik | 01-00-LC-14 Fall | 97 | 8 | f | 245 | 146 | 0.99 | 85 | 15 | 12 | 38 | - |

| Site | Fish ID | Appendix C Profile Page # | Age | Sex | F.L. (mm) | Weight (g) | Condition Factor | L.L. | AR | DR | GR | Sea Run? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ikroagvik | 01-00-LC-15 Fall | 97 | 11 | m | 295 | 306 | 1.19 | 94 | 13 | 13 | 40 | + |
| Ikroagvik | 01-00-LC-19 Fall | 98 | 10 | f | 318 | 381 | 1.18 | 91 | 14 | 13 | 40 | - |
| Ikroagvik | 01-00-LC-20 Fall | 98 | 10 | f | 299 | 305 | 1.14 | 93 | 14 | 13 | 41 | + |
| Ikroagvik | 01-00-LC-21 Fall | 98 | 7 | f | 253 | 164 | 1.01 | 82 | 13 | 13 | 40 | - |
| Ikroagvik | 01-00-LC-22 Fall | 98 | 8 | f | 238 | 134 | 0.99 | 93 | 14 | 13 | 41 | - |
| Ikroagvik | 01-00-LC-23 Fall | 98 | 7 | m | 250 | 168 | 1.08 | 94 | 14 | 14 | 31* | - |
| Ikroagvik | 01-00-LC-25 Fall | 98 | 9 | f | 265 | 178 | 0.96 | 90 | 13 | 13 | 32* | - |
| Ikroagvik | 01-00-LC-26 Fall | 98 | 10 | m | 312 | 328 | 1.08 | 90 | 14 | 13 | 37 | - |
| Ikroagvik | 01-00-LC-27 Fall | 98 | 11 | m | 295 | 270 | 1.05 | 91 | 15 | 13 | 42 | + |
| Ikroagvik | 01-00-LC-28 Fall | 98 | 10 | m | 315 | 317 | 1.01 | 10014 | | 13 | 40 | - |
| Ikroagvik | 01-00-LC-29 Fall | 98 | 12 | f | 315 | 353 | 1.13 | 95 | 14 | 12 | 37 | - |
| Ikroagvik | 01-00-LC-31 Fall | 99 | 8 | m | 284 | 235 | 1.03 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-32 Fall | 99 | 8 | f | 247 | 174 | 1.15 | 80 | 13 | 11 | 37 | - |
| Ikroagvik | 01-00-LC-35 Fall | 99 | 8 | f | 282 | 252 | 1.12 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-36 Fall | 99 | 8 | f | 271 | 201 | 1.01 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-39 Fall | 99 | 8 | m | 263 | 182 | 1.00 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-40 Fall | 99 | 8 | f | 272 | 204 | 1.01 | 86 | 15 | 13 | 41 | - |
| Ikroagvik | 01-00-LC-41 Fall | 99 | 12 | f | 310 | 364 | 1.22 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-44 Fall | 99 | 10 | f | 328 | 414 | 1.17 | 87 | 14 | 13 | 39 | - |
| Ikroagvik | 01-00-LC-45 Fall | 99 | 12 | m | 286 | 273 | 1.17 | **** | **** | **** | **** | + |
| Ikroagvik | 01-00-LC-48 Fall | 99 | 11 | f | 315 | 378 | 1.21 | 87 | 16 | 13 | 40 | - |
| Ikroagvik | 01-00-LC-51 Fall | 100 | 8 | f | 300 | 306 | 1.13 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-52 Fall | 100 | 8 | m | 307 | 306 | 1.06 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-53 Fall | 100 | 11 | f | 337 | 531 | 1.39 | 96 | 15 | 12 | **** | - |
| Ikroagvik | 01-00-LC-54 Fall | 100 | 5 | f | 223 | 103 | 0.93 | 88 | 14 | 13 | 43 | - |
| Ikroagvik | 01-00-LC-55 Fall | 100 | 7 | m | 250 | 162 | 1.04 | 88 | 14 | 13 | 42 | - |
| Ikroagvik | 01-00-LC-56 Fall | 100 | 7 | m | 223 | 111 | 1.00 | 94 | 14 | 13 | 38 | - |
| Ikroagvik | 01-00-LC-57 Fall | 100 | 12 | f | 304 | 314 | 1.12 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-59 Fall | 100 | 11 | f | 310 | 385 | 1.29 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-65 Fall | 100 | 8 | m | 257 | 193 | 1.14 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-67 Fall | 100 | 11 | m | 328 | 395 | 1.12 | 10014 | | 13 | 43 | - |
| Ikroagvik | 01-00-LC-69 Fall | 101 | 8 | m | 279 | 225 | 1.04 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-78 Fall | 101 | 11 | m | 309 | 333 | 1.13 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-83 Fall | 101 | 11 | m | 300 | 294 | 1.09 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-90 Fall | 101 | 10 | f | 310 | 335 | 1.12 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-91 Fall | 101 | 11 | m | 306 | 301 | 1.05 | **** | **** | **** | **** | + |
| Ikroagvik | 01-00-LC-98 Fall | 101 | 11 | f | 323 | 408 | 1.21 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-116 Fall | 101 | 10 | m | 324 | 420 | 1.23 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-121 Fall | 101 | 11 | m | 303 | 355 | 1.28 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-125 Fall | 101 | 8 | m | 262 | 189 | 1.05 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-127 Fall | 101 | 8 | m | 268 | 214 | 1.11 | **** | **** | **** | **** | + |
| Ikroagvik | 01-00-LC-129 Fall | 102 | 11 | m | 285 | 253 | 1.09 | 10215 | | 12 | 45 | - |
| Ikroagvik | 01-00-LC-130 Fall | 102 | 10 | f | 315 | 352 | 1.13 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-131 Fall | 102 | 8 | f | 270 | 227 | 1.15 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-134 Fall | 102 | 7 | m | 260 | 173 | 0.98 | 91 | 13 | 12 | 42 | - |
| Ikroagvik | 01-00-LC-135 Fall | 102 | 8 | f | 285 | 225 | 0.97 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-136 Fall | 102 | 11 | m | 318 | 317 | 0.99 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-137 Fall | 102 | 12 | f | 323 | 404 | 1.20 | 98 | 13 | 11 | 40 | - |
| Ikroagvik | 01-00-LC-138 Fall | 102 | 12 | f | 330 | 359 | 1.00 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-139 Fall | 102 | 12 | f | 322 | 347 | 1.04 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-141 Fall | 102 | 12 | f | 316 | 354 | 1.12 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-142 Fall | 103 | 12 | m | 313 | 349 | 1.14 | 92 | 14 | 12 | 42 | - |
| Ikroagvik | 01-00-LC-146 Fall | 103 | 12 | f | 334 | 388 | 1.04 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-147 Fall | 103 | 8 | m | 258 | 174 | 1.01 | 94 | 13 | 12 | 39 | - |
| Ikroagvik | 01-00-LC-148 Fall | 103 | 12 | f | 315 | 354 | 1.13 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-149 Fall | 103 | 11 | f | 330 | 372 | 1.04 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-150 Fall | 103 | 7 | m | 248 | 169 | 1.11 | 91 | 15 | 12 | 37 | - |
| Ikroagvik | 01-00-LC-151 Fall | 103 | 11 | f | 329 | 407 | 1.14 | **** | **** | **** | **** | - |
| Ikroagvik | 01-00-LC-153 Fall | 103 | 12 | f | 332 | 422 | 1.15 | **** | **** | **** | **** | - |

| Site | Fish ID | Appendix C Profile Page # | Age | Sex | F.L. (mm) | Weight (g) | Condition Factor | L.L. | AR | DR | GR | Sea Run? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ikroagvik | )1-00-LC-158 Fal | 103 | 8 | f | 260 | 202 | 1.15 | **** | **** | **** | **** | - |
| Ikroagvik | )1-00-LC-160 Fal | 103 | 12 | f | 323 | 443 | 1.31 | 93 | 14 | 12 | 40 | - |
| Joshua's | 01-01-LC-01 Fall | 104 | 8 | m | 214 | 114 | 1.16 | 95 | 13 | 12 | 40 | - |
| Joshua's | 01-01-LC-04 Fall | 104 | 6 | f | 178 | 53 | 0.94 | 93 | 12 | 11 | 39 | - |
| Joshua's | 01-01-LC-05 Fall | 104 | 3 | m | 163 | 42 | 0.97 | 85 | 13 | 11 | 41 | - |
| Joshua's | 01-01-LC-07 Fall | 104 | 3 | m | 136 | 28 | 1.11 | 90 | 13 | 11 | ^^ | - |
| Joshua's | 01-01-LC-08 Fall | 104 | 3 | f | 135 | 22 | 0.89 | 93 | 14 | 12 | ^^ | - |
| Joshua's | 01-01-LC-13 Fall | 104 | 4 | imm | 142 | 26 | 0.91 | 81 | 14 | 12 | 41 | - |
| Joshua's | 01-01-LC-14 Fall | 104 | 5 | f | 155 | 39 | 1.05 | 90 | 13 | 12 | 41 | - |
| Joshua's | 01-01-LC-16 Fall | 104 | 5 | f | 165 | 44 | 0.98 | 100 | 14 | 11 | ^^ | - |
| Joshua's | 01-01-LC-18 Fall | 104 | 7 | f | 232 | 126 | 1.01 | 92 | 13 | 12 | 42 | - |
| Joshua's | 01-01-LC-19 Fall | 104 | 5 | f | 168 | 44 | 0.93 | 96 | 14 | 12 | 41 | - |
| Joshua's | 01-01-LC-20 Fall | 105 | 16 | f | 400 | 931 | 1.45 | **** | **** | **** | 46 | - |
| Joshua's | 01-01-LC-21 Fall | 105 | 12 | f | 385 | 957 | 1.68 | 104 | 13 | 11 | 42 | - |
| Joshua's | 01-01-LC-22 Fall | 105 | 8 | m | 328 | 324 | 0.92 | 97 | 14 | 13 | 46 | - |
| Joshua's | 01-01-LC-23 Fall | 105 | 9 | f | 283 | 224 | 0.99 | 96 | 13 | 13 | 40 | - |
| Joshua's | 01-01-LC-24 Fall | 105 | 9 | m | 257 | 198 | 1.17 | 93 | 13 | 12 | 42 | - |
| Joshua's | 01-01-LC-30 Fall | 105 | 5 | m | 164 | 42 | 0.95 | 97 | 15 | 12 | 39 | - |
| Joshua's | 01-01-LC-32 Fall | 105 | 8 | m | 202 | 78 | 0.95 | 91 | 13 | 12 | 44 | - |
| Joshua's | 01-01-LC-33 Fall | 105 | 5 | m | 158 | 37 | 0.94 | 88 | 13 | 12 | ^^ | - |
| Joshua's | 01-01-LC-35 Fall | 105 | 8 | f | 220 | 130 | 1.22 | 108 | 14 | 12 | 42 | - |
| Joshua's | 01-01-LC-43 Fall | 105 | 4 | m | 140 | 22 | 0.80 | 84 | 13 | 11 | ^^ | - |
| Joshua's | 01-01-LC-44 Fall | 106 | 8 | m | 194 | 68 | 0.93 | 83 | 13 | 12 | 43 | - |
| Joshua's | 01-01-LC-46 Fall | 106 | 10 | f | 289 | 319 | 1.32 | 94 | 12 | 11 | 41 | - |
| Joshua's | 01-01-LC-47 Fall | 106 | 11 | f | 305 | 352 | 1.24 | 104 | 13 | 11 | ^^ | - |
| Joshua's | 01-01-LC-49 Fall | 106 | 5 | f | 185 | 53 | 0.84 | 88 | 13 | 10 | ^^ | - |
| Joshua's | 01-01-LC-50 Fall | 106 | 8 | f | 205 | 79 | 0.92 | 94 | 13 | 12 | ^^ | - |
| Joshua's | 01-01-LC-55 Fall | 106 | 8 | f | 186 | 70 | 1.09 | 91 | 13 | 11 | 42 | - |
| Joshua's | 01-01-LC-57 Fall | 106 | 6 | m | 162 | 41 | 0.96 | 92 | 14 | 11 | 43 | - |
| Joshua's | 01-01-LC-59 Fall | 106 | 5 | imm | 162 | 44 | 1.03 | 103 | 14 | 12 | 43 | - |
| Joshua's | 01-01-LC-60 Fall | 106 | 4 | f | 143 | 30 | 1.03 | 97 | 13 | 12 | 42 | - |
| Joshua's | 01-01-LC-61 Fall | 106 | 5 | f | 162 | 42 | 0.99 | 90 | 14 | 12 | 42 | - |
| Joshua's | 01-01-LC-62 Fall | 107 | 7 | m | 186 | 64 | 0.99 | 100 | 14 | 12 | 41 | - |
| Joshua's 2nd | 01-13-LC-01 Fall | 108 | 8 | f | 240 | 126 | 0.91 | 87 | 14 | 12 | 45 | - |
| Joshua's 2nd | 01-13-LC-02 Fall | 108 | 5 | m | 236 | 126 | 0.96 | 101 | 14 | 12 | 44 | - |
| Joshua's 2nd | 01-13-LC-03 Fall | 108 | 9 | m | 233 | 126 | 1.00 | 100 | 15 | 12 | 44 | - |
| Joshua's 2nd | 01-13-LC-05 Fall | 108 | 6 | m | 215 | 92 | 0.93 | 99 | 14 | 12 | ^^ | - |
| Joshua's 2nd | 01-13-LC-06 Fall | 108 | 8 | m | 230 | 129 | 1.06 | 95 | 14 | 12 | 41 | - |
| Joshua's 2nd | 01-13-LC-07 Fall | 108 | 8 | m | 245 | 136 | 0.92 | 91 | 13 | 12 | 41 | - |
| Joshua's 2nd | 01-13-LC-08 Fall | 108 | 6 | f | 259 | 127 | 0.73 | 88 | 14 | 12 | 43 | - |
| Joshua's 2nd | 01-13-LC-09 Fall | 108 | 8 | f | 302 | 263 | 0.95 | 103 | 14 | 11 | 42 | - |
| Joshua's 2nd | 01-13-LC-10 Fall | 108 | 8 | m | 240 | 143 | 1.03 | 101 | 14 | 12 | 41 | - |
| Joshua's 2nd | 01-13-LC-11 Fall | 108 | 8 | f | 281 | 236 | 1.06 | 97 | 14 | 12 | 42 | - |
| Joshua's 2nd | 01-13-LC-13 Fall | 109 | 8 | f | 302 | 296 | 1.07 | 102 | 13 | 12 | 46 | - |
| Joshua's 2nd | 01-13-LC-15 Fall | 109 | 6 | m | 208 | 93 | 1.03 | 87 | 15 | 13 | 43 | - |
| Joshua's 2nd | 01-13-LC-16 Fall | 109 | 5 | f | 216 | 96 | 0.95 | 97 | 14 | 11 | 42 | - |
| Joshua's 2nd | 01-13-LC-17 Fall | 109 | 4 | m | 152 | 32 | 0.91 | **** | 14 | 12 | ^^ | - |
| Joshua's 2nd | 01-13-LC-19 Fall | 109 | 4 | f | 132 | 21 | 0.91 | 89 | 14 | 12 | ^^ | - |
| Joshua's 2nd | 01-13-LC-21 Fall | 109 | 8 | f | 235 | 130 | 1.00 | 97 | 14 | 12 | ^^ | + |
| Joshua's 2nd | 01-13-LC-22 Fall | 109 | 8 | f | 229 | 120 | 1.00 | 95 | 14 | 11 | 40 | - |
| Joshua's 2nd | 01-13-LC-23 Fall | 109 | 8 | m | 226 | 117 | 1.01 | 95 | 14 | 13 | 41 | - |
| Joshua's 2nd | 01-13-LC-24 Fall | 109 | 6 | m | 215 | 102 | 1.03 | 93 | 13 | 11 | 44 | - |
| Joshua's 2nd | 01-13-LC-25 Fall | 109 | 8 | f | 229 | 102 | 0.85 | 95 | 13 | 11 | 42 | - |
| Joshua's 2nd | 01-13-LC-27 Fall | 110 | 8 | imm | 221 | 92 | 0.85 | 93 | 14 | 13 | 40 | - |
| Joshua's 2nd | 01-13-LC-30 Fall | 110 | 8 | f | 229 | 100 | 0.83 | 96 | 13 | 12 | 43 | - |
| Joshua's 2nd | 01-13-LC-31 Fall | 110 | 7 | f | 217 | 96 | 0.94 | 95 | 13 | 11 | 42 | - |
| Joshua's 2nd | 01-13-LC-33 Fall | 110 | 6 | m | 227 | 112 | 0.96 | 92 | 13 | 11 | 40 | + |
| Joshua's 2nd | 01-13-LC-37 Fall | 110 | 4 | imm | 192 | 64 | 0.90 | 96 | 13 | 12 | 43 | - |
| Joshua's 2nd | 01-13-LC-39 Fall | 110 | 8 | f | 222 | 109 | 1.00 | 1071 | 5 | 13 | 41 | - |

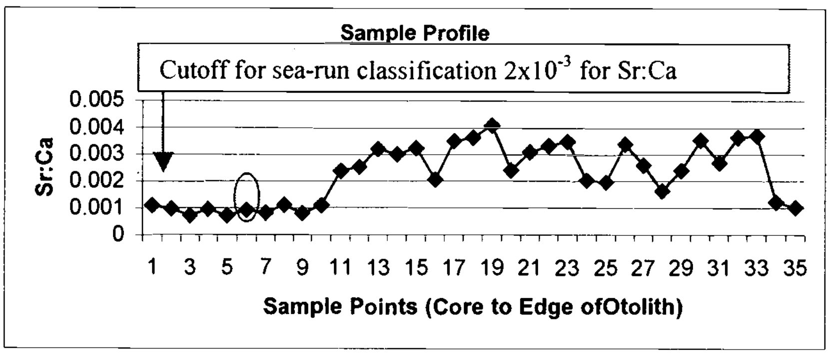
| Site | Fish ID | Appendix C Profile Page # | Age | Sex | F.L. (mm) | Weight (g) | Condition Factor | L.L. | AR | DR | GR | Sea Run? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Joshua's 2nd | 01-13-LC-41 Fall | 110 | 8 | m | 272 | 198 | 0.98 | 92 | 14 | 13 | 42 | - |
| Joshua's 2nd | 01-13-LC-42 Fall | 110 | 9 | f | 300 | 272 | 1.01 | 91 | 13 | 12 | 40 | - |
| Joshua's 2nd | 01-13-LC-47 Fall | 110 | 8 | m | 230 | 124 | 1.02 | 94 | 13 | 12 | 41 | - |
| Joshua's 2nd | 01-13-LC-50 Fall | 110 | 8 | m | 293 | 232 | 0.92 | 97 | 13 | 12 | 42 | - |
| Luther's | 00-03-LC-03 | 111 | 7 | f | 264 | 200 | 1.09 | **** | **** | **** | **** | - |
| Luther's | 00-03-LC-06 | 111 | 8 | m | 313 | 309 | 1.01 | **** | **** | **** | **** | - |
| Luther's | 00-03-LC-07 | 111 | 19 | f | 380 | 562 | 1.02 | **** | **** | **** | **** | - |
| Luther's | 01-03-LC-01 | 111 | 11 | f | 300 | 274 | 1.01 | **** | 13 | 12 | 45 | - |
| Luther's | 01-03-LC-02 | 111 | 6 | f | 255 | 171 | 1.03 | **** | **** | **** | 33* | - |
| Luther's | 01-03-LC-03 | 111 | 9 | f | 325 | 372 | 1.08 | 97 | 13 | 12 | 40 | - |
| Luther's | 01-03-LC-04 | 111 | 8 | f | 305 | 286 | 1.01 | **** | 13 | 12 | 44 | - |
| Luther's | 01-03-LC-05 | 111 | 7 | m | 235 | 128 | 0.99 | 94 | 13 | 11 | 40 | - |
| Luther's | 01-03-LC-06 | 111 | 10 | f | 321 | 295 | 0.89 | 95 | 13 | 11 | 41 | - |
| Luther's | 01-03-LC-07 | 111 | 9 | m | 298 | 273 | 1.03 | 89 | 15 | 13 | 43 | - |
| Luther's | 01-03-LC-08 | 112 | 7 | f | 290 | 199 | 0.82 | 95 | 13 | 12 | 37 | - |
| Luther's | 01-03-LC-09 | 112 | 5 | m | 290 | 271 | 1.11 | 97 | 13 | 13 | 41 | - |
| Luther's | 01-03-LC-10 | 112 | 7 | f | 283 | 230 | 1.01 | 93 | 14 | 13 | 42 | - |
| Luther's | 01-03-LC-11 | 112 | 8 | m | 306 | 259 | 0.90 | 95 | 14 | 13 | 42 | - |
| Luther's | 01-03-LC-12 | 112 | 7 | m | 309 | 319 | 1.08 | 99 | 14 | 12 | 42 | - |
| Luther's | 01-03-LC-13 | 112 | 5 | f | 248 | 169 | 1.11 | 89 | 14 | 13 | 43 | - |
| Luther's | 01-03-LC-14 | 112 | 5 | m | 280 | 210 | 0.96 | 91 | 14 | 12 | 42 | - |
| Joeb's | 00-09-LC-01 | 113 | 6 | f | 215 | 118 | 1.19 | 85 | 13 | 12 | **** | + |
| Joeb's | 00-09-LC-02 | 113 | 7 | f | 243 | 161 | 1.12 | 94 | 12 | 12 | **** | + |
| Joeb's | 00-09-LC-03 | 113 | 7 | f | 251 | 175 | 1.11 | 90 | 13 | 12 | **** | - |
| Joeb's | 00-09-LC-05 | 113 | 8 | f | 271 | 235 | 1.18 | 77 | 12 | 11 | **** | - |
| Joeb's | 00-09-LC-07 | 113 | 5 | f | 225 | 137 | 1.20 | 96 | 12 | 11 | **** | + |
| Joeb's | 01-09-LC-01 | 113 | 7 | m | 281 | 309 | 1.39 | 90 | 15 | 14 | 42 | - |
| Joeb's | 01-09-LC-02 | 113 | 3 | m | 259 | 208 | 1.20 | 95 | 15 | 14 | 40 | - |
| Joeb's | 01-09-LC-03 | 113 | 6 | f | 224 | 139 | 1.24 | 83 | 15 | 14 | 42 | - |
| Joeb's | 01-09-LC-04 | 113 | 12 | f | 313 | 425 | 1.39 | 89 | 14 | 14 | 43 | - |
| Joeb's | 01-09-LC-05 | 113 | 12 | m | 308 | 382 | 1.31 | 92 | 15 | 14 | 43 | + |
| Joeb's | 01-09-LC-06 | 114 | 7 | f | 250 | 200 | 1.28 | 87 | 14 | 13 | 43 | - |
| Joeb's | 01-09-LC-03 Fall | 114 | 2 | imm | 120 | 13 | 0.75 | 84 | 14 | 13 | 41 | - |
| Joeb's | 01-09-LC-04 Fall | 114 | 2 | imm | 129 | 15 | 0.70 | 86 | 13 | 12 | ^^ | - |
| Joeb's | 01-09-LC-05 Fall | 114 | 2 | imm | 121 | 14 | 0.79 | 81 | 14 | 14 | ^^ | - |
| Joeb's | 01-09-LC-06 Fall | 114 | 2 | imm | 161 | 36 | 0.86 | 89 | ^^ | 13 | 40 | - |
| Joeb's | 01-09-LC-08 Fall | 114 | 2 | imm | 130 | 17 | 0.77 | 86 | 14 | 13 | 43 | - |
| Joeb's | 01-09-LC-09 Fall | 114 | 5 | imm | 249 | 148 | 0.96 | 105 | 13 | 12 | 46 | - |
| Joeb's | 01-09-LC-10 Fall | 114 | 6 | imm | 147 | 36 | 1.13 | 86 | 13 | 12 | ^^ | - |
| Joeb's | 01-09-LC-11 Fall | 114 | 7 | f | 274 | 236 | 1.15 | 86 | 13 | 12 | 42 | + |
| Joeb's | 01-09-LC-12 Fall | 114 | 2 | imm | 126 | 16 | 0.80 | 87 | 14 | 11 | 42 | - |
| Joeb's | 01-09-LC-16 Fall | 115 | 7 | m | 203 | 103 | 1.23 | 81 | 15 | 14 | 41 | + |
| Joeb's | 01-09-LC-17 Fall | 115 | 2 | imm | 231 | 24 | 0.19 | 91 | 13 | 11 | ^^ | - |
| Joeb's | 01-09-LC-18 Fall | 115 | 2 | imm | 142 | 38 | 1.33 | 93 | 11 | 12 | 40 | - |
| Joeb's | 01-09-LC-19 Fall | 115 | 2 | imm | 123 | 20 | 1.07 | 80 | 14 | 13 | ^^ | - |
| Joeb's | 01-09-LC-21 Fall | 115 | 2 | imm | 149 | 35 | 1.06 | 90 | 12 | 11 | 41 | - |
| Joeb's | 01-09-LC-22 Fall | 115 | 11 | imm | 134 | 25 | 1.04 | 87 | 14 | 13 | ^^ | - |
| Joeb's 2nd | 01-12-LC-02 | 116 | 8 | f | 276 | 195 | 0.93 | 95 | 14 | 13 | 47 | - |
| Joeb's 2nd | 01-12-LC-03 | 116 | 9 | m | 253 | 136 | 0.84 | 86 | 13 | 12 | 40 | - |
| Joeb's 2nd | 01-12-LC-04 | 116 | 6 | f | 228 | 123 | 1.04 | 94 | 14 | 13 | 41 | - |
| Joeb's 2nd | 01-12-LC-05 | 116 | 8 | f | 291 | 247 | 1.00 | 93 | 15 | 14 | 42 | - |
| Joeb's 2nd | 01-12-LC-06 | 116 | 12 | m | 328 | 366 | 1.04 | 95 | 15 | 18 | 41 | + |
| Joeb's 2nd | 01-12-LC-07 | 116 | 5 | m | 234 | 121 | 0.94 | 93 | 13 | 12 | 43 | - |
| Joeb's 2nd | 01-12-LC-08 | 116 | 6 | m | 230 | 124 | 1.02 | 93 | 13 | 12 | 38* | - |
| Joeb's 2nd | 01-12-LC-09 | 116 | 7 | f | 221 | 106 | 0.98 | 87 | 13 | 11 | **** | - |
| Joeb's 2nd | 01-12-LC-10 | 116 | 7 | m | 238 | 152 | 1.13 | 90 | 14 | 13 | 41 | - |
| Joeb's 2nd | 01-12-LC-12 | 116 | 6 | f | 230 | 123 | 1.01 | 88 | 13 | 12 | 41 | - |
| Joeb's 2nd | 01-12-LC-13 | 117 | 9 | m | 254 | 146 | 0.89 | 92 | 15 | 13 | 43 | - |
| Joeb's 2nd | 01-12-LC-14 | 117 | 4 | f | 248 | 140 | 0.92 | 86 | 14 | 13 | 38 | - |

| Site | Fish ID | Appendix C Profile Page # | Age | Sex | F.L. (mm) | Weight (g) | Condition Factor | L.L. | AR | DR | GR | Sea Run? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Joeb's 2nd | 01-12-LC-15 | 117 | 7 | f | 238 | 129 | 0.96 | 99 | 14 | 13 | 41 | - |
| Joeb's 2nd | 01-12-LC-16 | 117 | 6 | f | 248 | 146 | 0.96 | 96 | 13 | 12 | ^^ | - |
| Joeb's 2nd | 01-12-LC-17 | 117 | 6 | m | 247 | 134 | 0.89 | 94 | 14 | 13 | 43 | - |
| Joeb's 2nd | 01-12-LC-18 | 117 | 5 | f | 225 | 112 | 0.98 | **** | **** | **** | **** | - |
| Elson Lagoon | 00-11-LC-01 | 118 | 7 | m | 278 | 252 | 1.17 | 82 | 14 | 13 | 40 | + |
| Elson Lagoon | 00-11-LC-02 | 118 | 11 | f | 304 | 313 | 1.11 | 80 | 15 | 12 | 46 | + |
| Elson Lagoon | 00-11-LC-03 | 118 | 11 | f | 307 | 362 | 1.25 | 77 | 13 | 12 | 39 | + |
| Elson Lagoon | 00-11-LC-04 | 118 | 11 | f | 318 | 336 | 1.04 | 90 | 14 | 12 | 45 | + |
| Elson Lagoon | 00-11-LC-05 | 118 | 10 | f | 310 | 384 | 1.29 | 81 | 13 | 12 | 39 | + |
| Elson Lagoon | 01-11-LC-01 | 118 | 13 | f | 284 | 352 | 1.54 | 97 | 13 | 12 | 46 | + |
| Elson Lagoon | 01-11-LC-02 | 118 | 12 | f | 332 | 491 | 1.34 | 86 | 14 | 12 | 43 | + |
| Elson Lagoon | 01-11-LC-03 | 118 | 12 | f | 316 | 358 | 1.13 | 88 | 15 | 14 | ^^ | + |
| Elson Lagoon | 01-11-LC-04 | 118 | 15 | m | 297 | 291 | 1.11 | 93 | 14 | 12 | ^^ | + |
| Teshekpuk | 001 - 007 | 119 | 8 | 1 | 251 | 117.1 | 0.74 | **** | **** | **** | **** | - |
| Teshekpuk | 001 - 014 | 119 | 15 | 2 | 190 | 42.4 | 0.62 | **** | **** | **** | **** | - |
| Teshekpuk | 001 - 016 | 119 | 11 | 3 | 157 | 29.2 | 0.75 | **** | **** | **** | **** | - |
| Teshekpuk | 002 - 002 | 119 | 3 | 3 | 133 | 14.5 | 0.62 | **** | **** | **** | **** | + |
| Teshekpuk | 002 - 005 | 119 | 7 | 2 | 223 | 86 | 0.78 | **** | **** | **** | **** | - |
| Teshekpuk | 002 - 006 | 119 | 12 | 2 | 170 | 24.8 | 0.50 | **** | **** | **** | **** | - |
| Teshekpuk | 002 - 012 | 119 | 16 | 1 | 181 | 29.7 | 0.50 | **** | **** | **** | **** | - |
| Teshekpuk | 002 - 015 | 119 | 13 | 2 | 367 | 499.3 | 1.01 | **** | **** | **** | **** | + |
| Teshekpuk | t791- 001 | 119 | 3 | **** | **** | **** | **** | **** | **** | **** | **** | - |

# Appendix C.

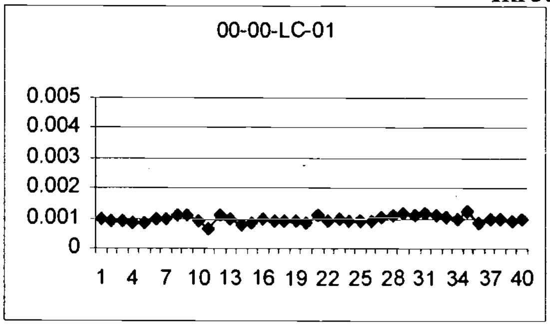
Profiles of Sr:Ca in otoliths of all least cisco by site

(pp. 92-119)




 = data point that was replaced with the average of baseline freshwater phase Sr:Ca. The previous value was zero due to a mis-read in Ca for that point by the electron microprobe.

# Ikroagvik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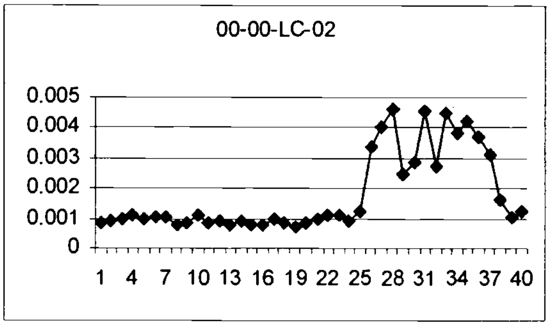
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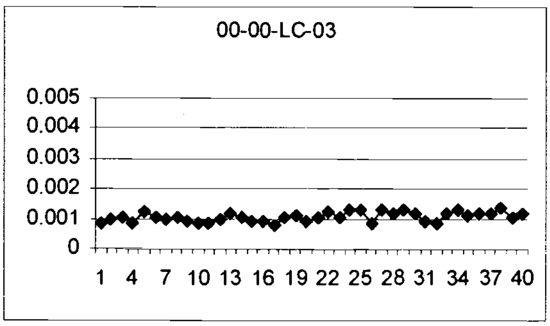
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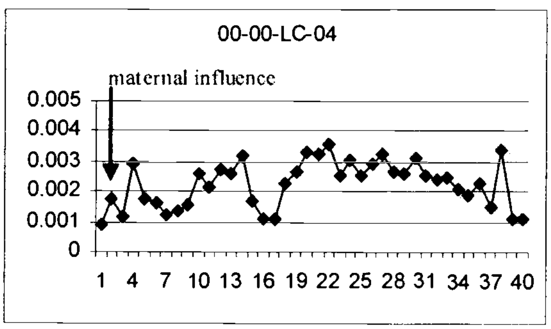
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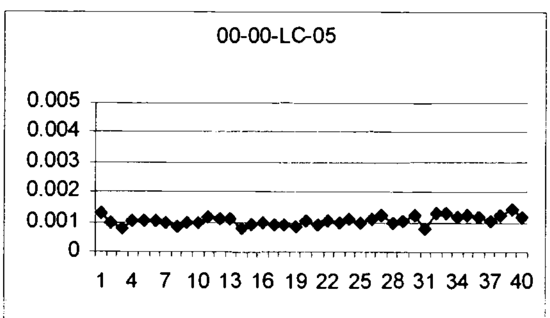
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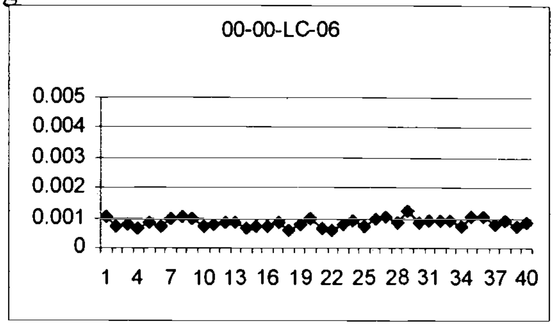
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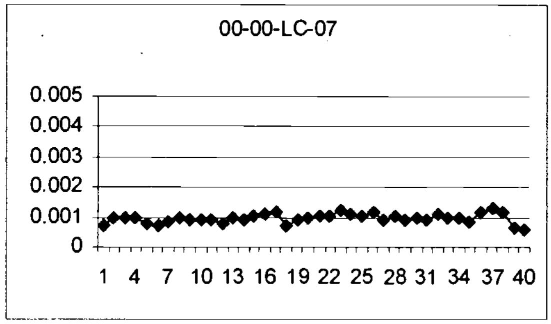
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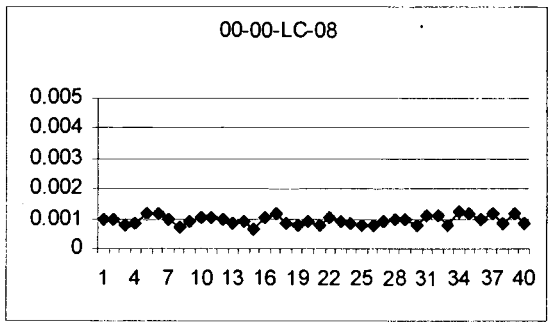
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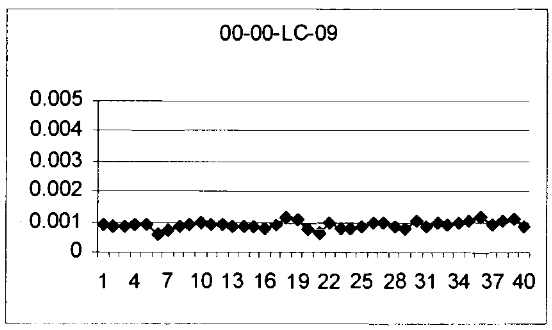
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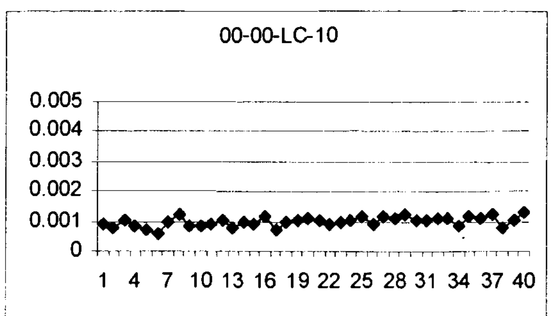
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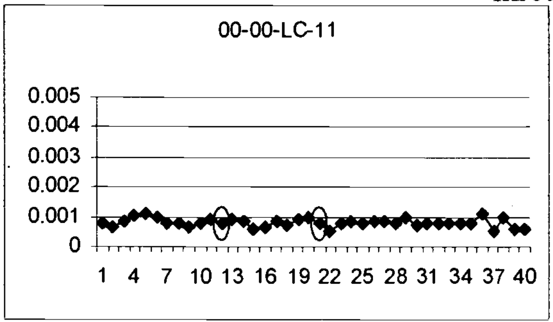
## Ikroagvik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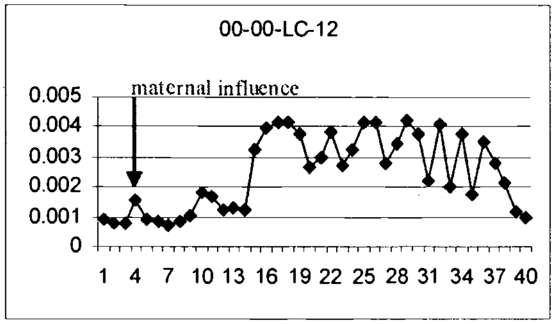
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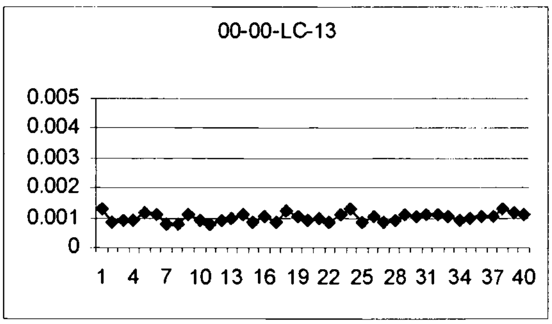
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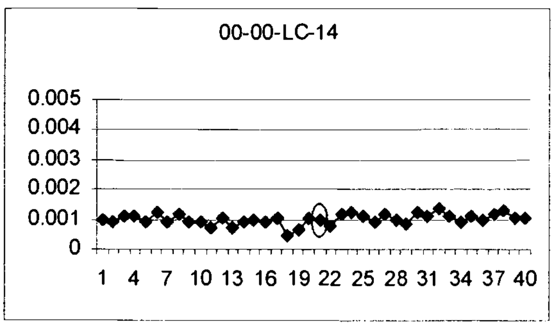
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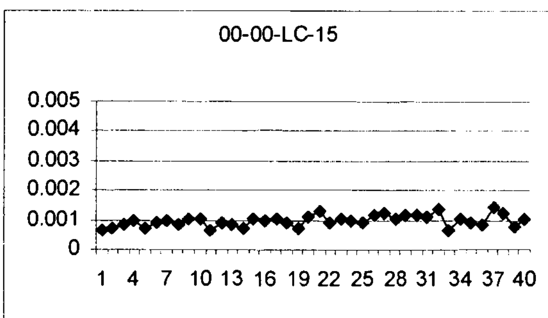
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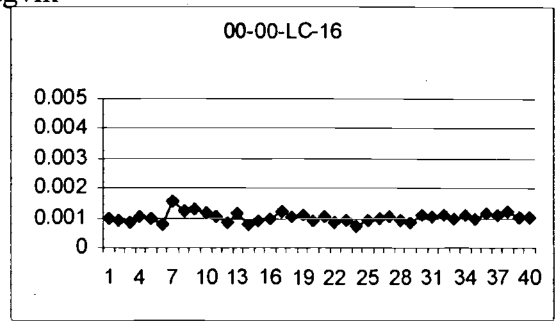
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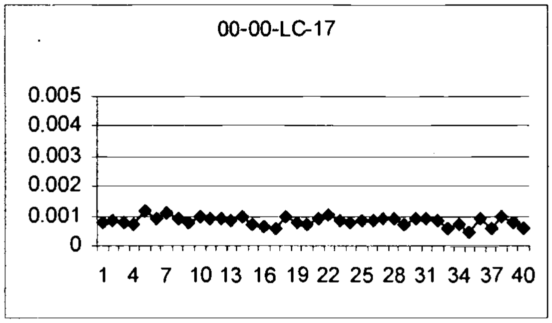
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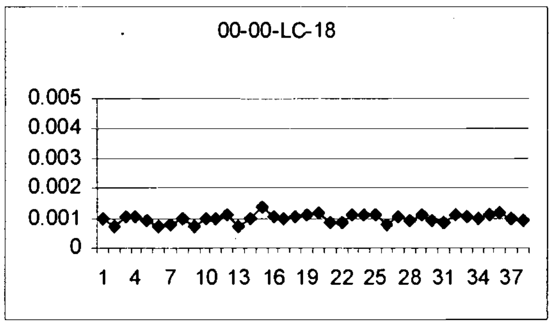
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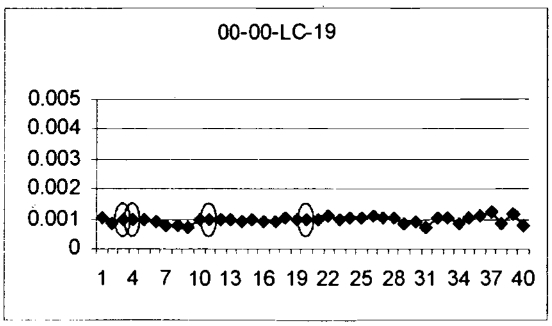
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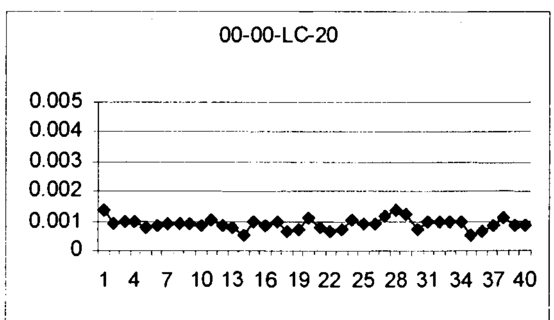
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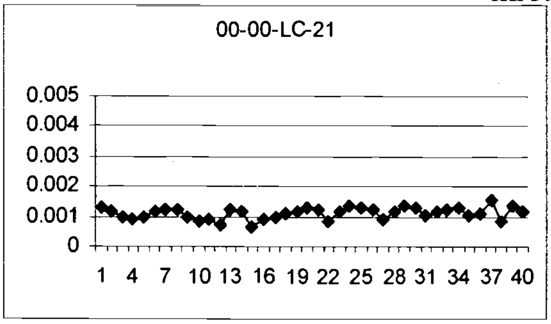
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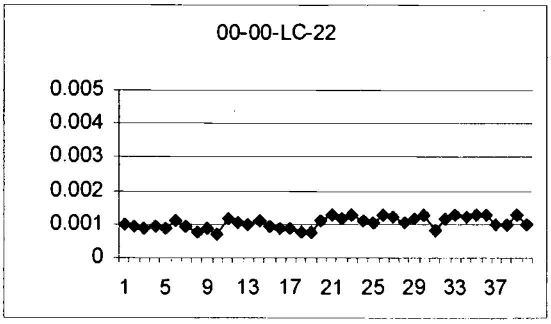
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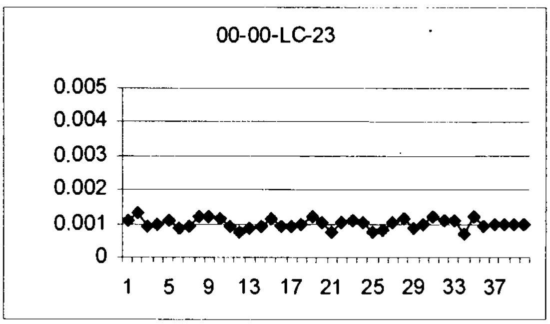
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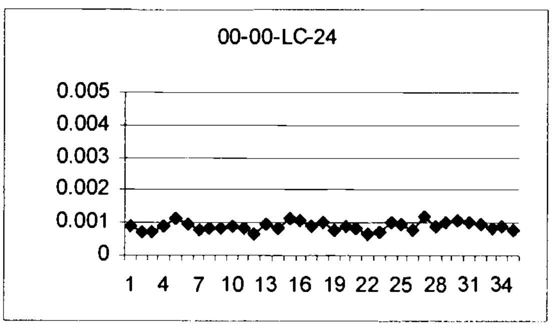
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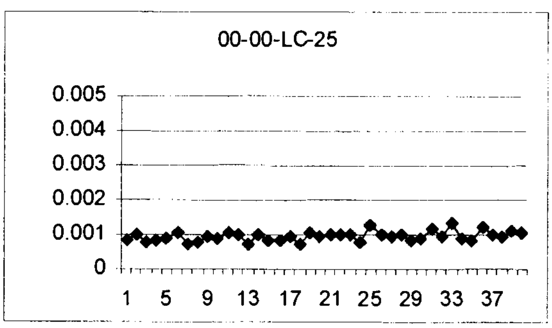
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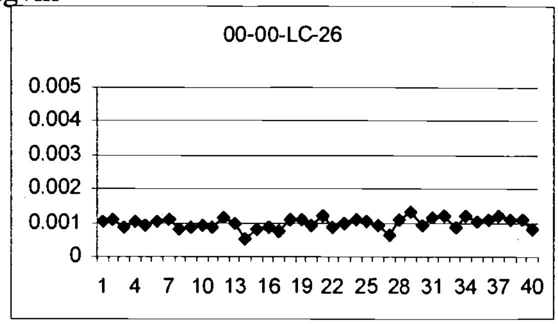
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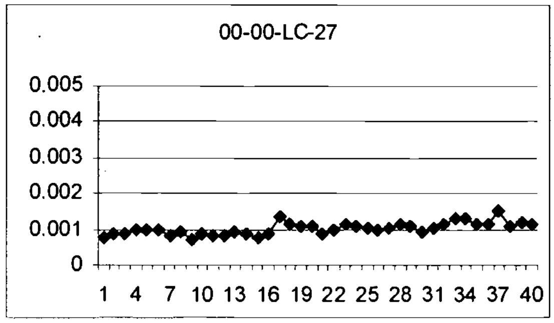
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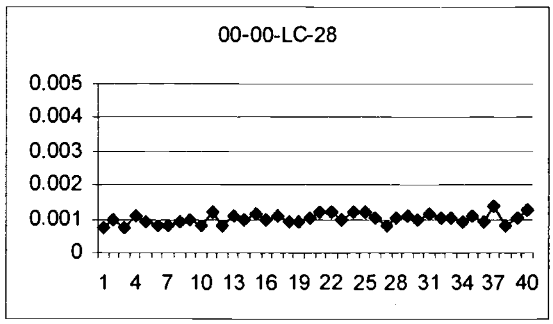
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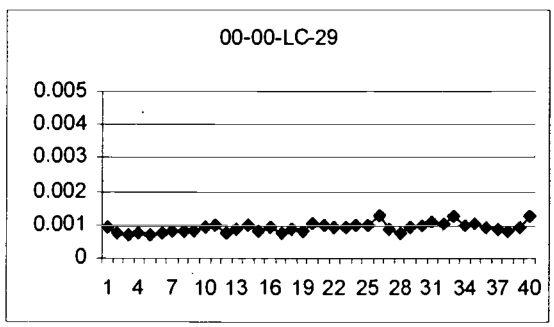
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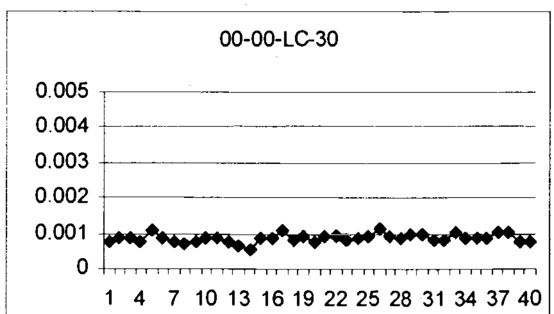
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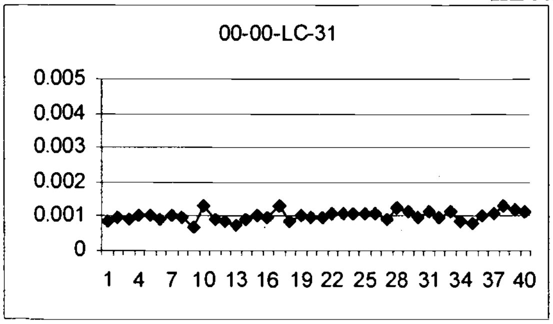
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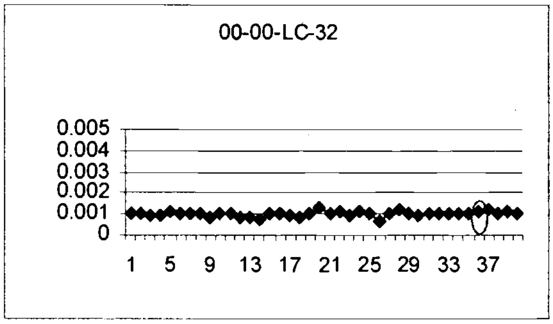
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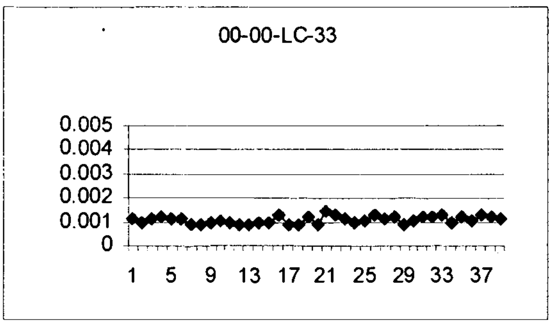
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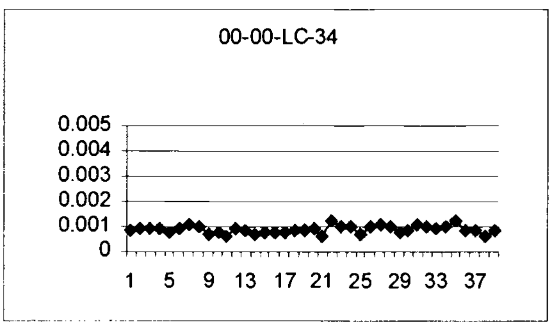
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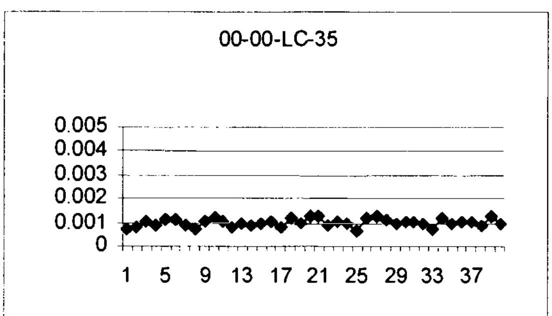
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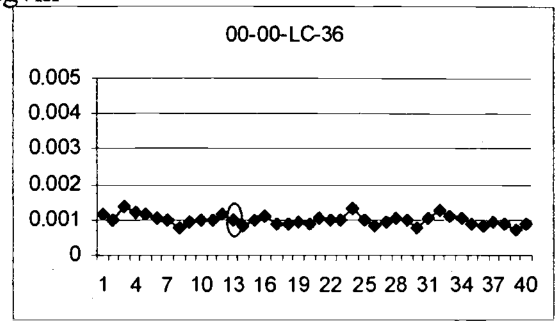
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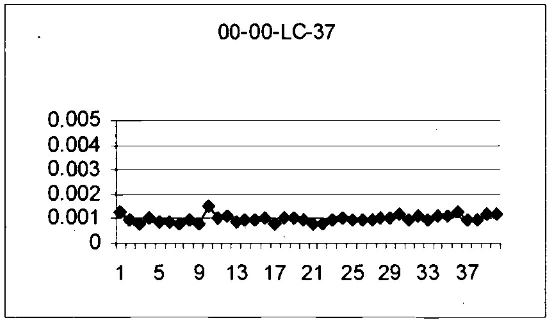
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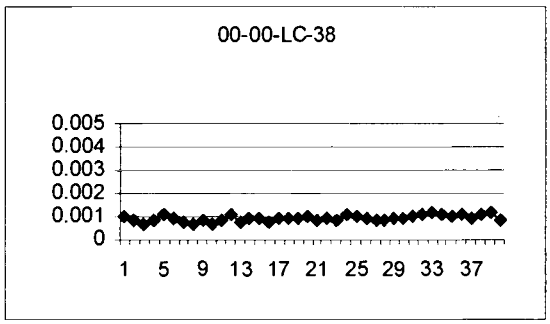
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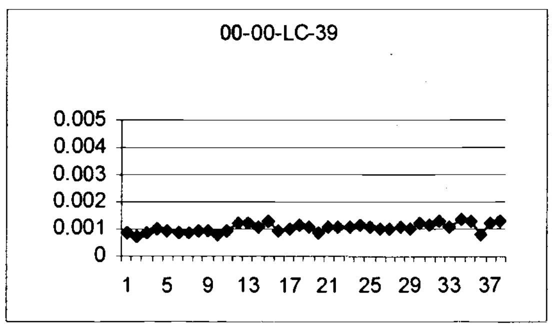
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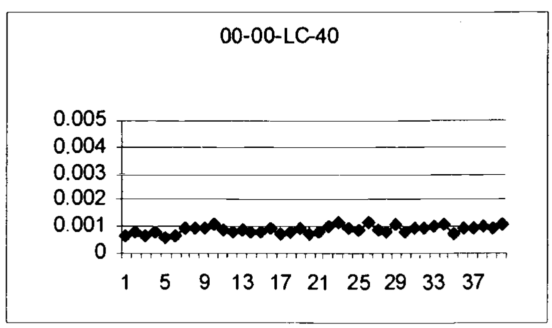
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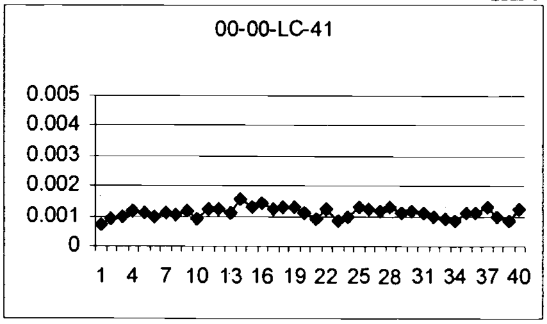
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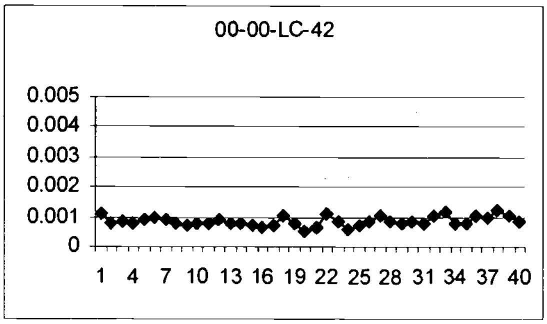
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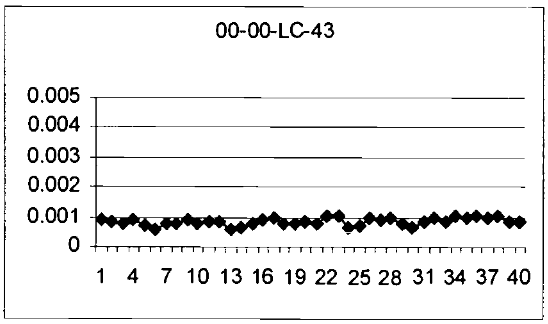
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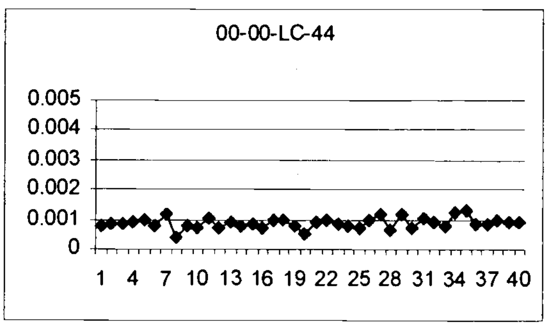
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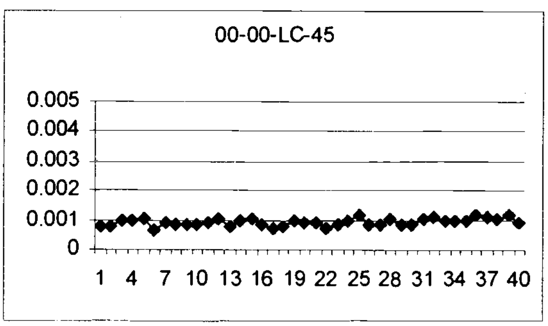
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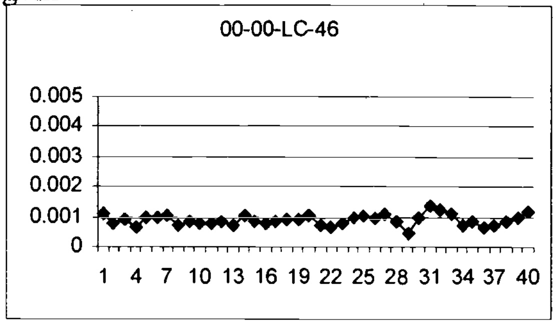
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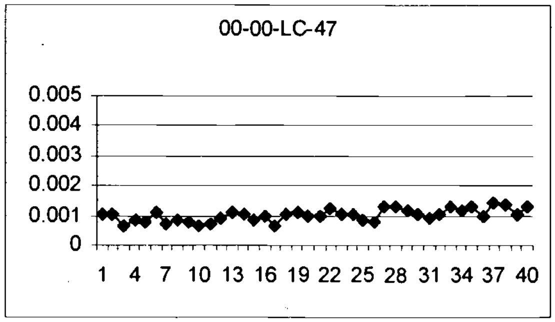
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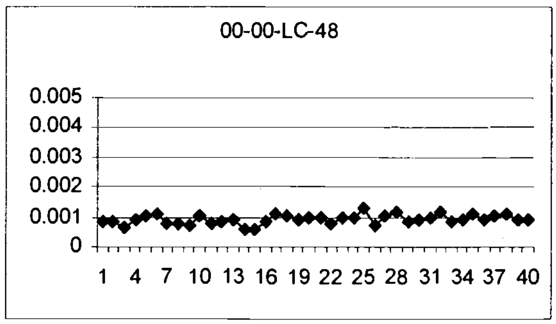
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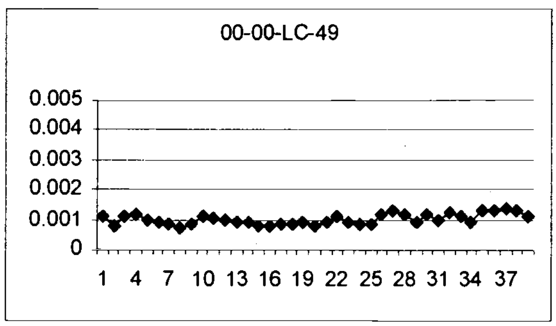
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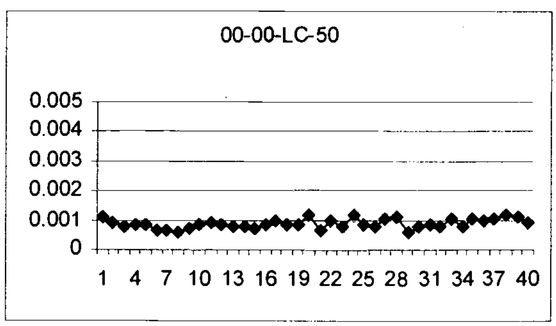
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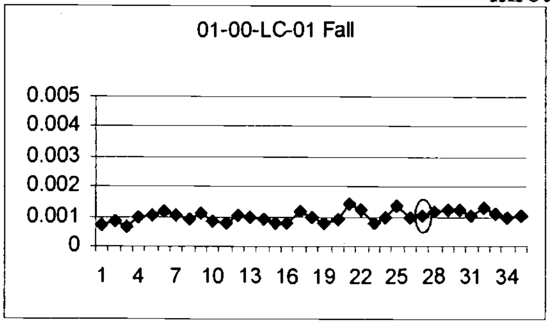
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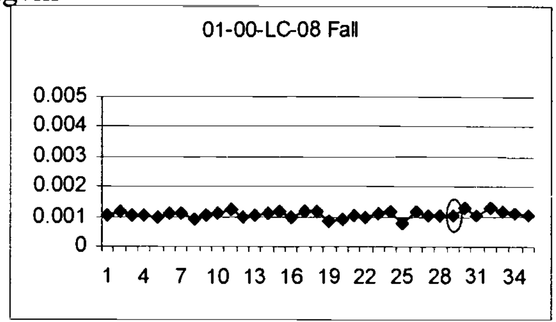
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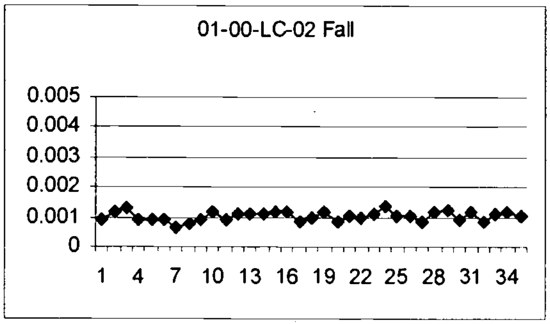
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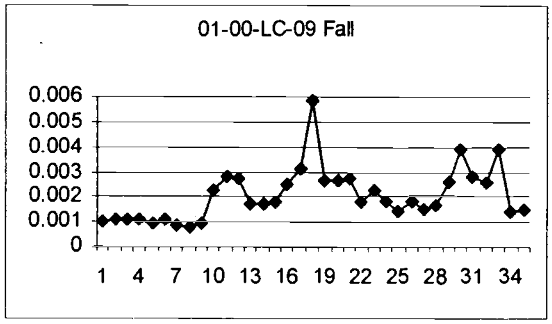
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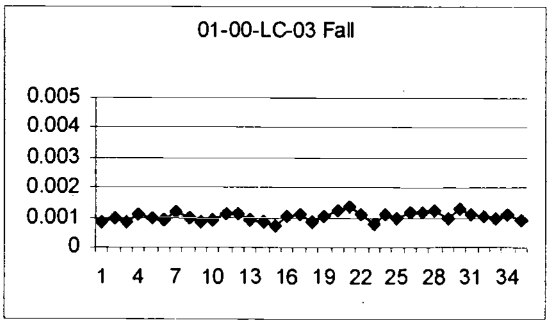
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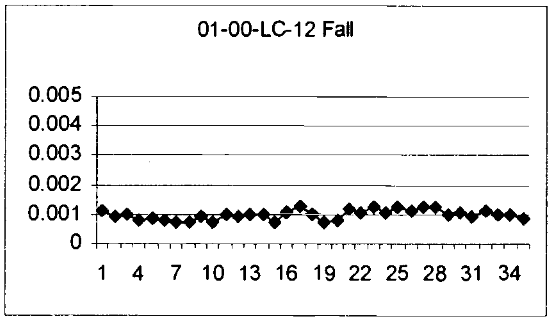
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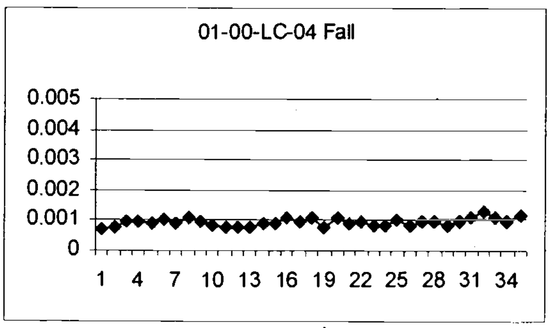
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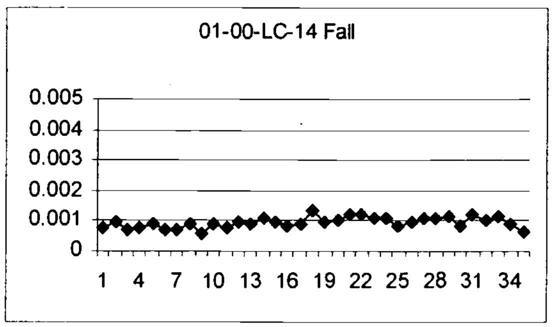
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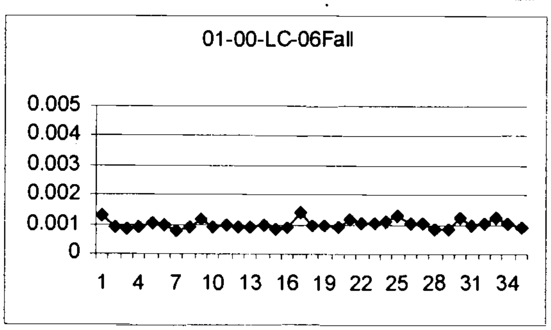
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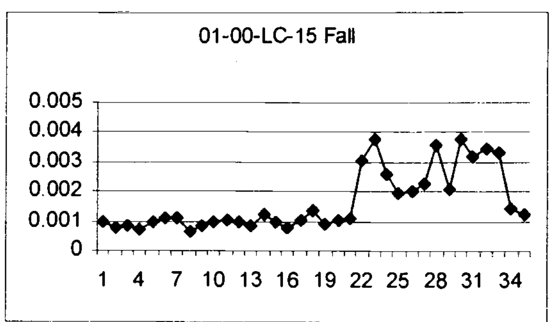
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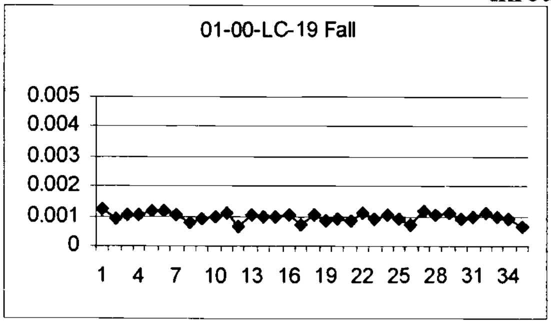
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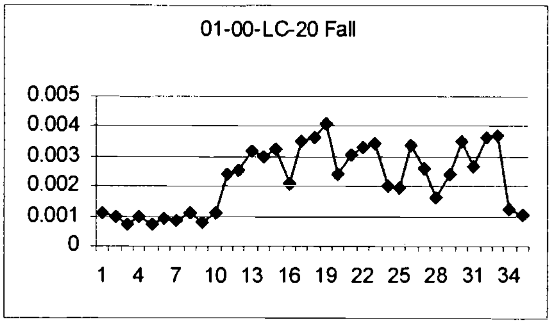
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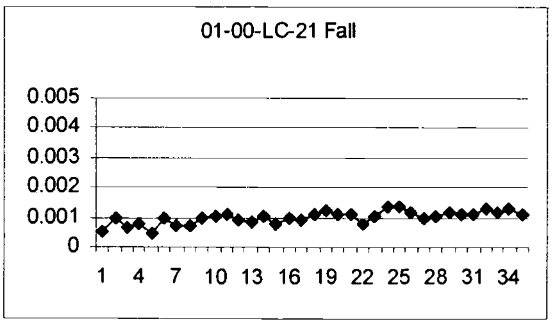
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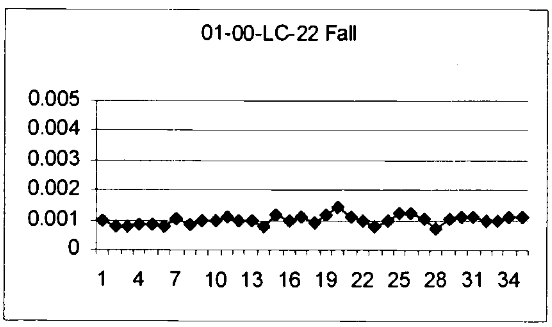
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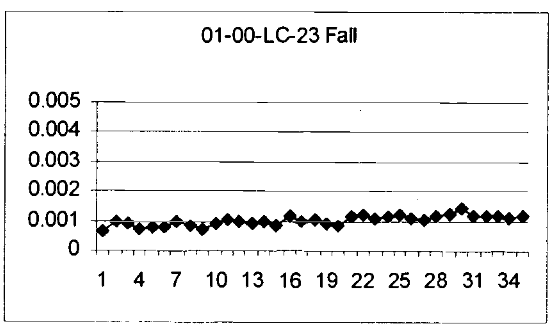
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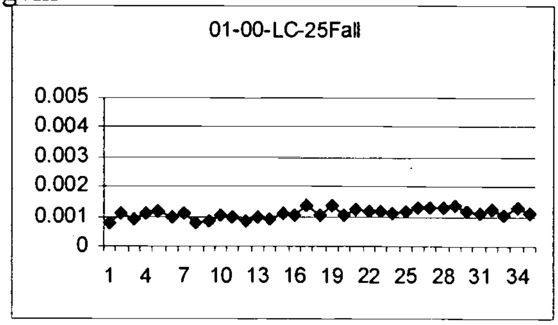
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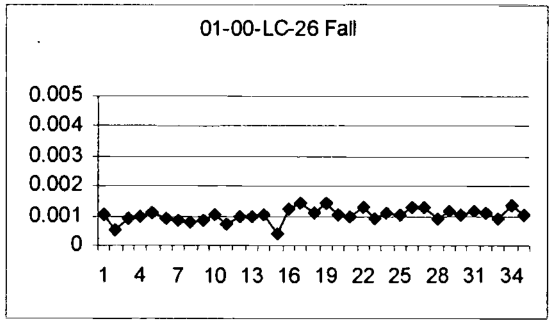
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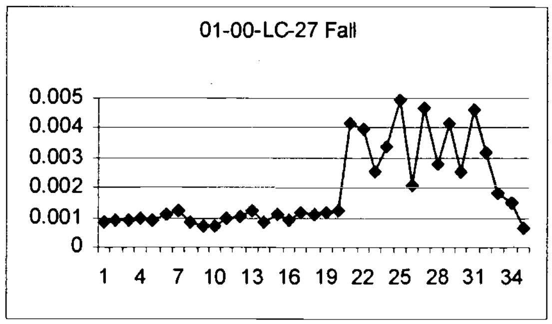
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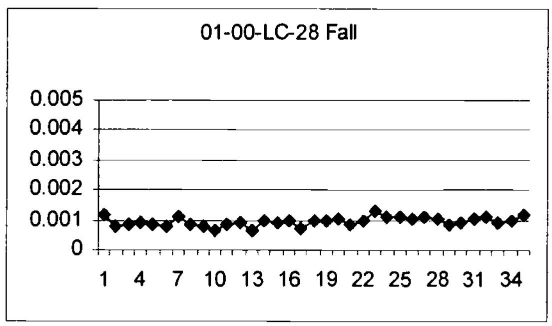
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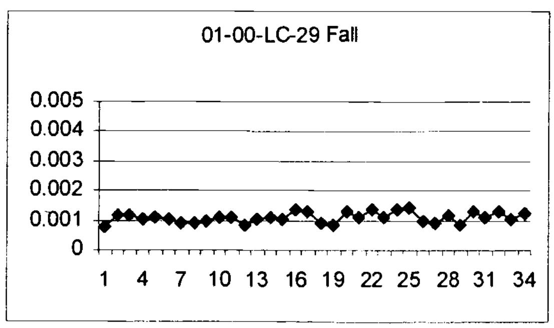
01-00-LC-29 Fall
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0.003
0.002
0.001
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1 4 7 10 13 16 19 22 25 28 31 34

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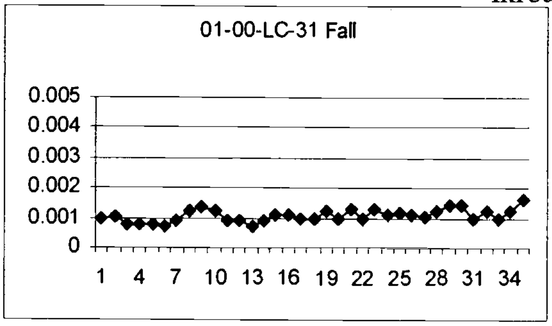
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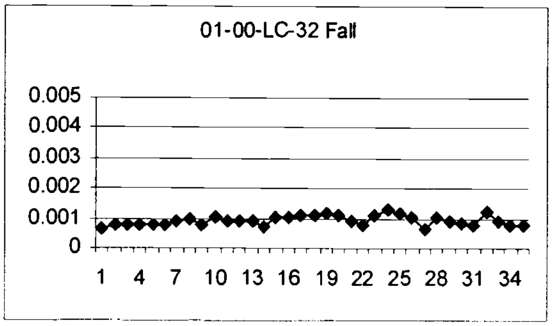
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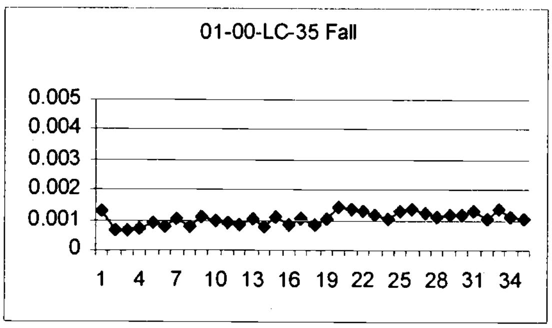
01-00-LC-35 Fall
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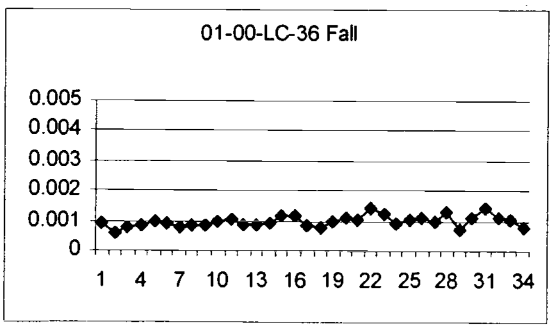
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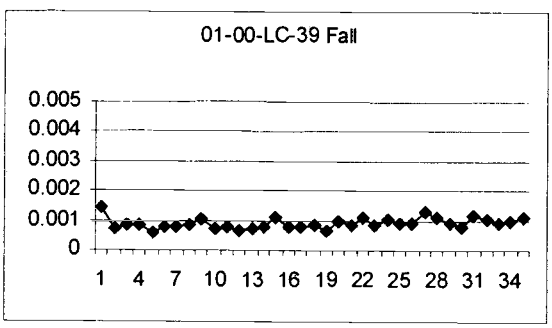
01-00-LC-39 Fall
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0.002
0.001
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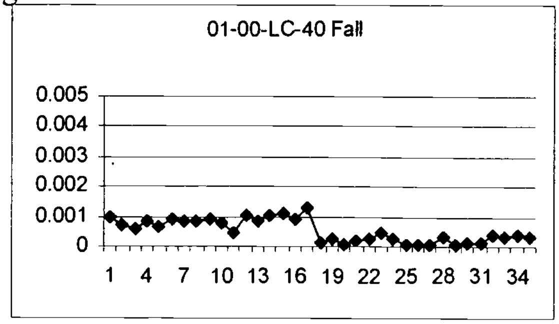
01-00-LC-40 Fall
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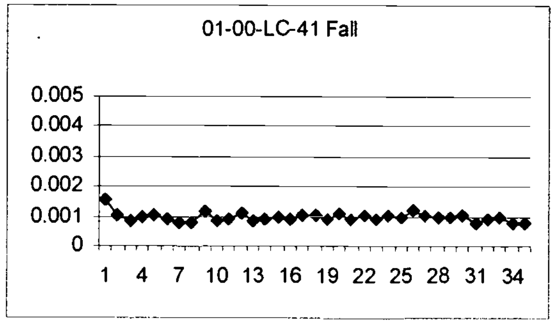
01-00-LC-41 Fall
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0.002
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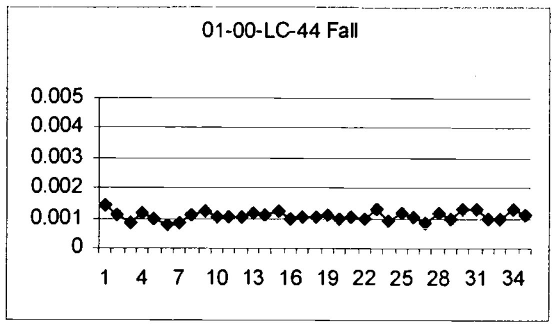
01-00-LC-44 Fall
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0.004
0.003
0.002
0.001
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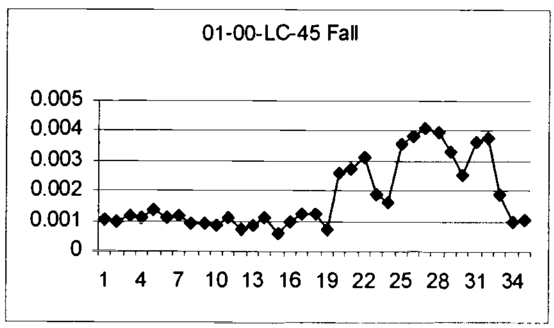
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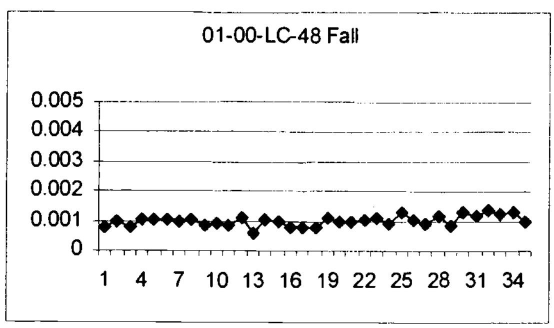
01-00-LC-48 Fall
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0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

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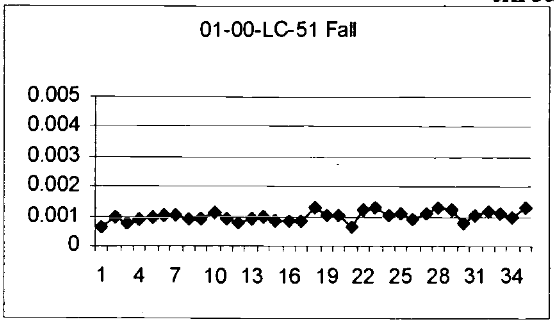
01-00-LC-51 Fall
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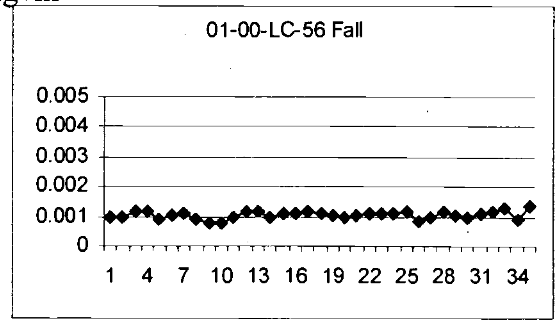
01-00-LC-56 Fall
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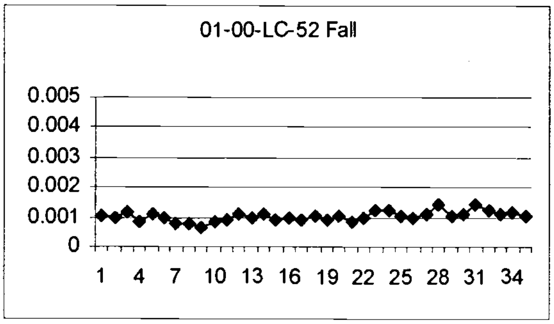
01-00-LC-52 Fall
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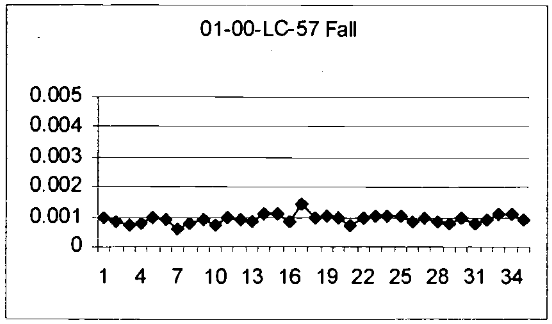
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-00-LC-57 Fall
0.005
0.004
0.003
0.002
0.001
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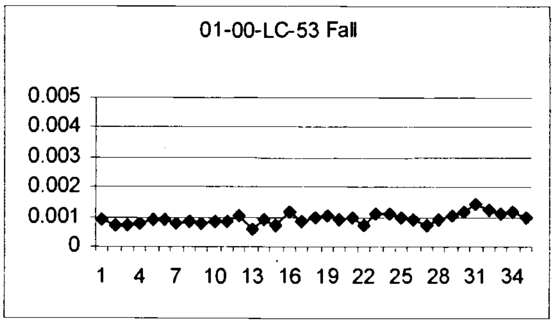
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0.003
0.002
0.001
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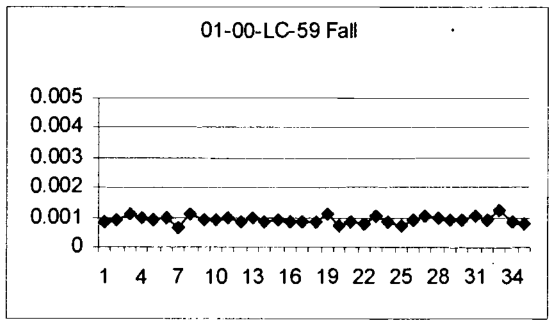
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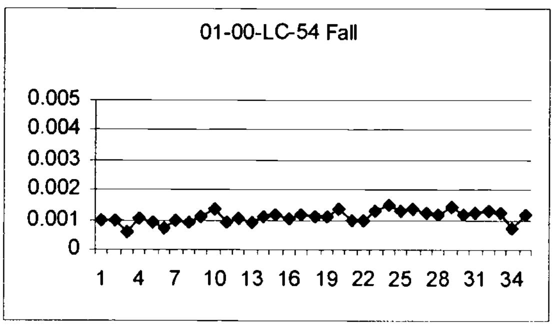
01-00-LC-54 Fall
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0.003
0.002
0.001
0
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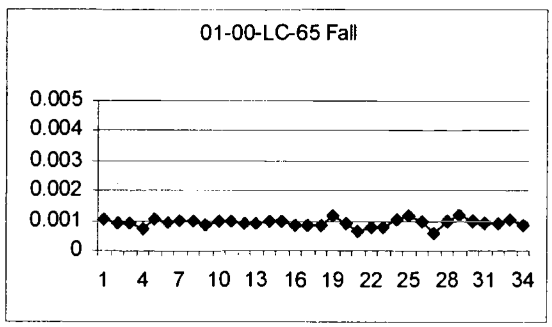
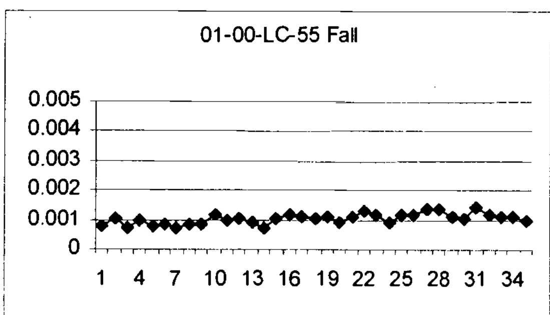

01-00-LC-65 Fall
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-00-LC-55 Fall
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0.004
0.003
0.002
0.001
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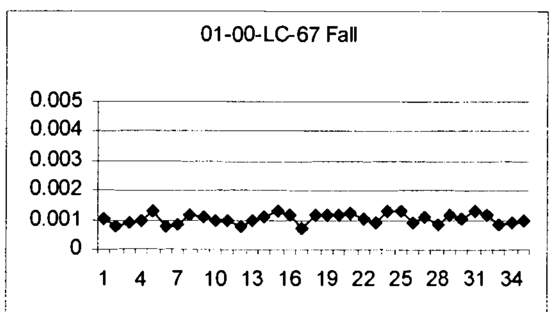
01-00-LC-67 Fall
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

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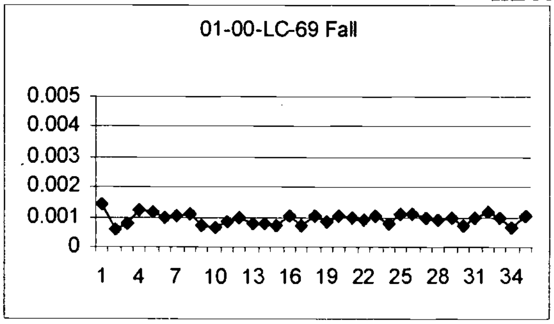
01-00-LC-69 Fall
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0.004
0.003
0.002
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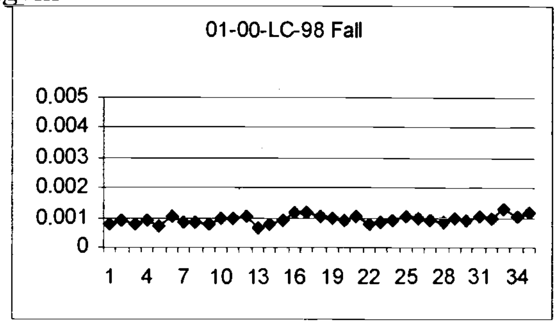
01-00-LC-98 Fall
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0.002
0.001
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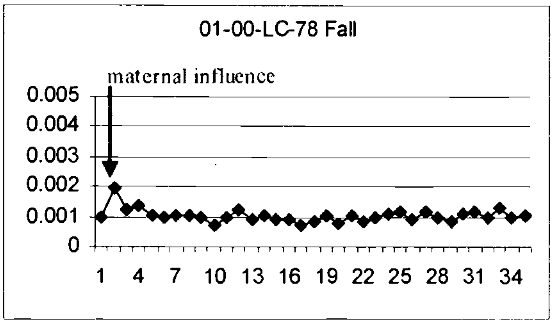
01-00-LC-78 Fall
maternal influence
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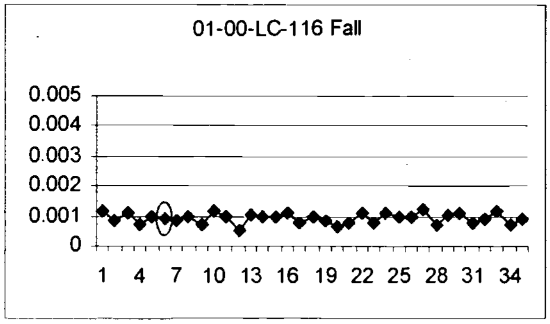
01-00-LC-116 Fall
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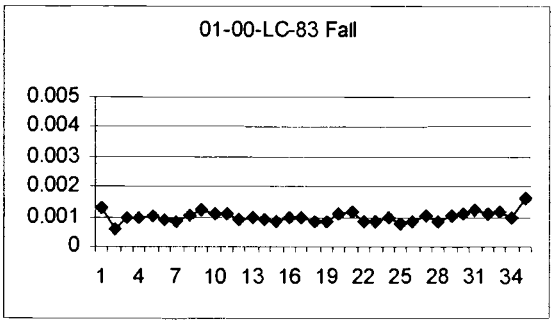
01-00-LC-83 Fall
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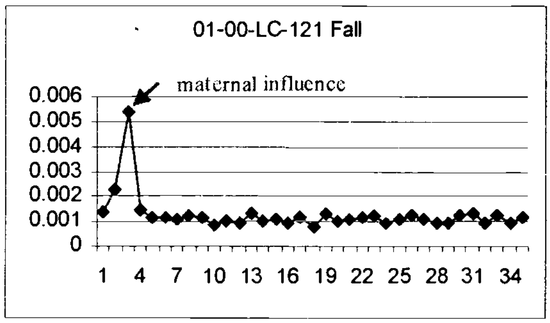
01-00-LC-121 Fall
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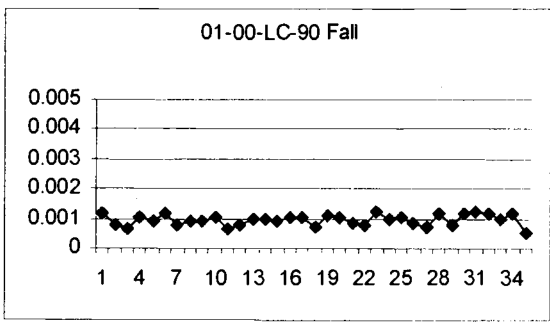
01-00-LC-90 Fall
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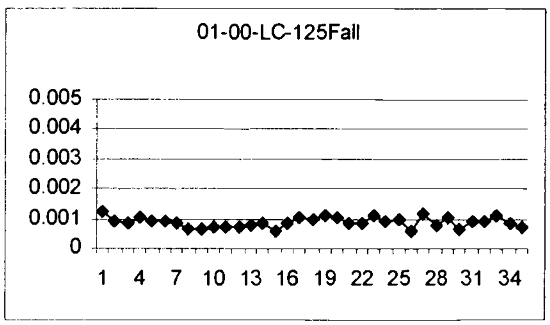
01-00-LC-125Fall
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0.003
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0.001
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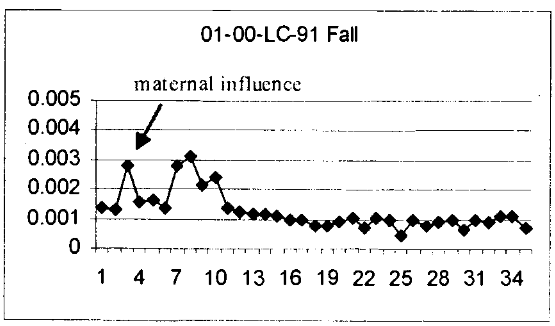
01-00-LC-91 Fall
maternal influence
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0.003
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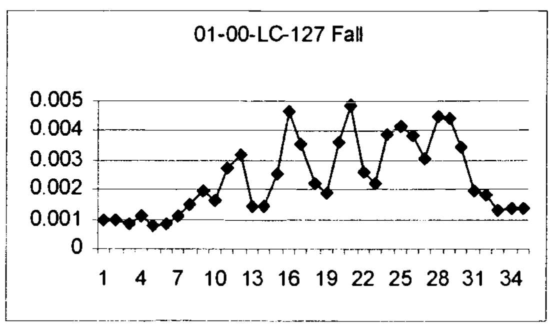
01-00-LC-127 Fall
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0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

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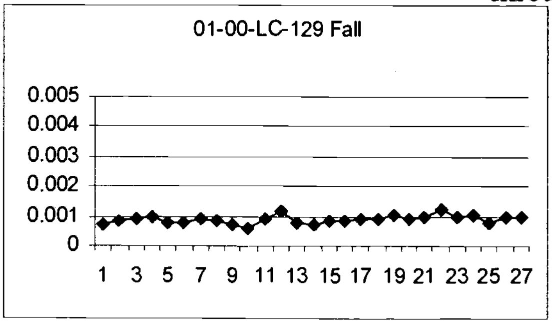
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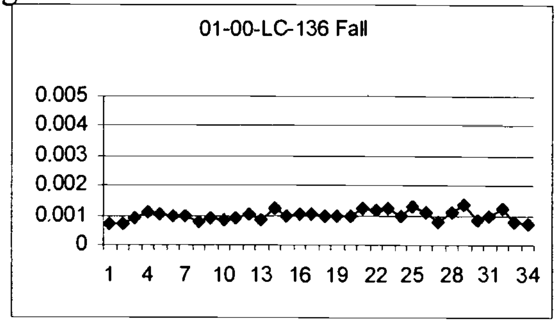
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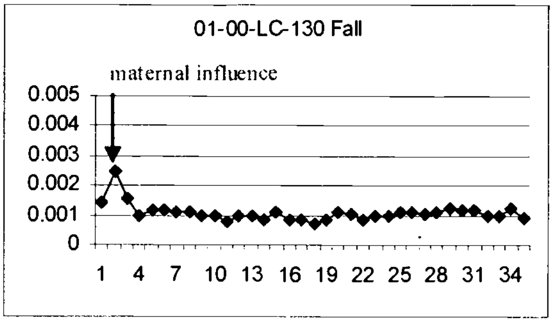
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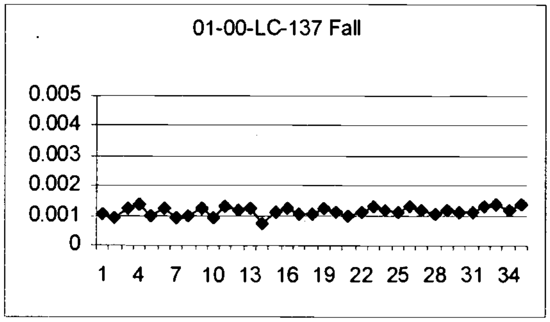
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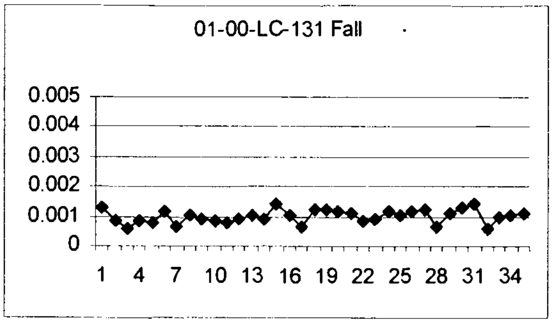
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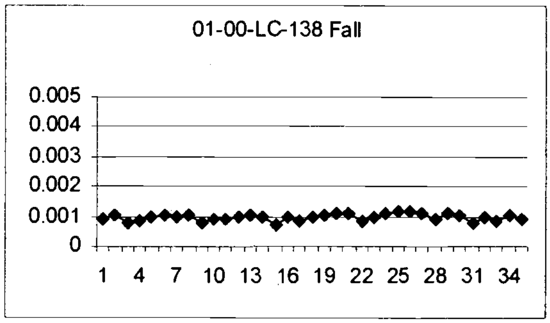
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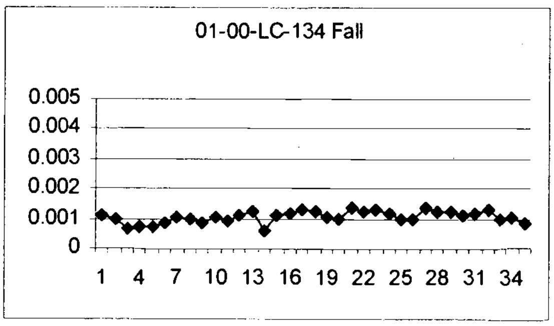
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0.001
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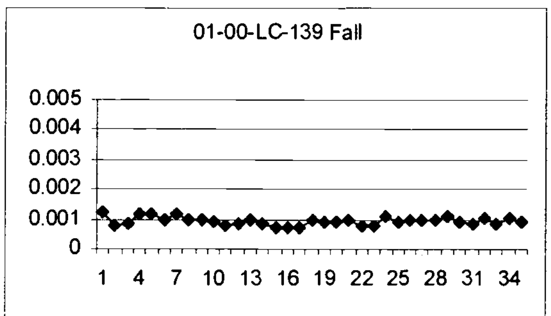
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0.001
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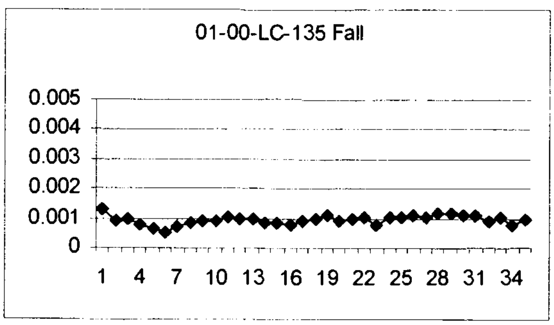
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0.001
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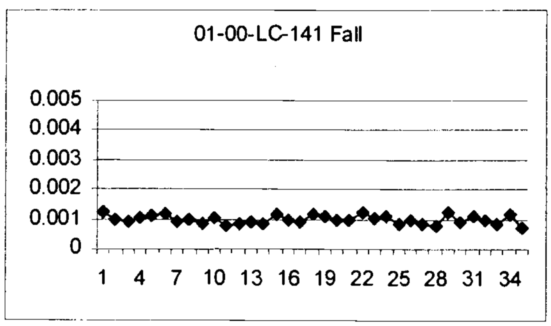
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0.003
0.002
0.001
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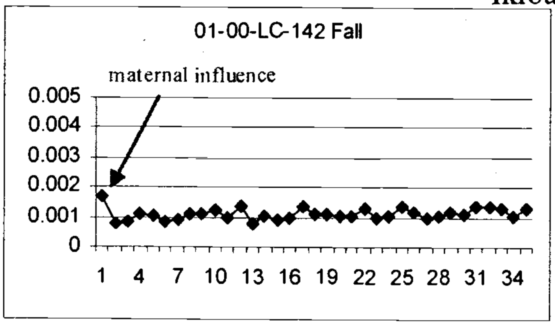
01-00-LC-142 Fall
maternal influence
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0.003
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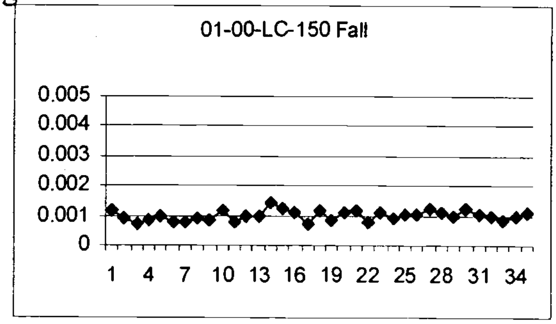
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0.003
0.002
0.001
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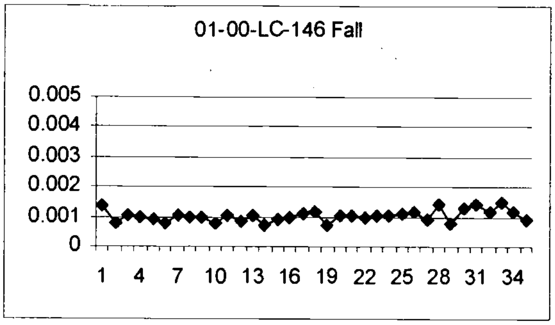
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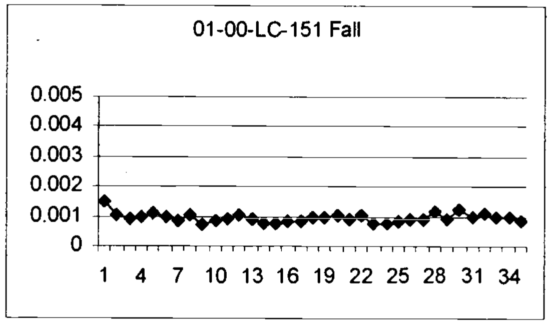
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0.003
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0.001
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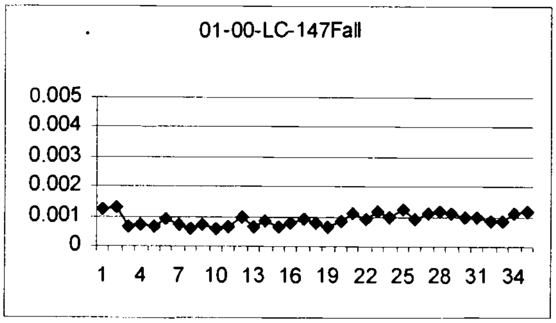
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0.003
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0.001
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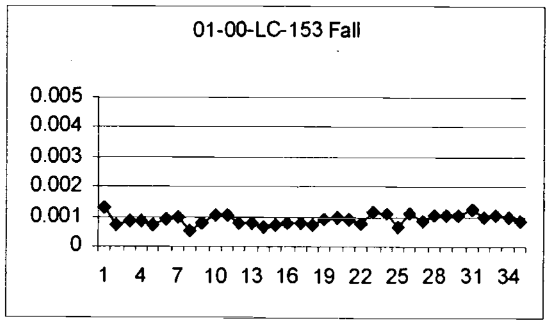
1 4 7 10 13 16 19 22 25 28 31 34


01-00-LC-153 Fall
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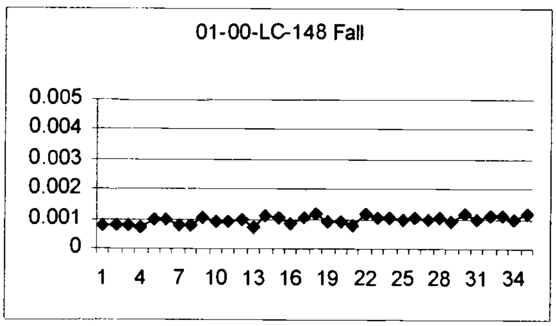
01-00-LC-148 Fall
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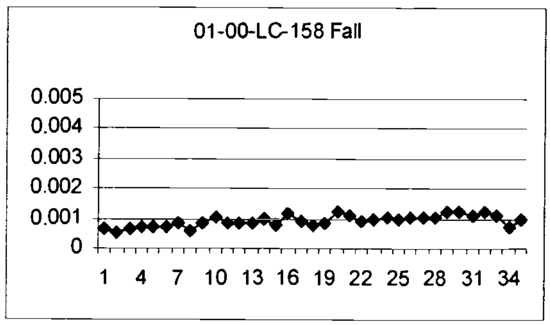
1 4 7 10 13 16 19 22 25 28 31 34


01-00-LC-158 Fall
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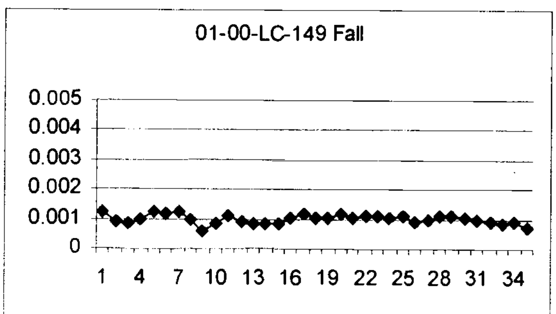
1 4 7 10 13 16 19 22 25 28 31 34


01-00-LC-149 Fall
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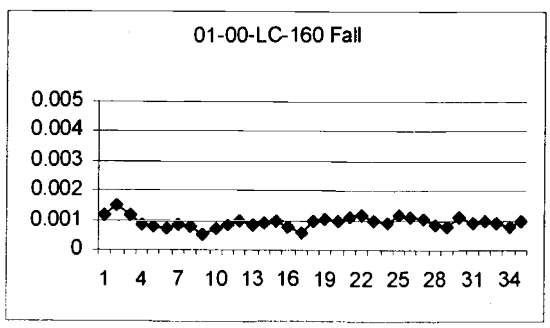
1 4 7 10 13 16 19 22 25 28 31 34


01-00-LC-160 Fall
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0.002
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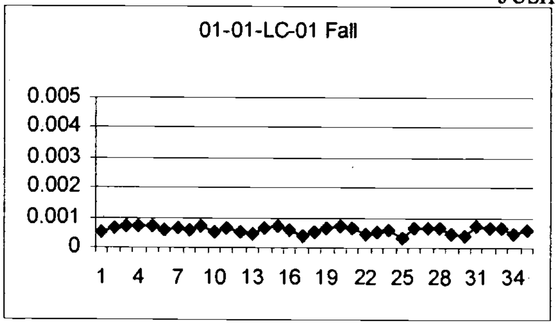
1 4 7 10 13 16 19 22 25 28 31 34

Joshua's


01-01-LC-01 Fall
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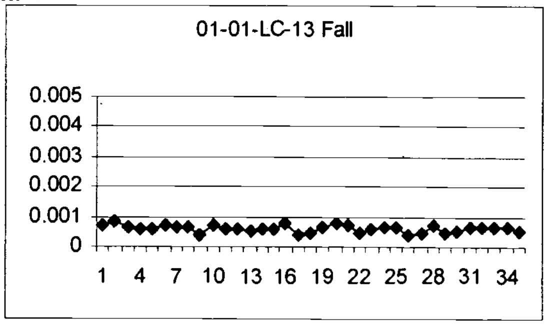
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-13 Fall
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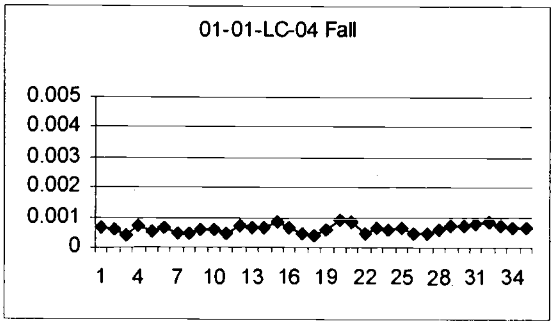
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-04 Fall
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0.002
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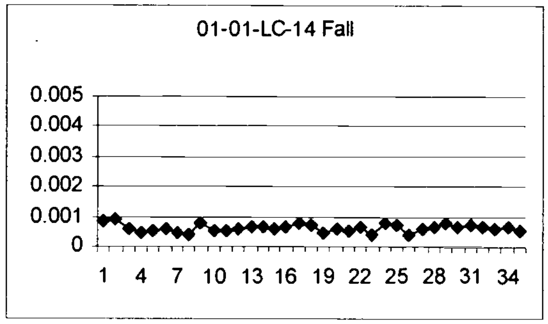
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-14 Fall
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0.002
0.001
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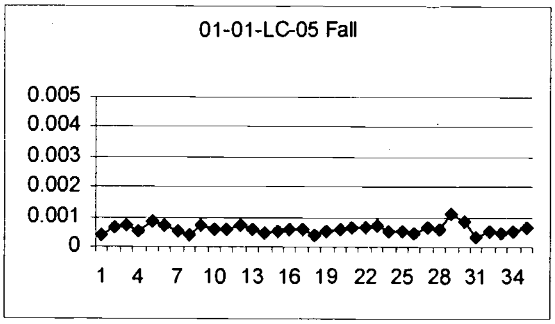
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-05 Fall
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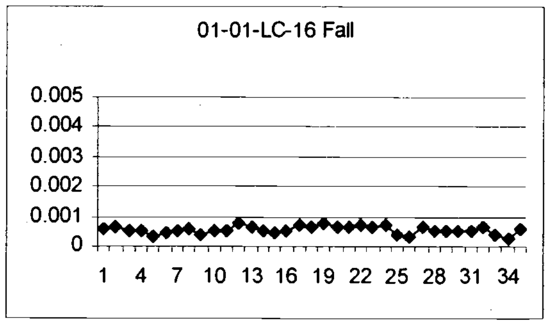
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-16 Fall
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0.002
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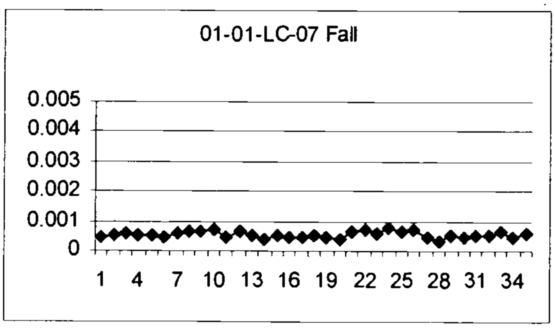
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-07 Fall
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0.002
0.001
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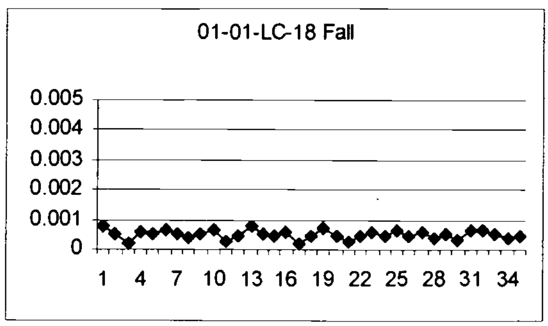
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-18 Fall
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0.003
0.002
0.001
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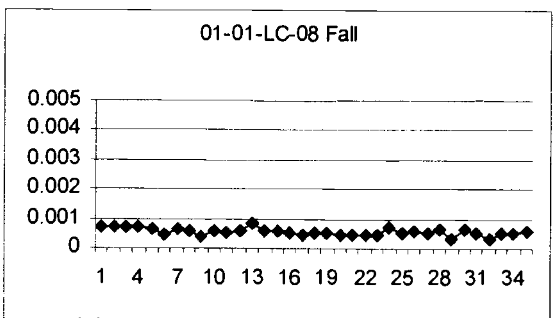
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-08 Fall
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0.002
0.001
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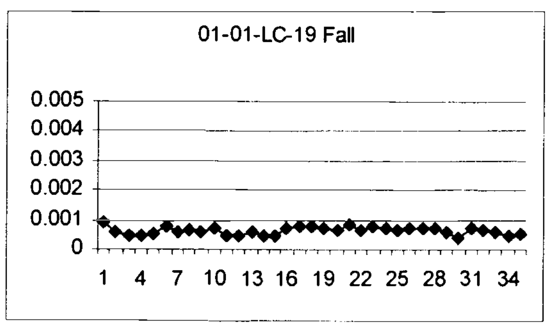
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-19 Fall
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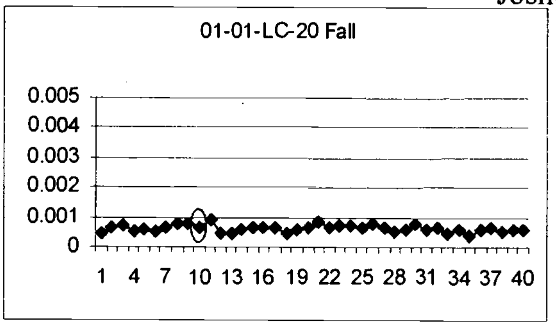
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

Joshua's


01-01-LC-20 Fall
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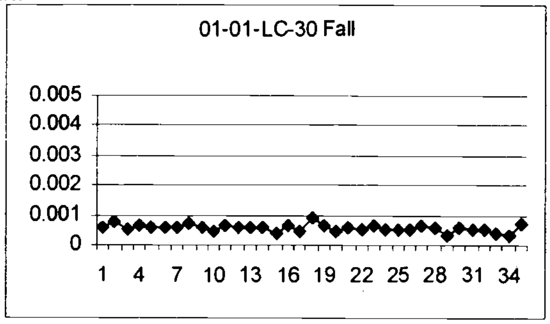
1 4 7 10 13 16 19 22 25 28 31 34 37 40


01-01-LC-30 Fall
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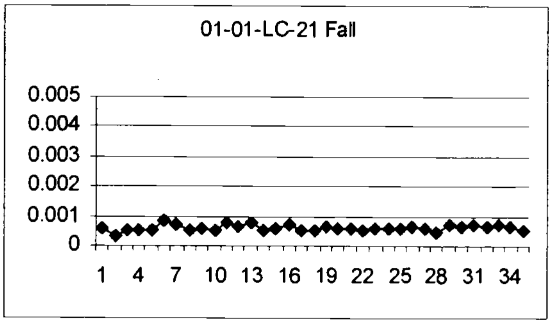
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-21 Fall
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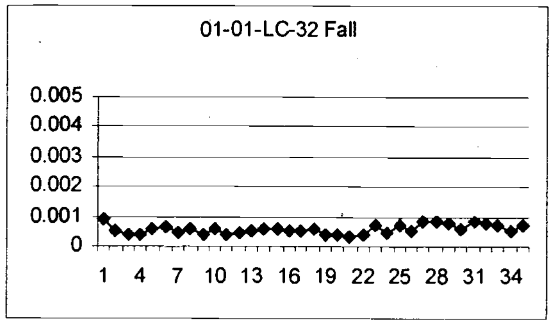
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-32 Fall
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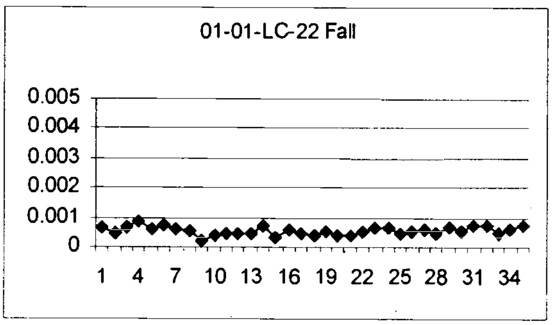
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-22 Fall
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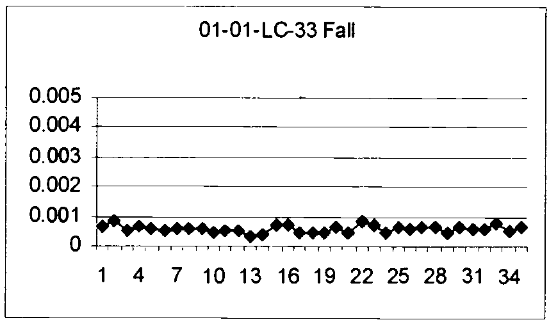
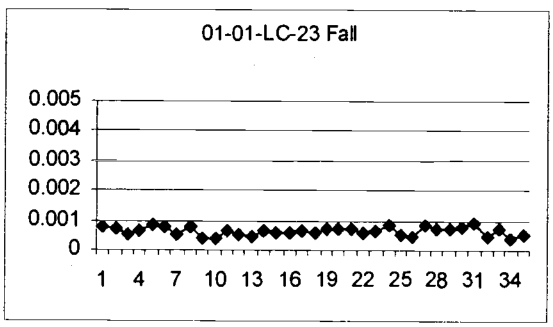
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-33 Fall
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-23 Fall
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0.004
0.003
0.002
0.001
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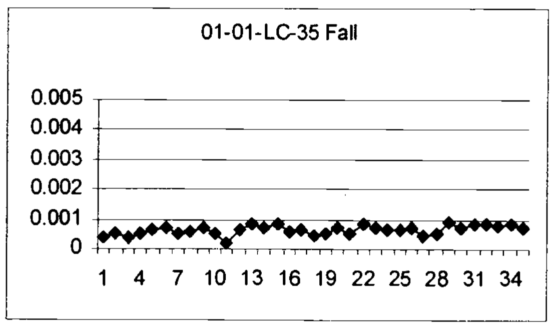
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-35 Fall
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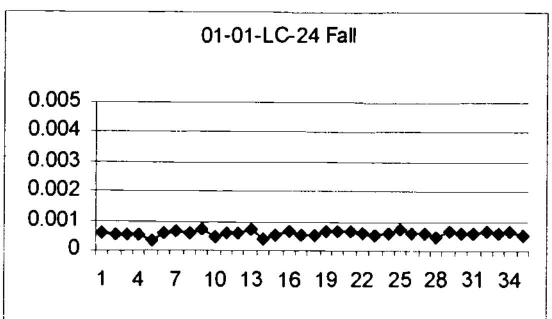
01-01-LC-24 Fall
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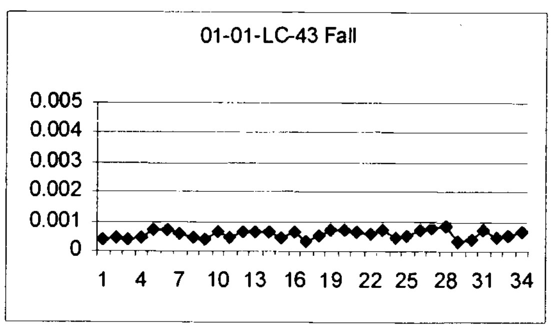
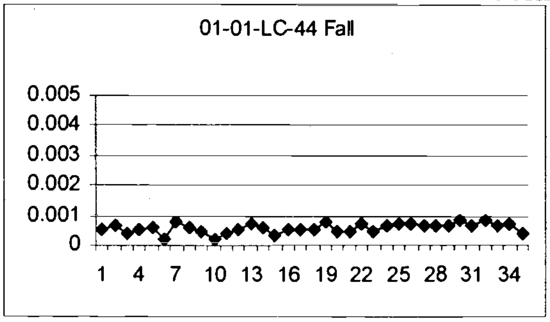
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-43 Fall
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

Joshua's


01-01-LC-44 Fall
0.005
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0.003
0.002
0.001
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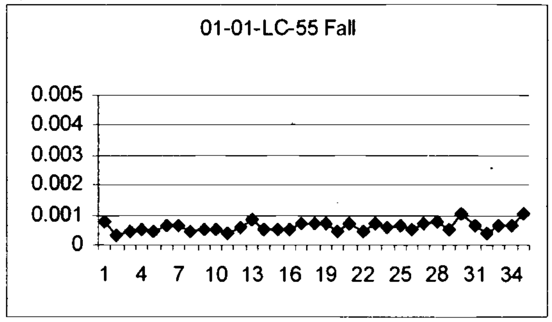
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-55 Fall
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0.003
0.002
0.001
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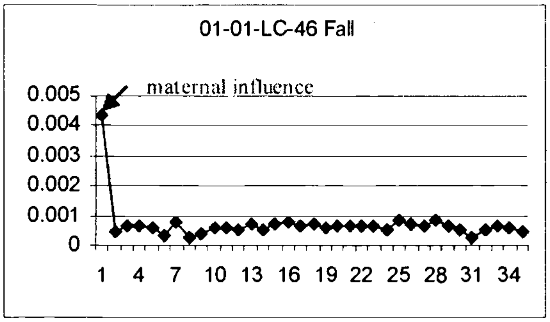
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-46 Fall
maternal influence
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0.004
0.003
0.002
0.001
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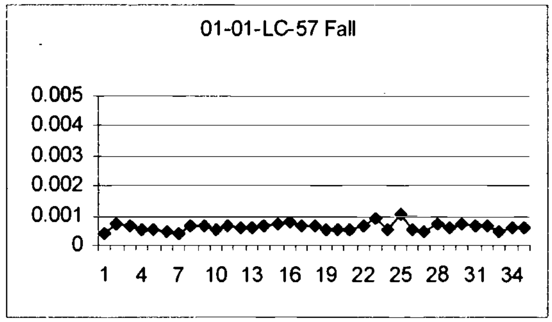
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-57 Fall
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0.004
0.003
0.002
0.001
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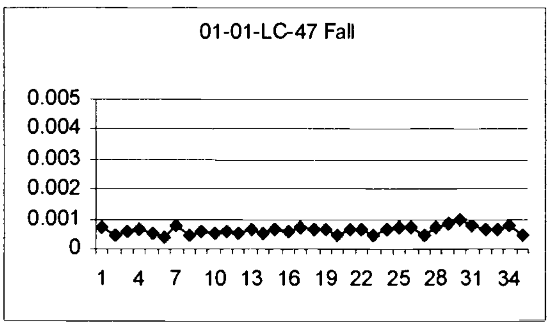
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-47 Fall
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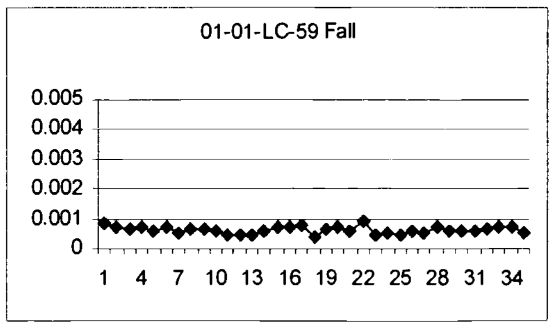
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-59 Fall
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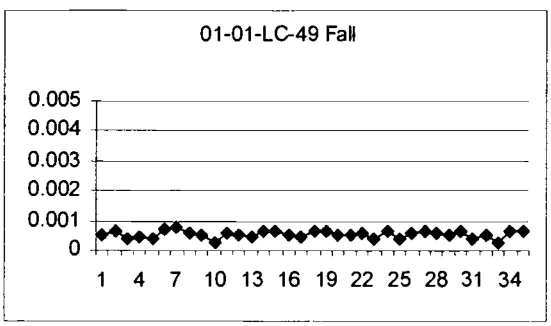
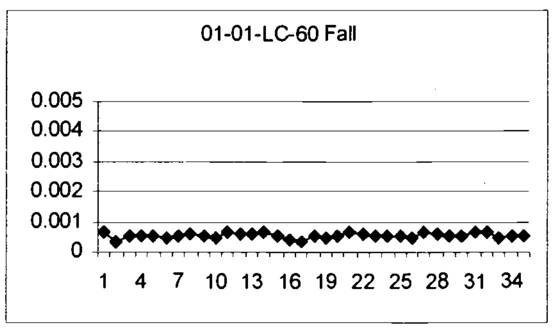
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-49 Fall
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-60 Fall
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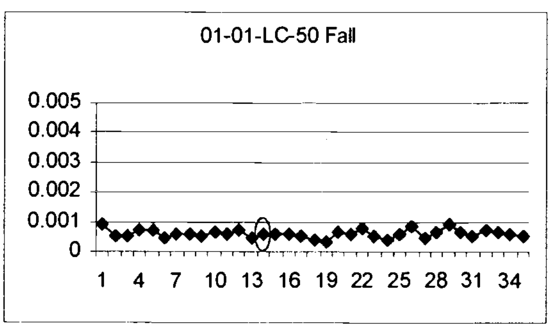
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-50 Fall
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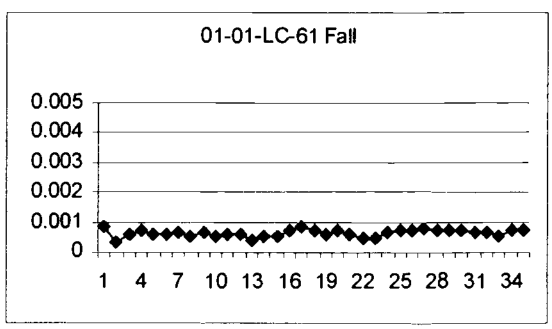
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-01-LC-61 Fall
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0.003
0.002
0.001
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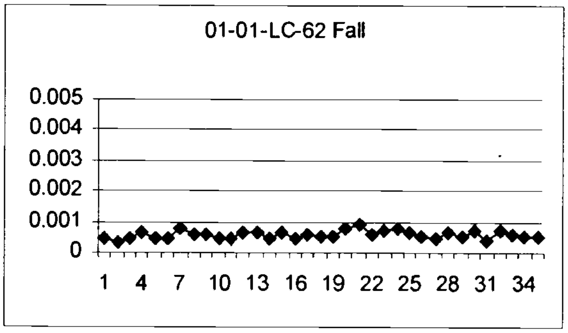
1 4 7 10 13 16 19 22 25 28 31 34

Joshua's


01-01-LC-62 Fall
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0.004
0.003
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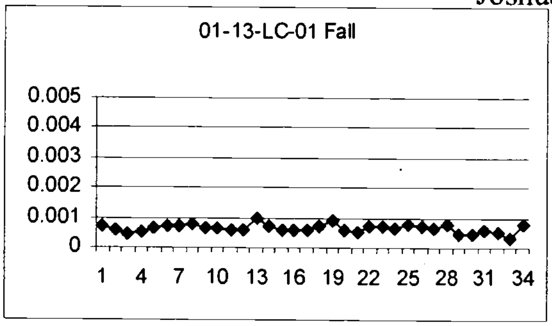
0
1
4
7
10
13
16
19
22
25
28
31
34

Joshua's 2$^{nd}$


01-13-LC-01 Fall
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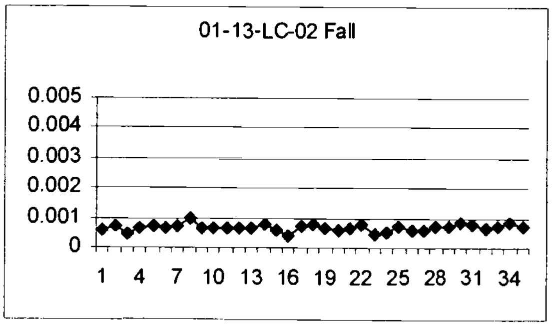
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-02 Fall
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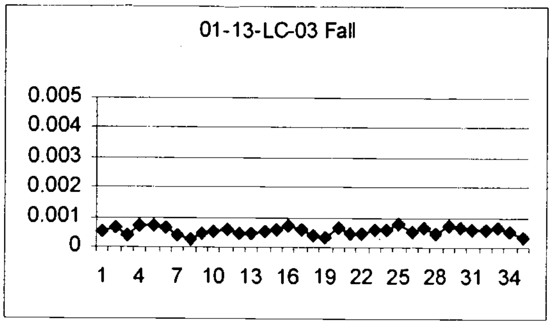
01-13-LC-03 Fall
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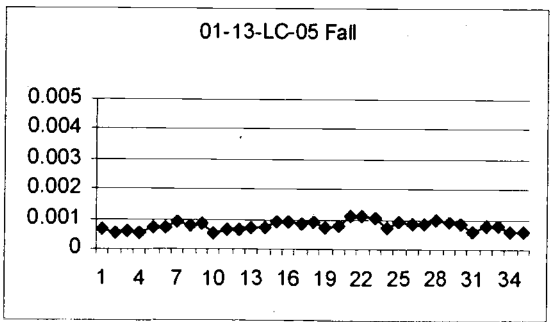
01-13-LC-05 Fall
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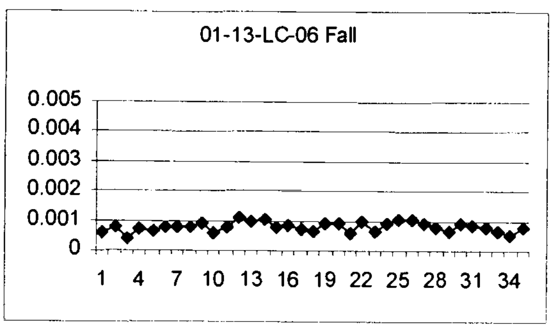
01-13-LC-06 Fall
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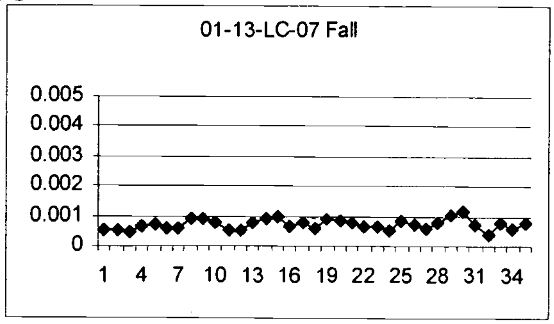
01-13-LC-07 Fall
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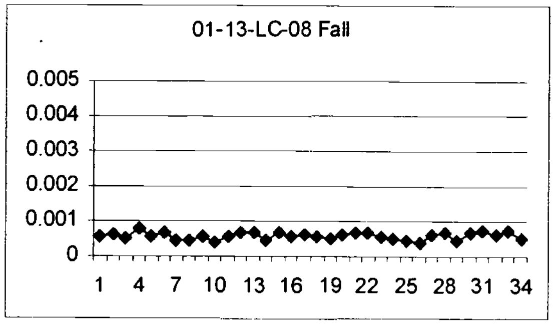
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-08 Fall
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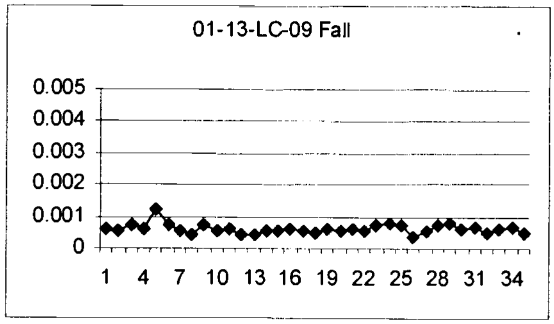
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-09 Fall
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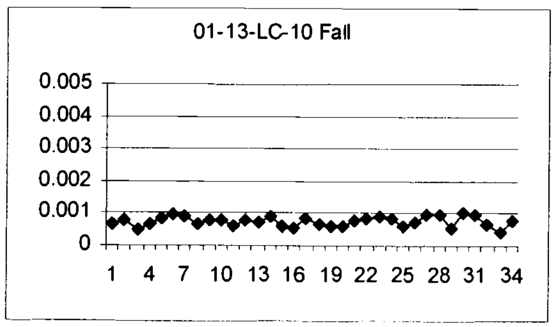
01-13-LC-10 Fall
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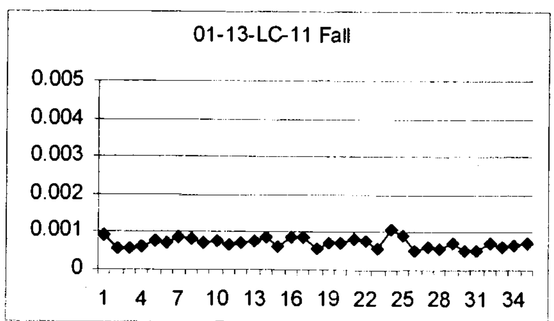
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-11 Fall
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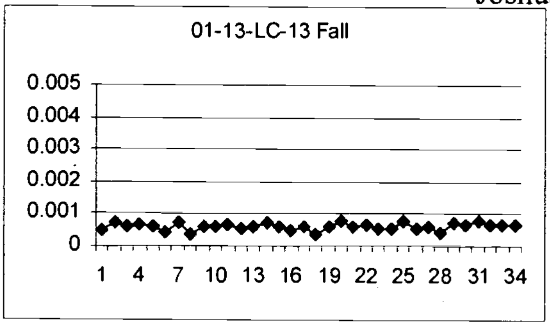
1 4 7 10 13 16 19 22 25 28 31 34

Joshua's 2nd


01-13-LC-13 Fall
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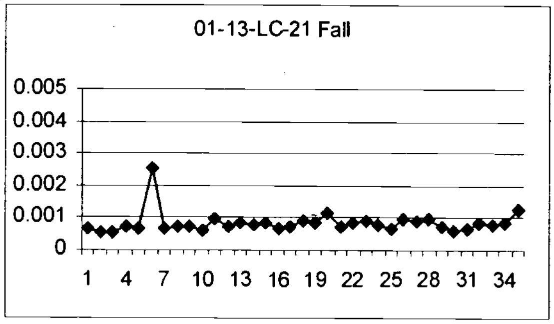
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-21 Fall
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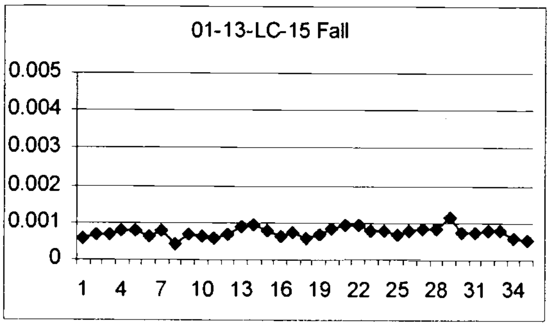
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-15 Fall
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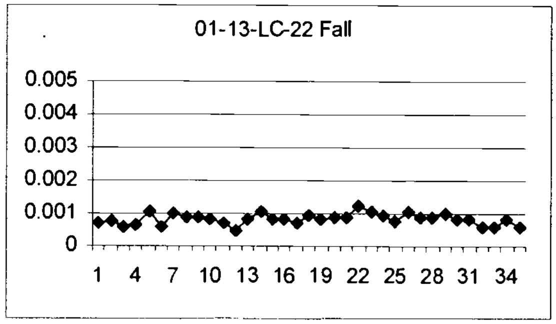
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-22 Fall
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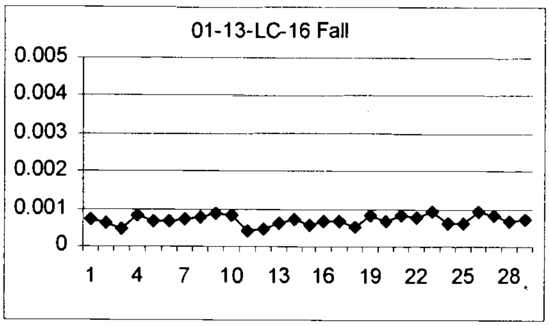
01-13-LC-16 Fall
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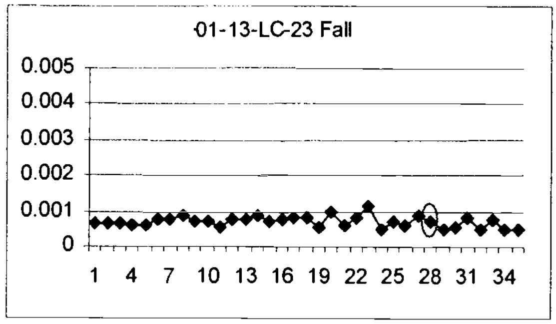
01-13-LC-23 Fall
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0.002
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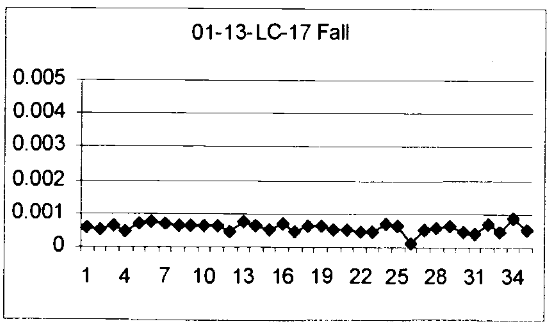
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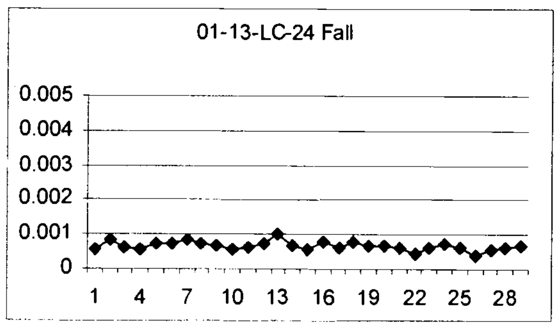
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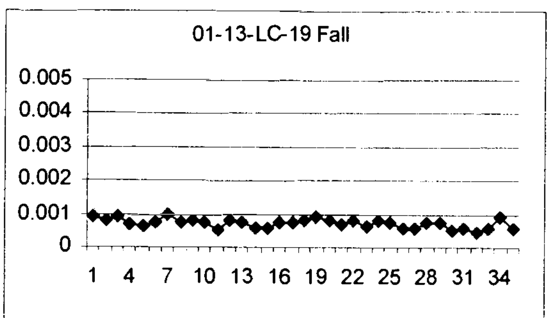
01-13-LC-19 Fall
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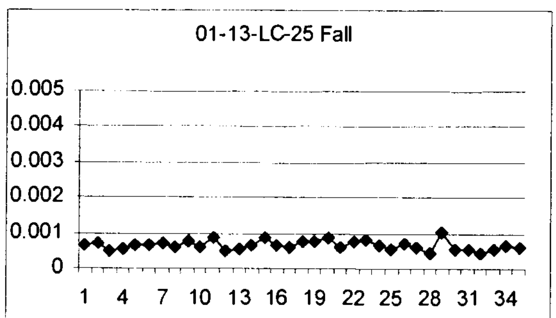
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-25 Fall
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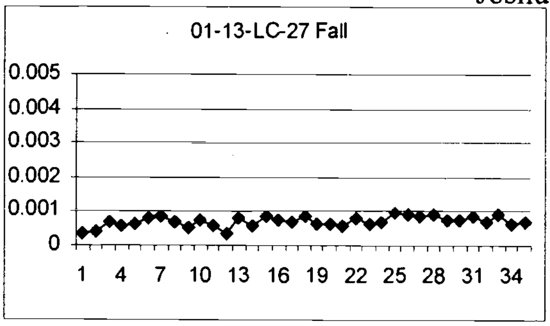
1 4 7 10 13 16 19 22 25 28 31 34

# Joshua's 2nd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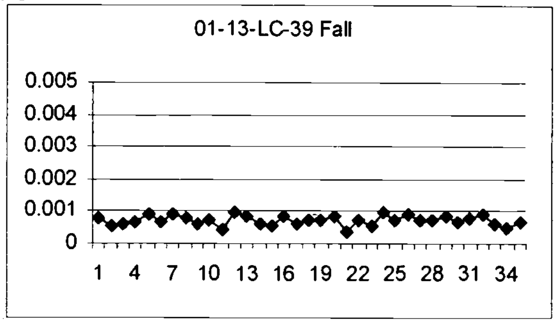
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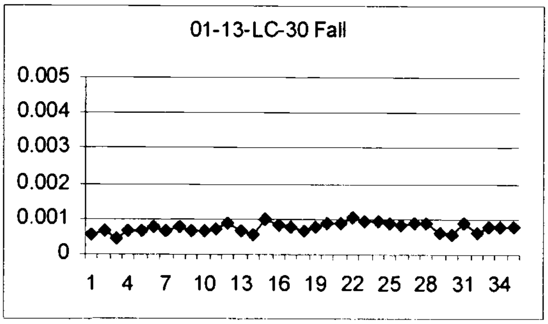
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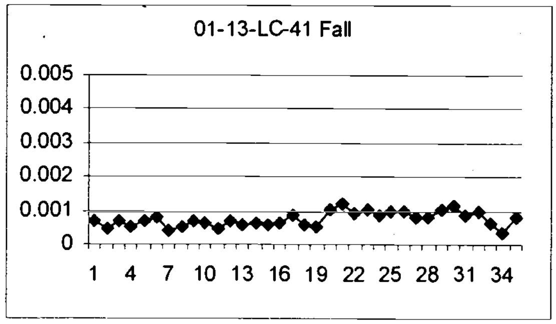
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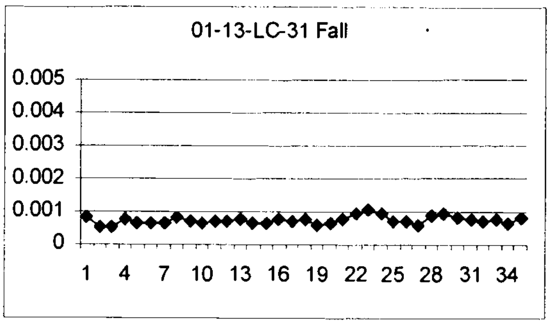
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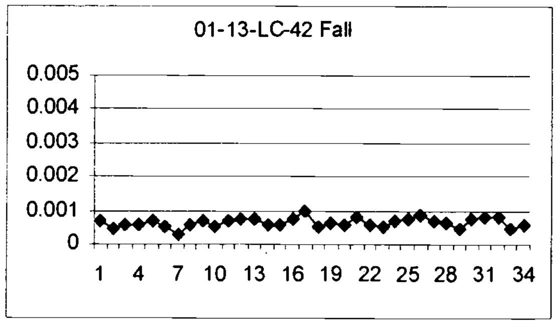
01-13-LC-42 Fall
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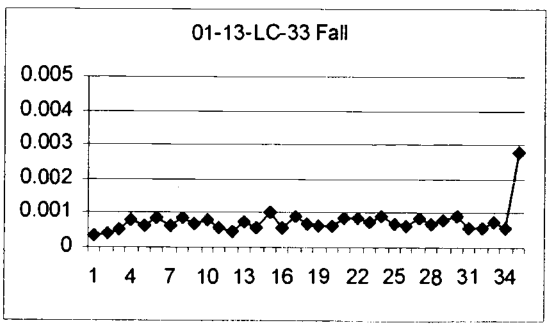
1 4 7 10 13 16 19 22 25 28 31 34


01-13-LC-33 Fall
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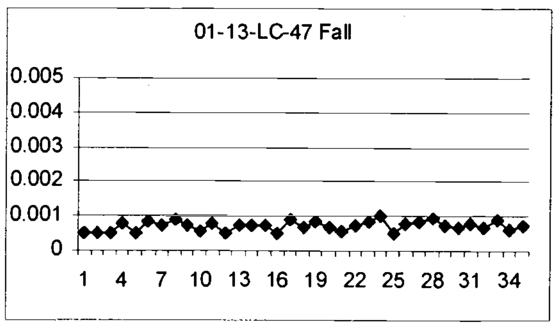
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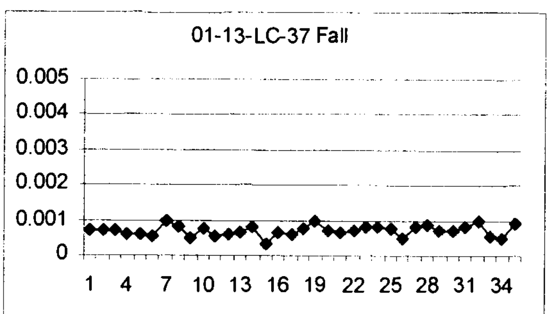
01-13-LC-37 Fall
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0.002
0.001
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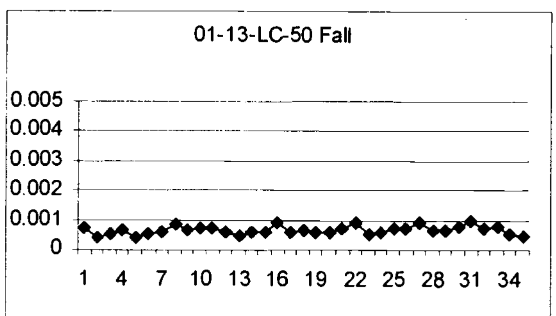
01-13-LC-50 Fall
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0.001
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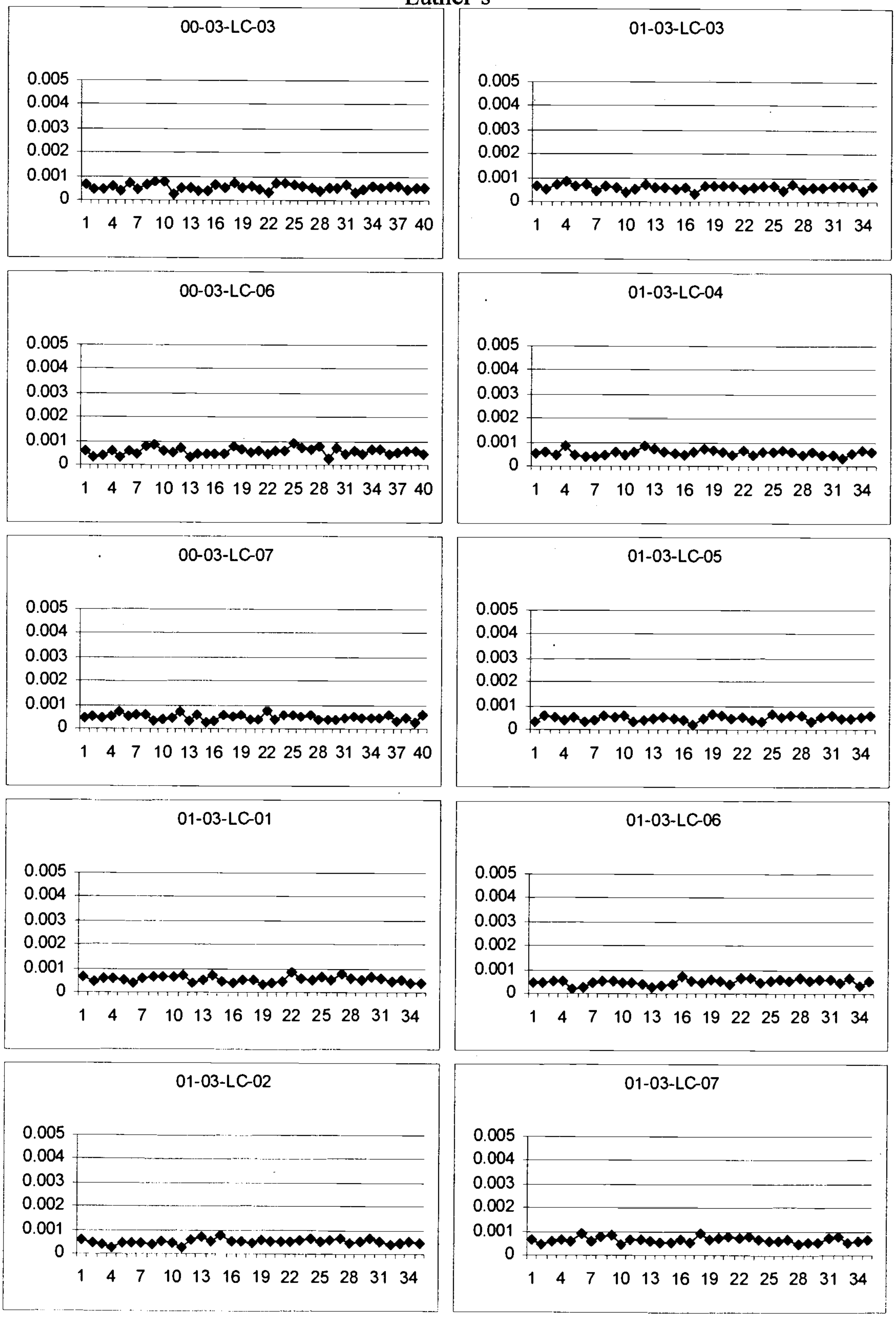
1 4 7 10 13 16 19 22 25 28 31 34

Luther's


00-03-LC-03
01-03-LC-03
00-03-LC-06
01-03-LC-04
00-03-LC-07
01-03-LC-05
01-03-LC-01
01-03-LC-06
01-03-LC-02
01-03-LC-07
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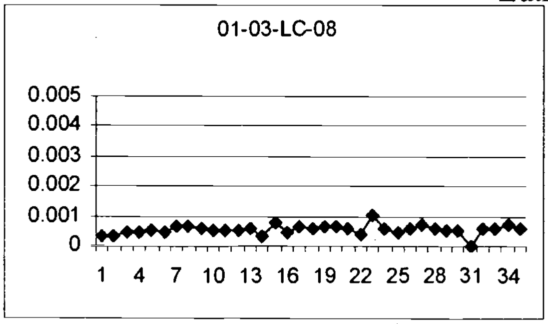
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40
1 4 7 10 13 16 19 22 25 28 31 34

Luther's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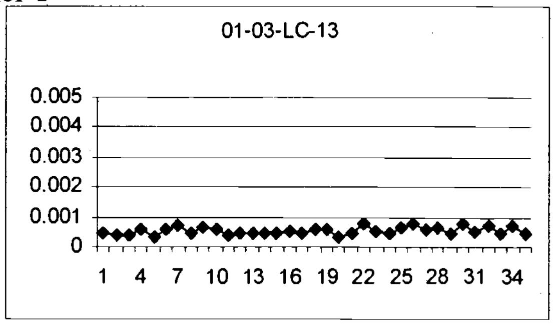
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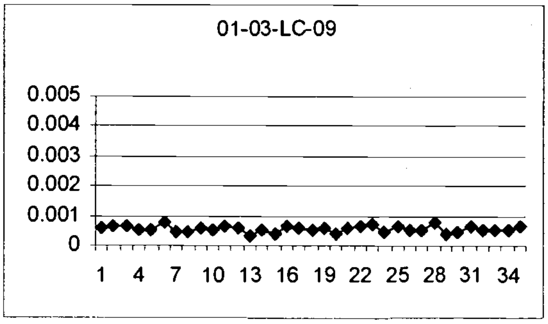
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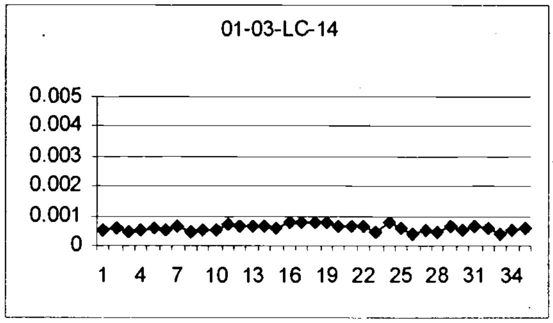
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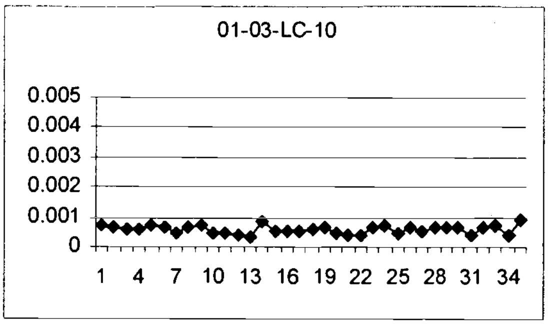
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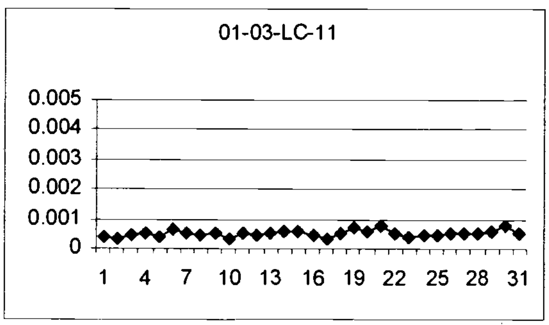
01-03-LC-11
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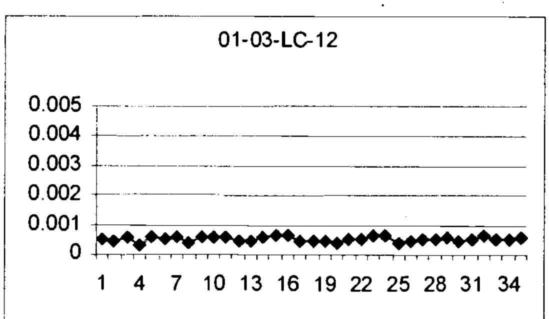
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0.003
0.002
0.001
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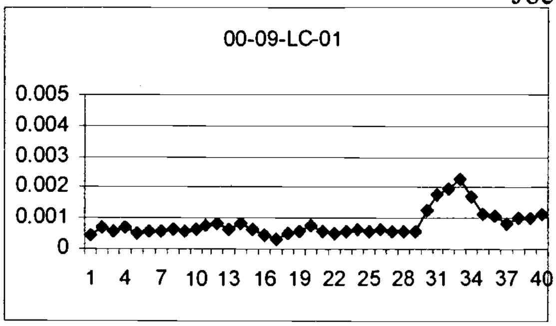
1 4 7 10 13 16 19 22 25 28 31 34

Joeb's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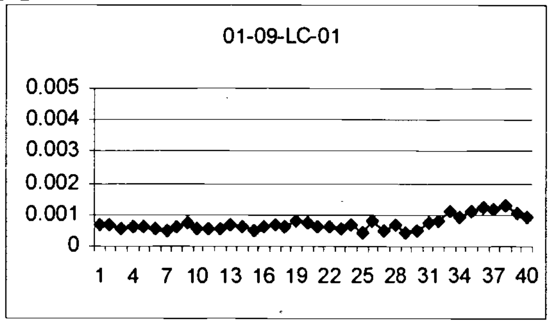
1 4 7 10 13 16 19 22 25 28 31 34 37 40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0.002
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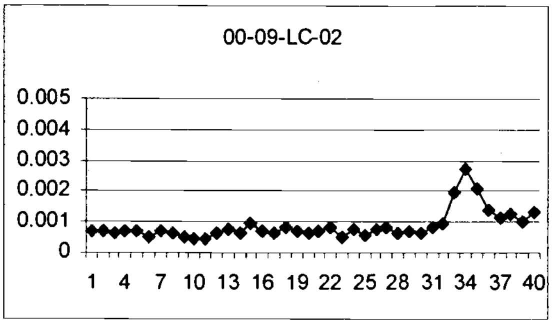
1 4 7 10 13 16 19 22 25 28 31 34 37 40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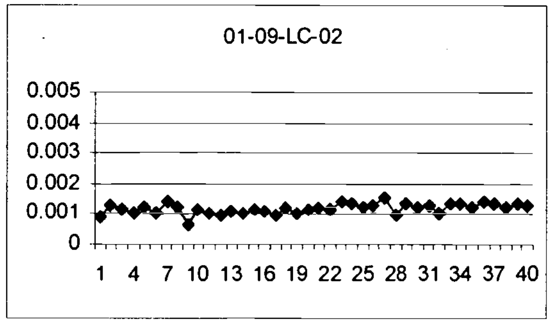
1 4 7 10 13 16 19 22 25 28 31 34 37 40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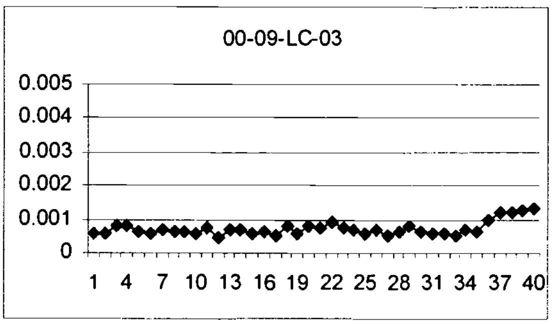
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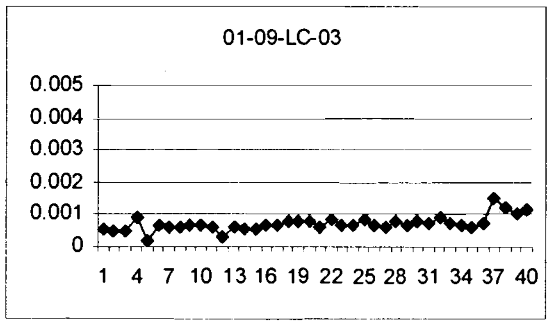
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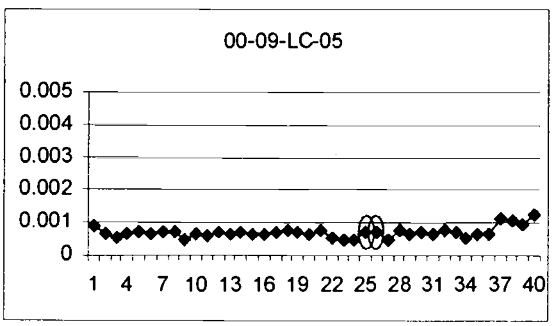
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0.002
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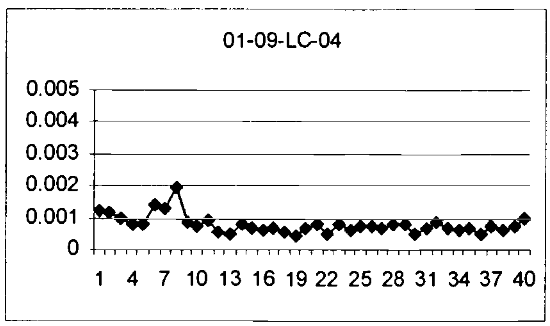
1 4 7 10 13 16 19 22 25 28 31 34 37 40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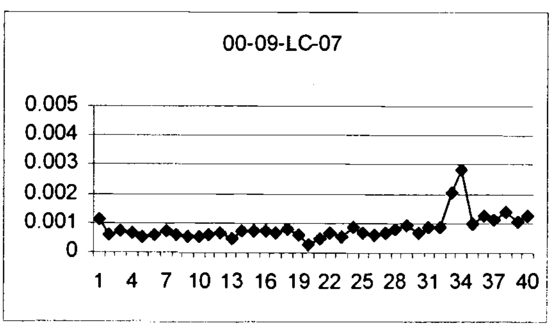
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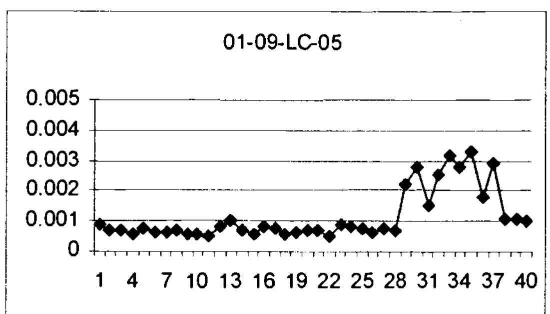
01-09-LC-05
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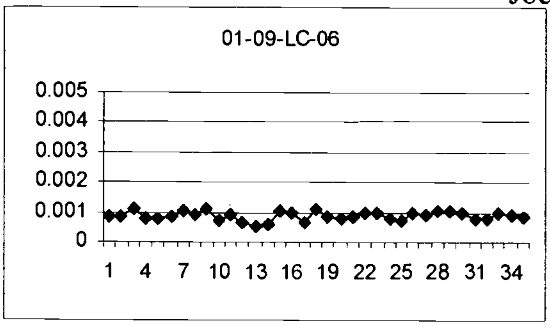
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40

Joeb's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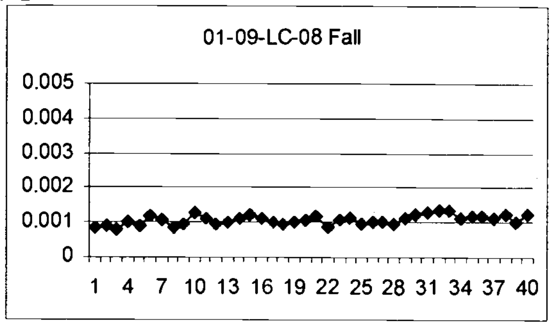
01-09-LC-08 Fall
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0.002
0.001
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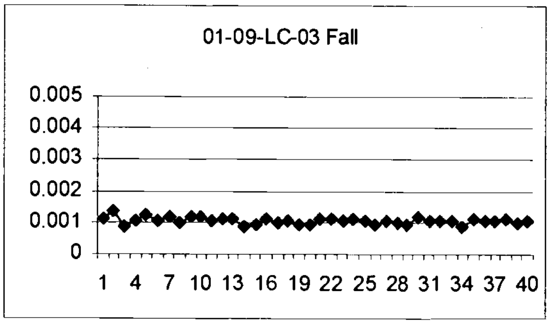
1 4 7 10 13 16 19 22 25 28 31 34 37 40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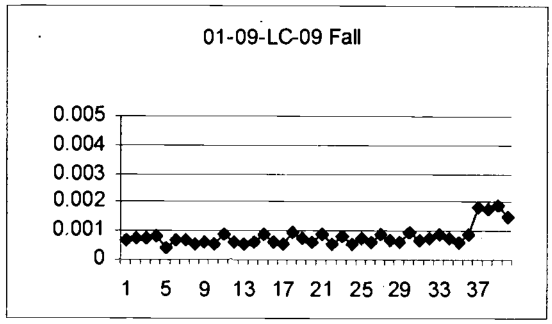
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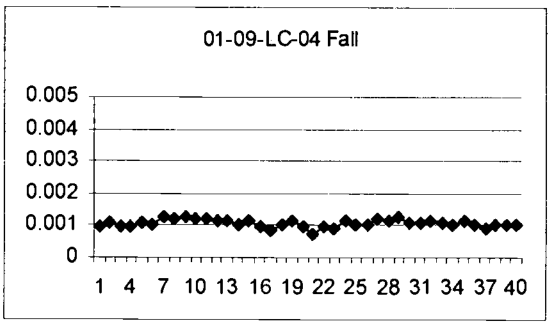
1 5 9 13 17 21 25 29 33 37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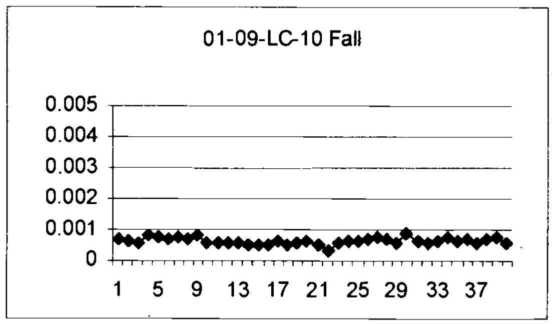
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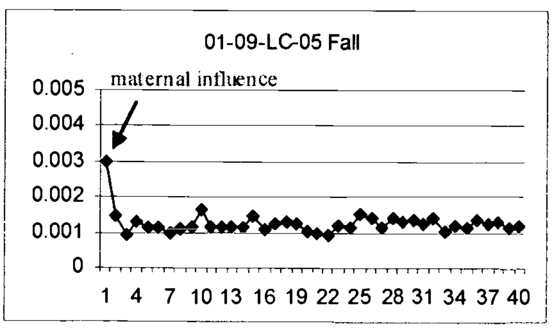
01-09-LC-05 Fall
maternal influence
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0.004
0.003
0.002
0.001
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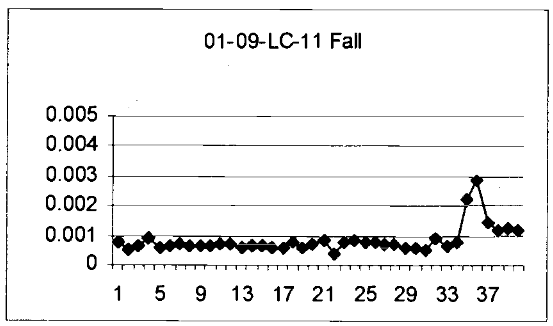
01-09-LC-11 Fall
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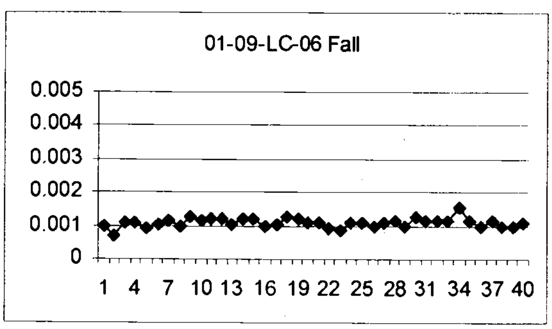
1 5 9 13 17 21 25 29 33 37


01-09-LC-06 Fall
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0.001
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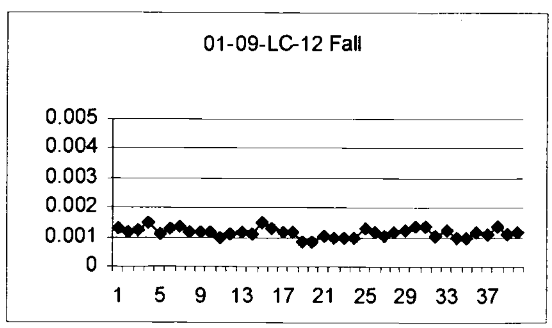
01-09-LC-12 Fall
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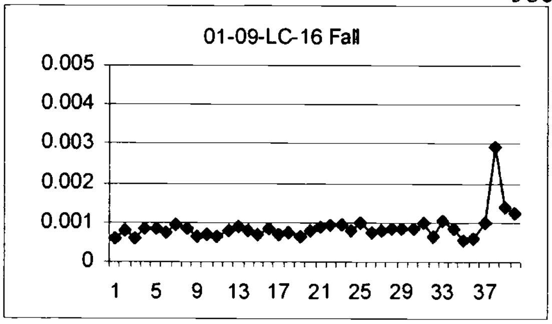
0.002
0.001
0
1 5 9 13 17 21 25 29 33 37

Joeb's


01-09-LC-16 Fall
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0.002
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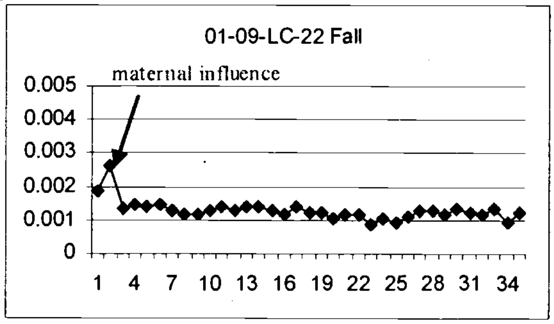
01-09-LC-22 Fall
maternal influence
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0.003
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0.001
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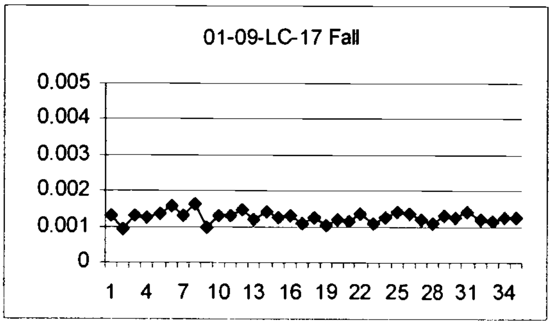
01-09-LC-17 Fall
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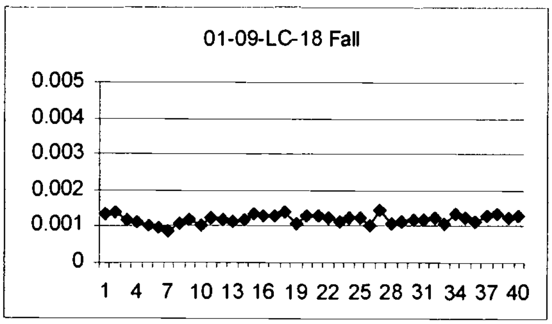
01-09-LC-18 Fall
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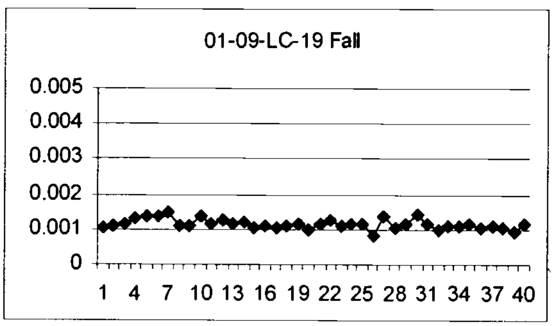
01-09-LC-19 Fall
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0.003
0.002
0.001
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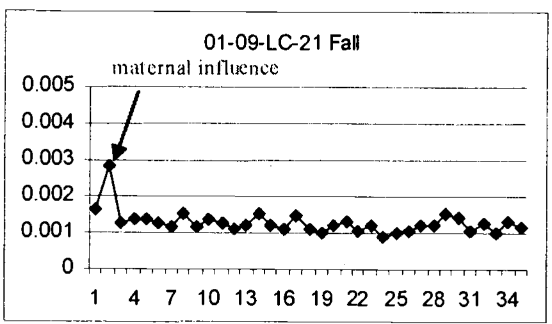
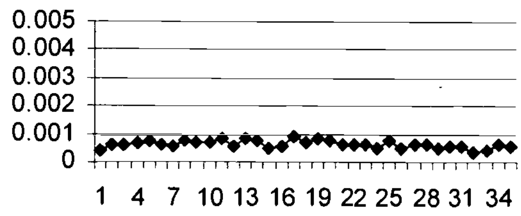
1 4 7 10 13 16 19 22 25 28 31 34 37 40

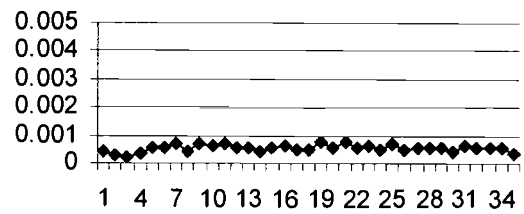

01-09-LC-21 Fall
maternal influence
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

Joeb's 2nd

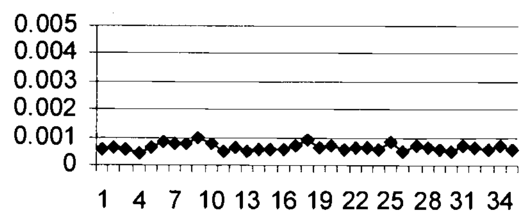
**01-12-LC-02**



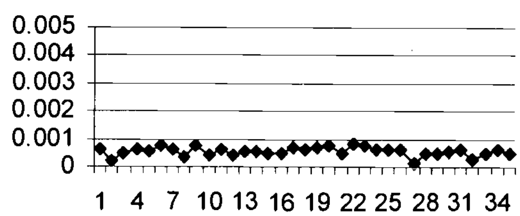

**01-12-LC-03**



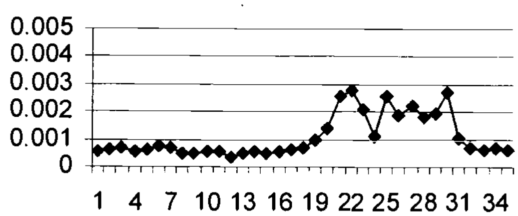

**01-12-LC-04**



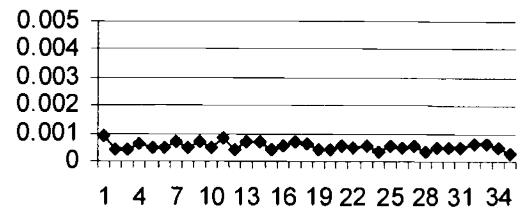

**01-12-LC-05**



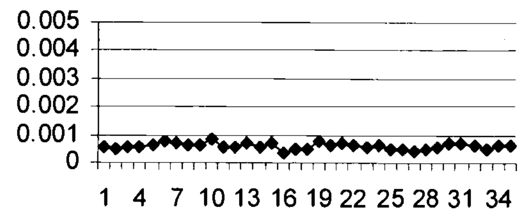

**01-12-LC-06**



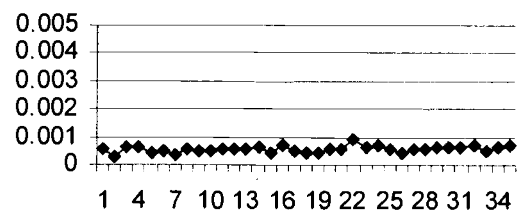

**01-12-LC-07**



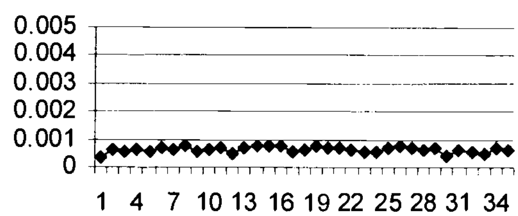

**01-12-LC-08**



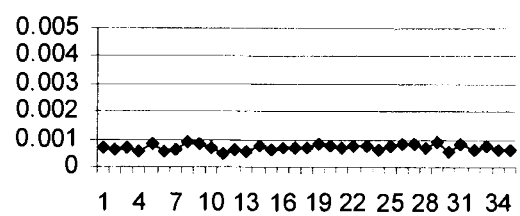

**01-12-LC-09**



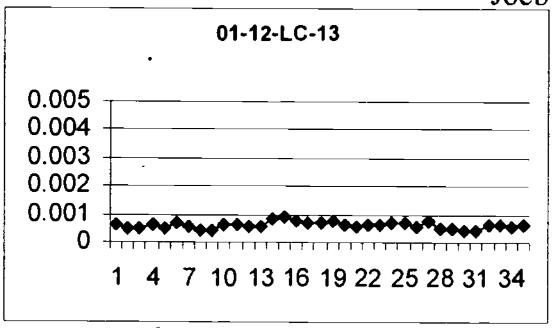

**01-12-LC-10**

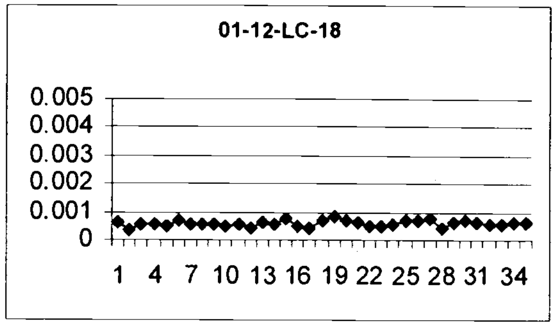


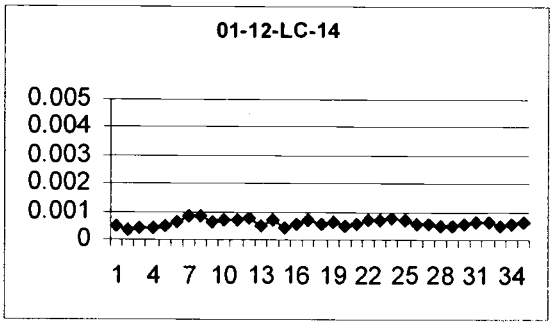

**01-12-LC-12**

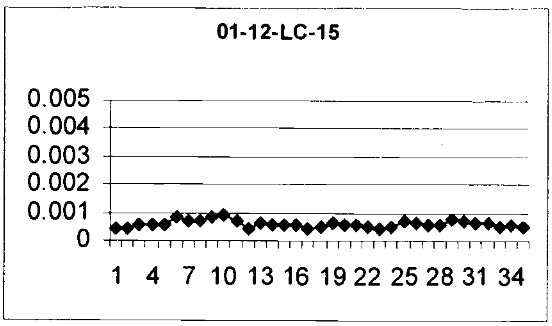


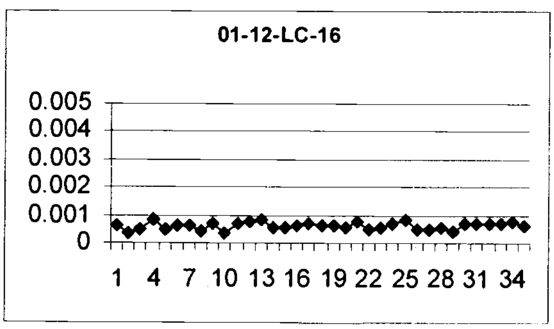
Joeb's 2nd

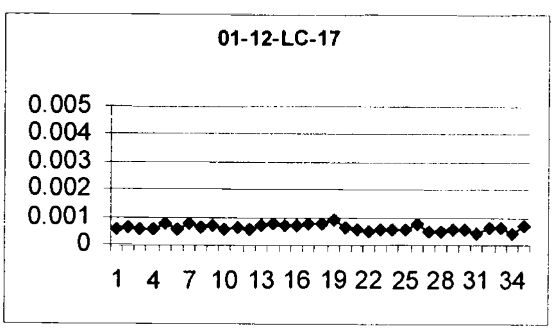

01-12-LC-13
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34


01-12-LC-18
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

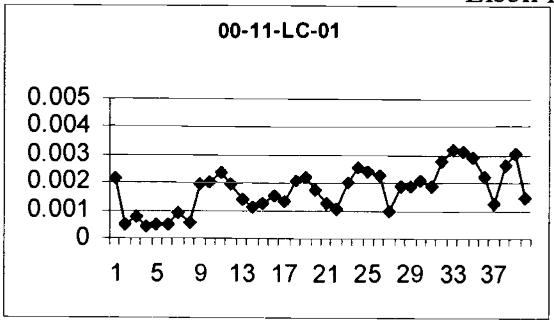

01-12-LC-14
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

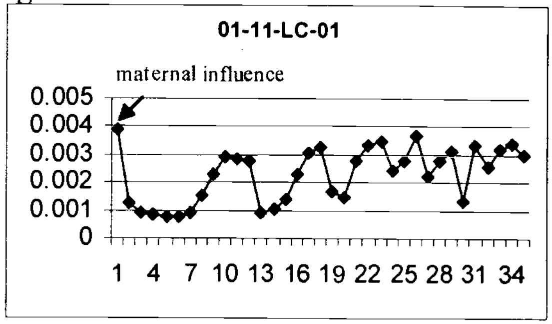

01-12-LC-15
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

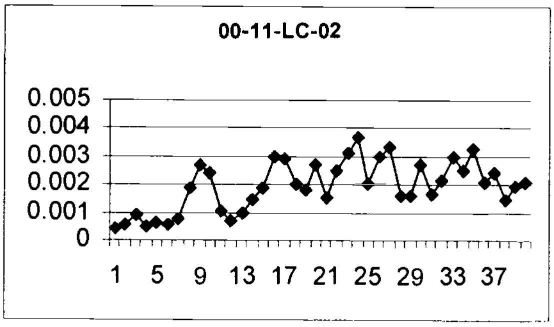

01-12-LC-16
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

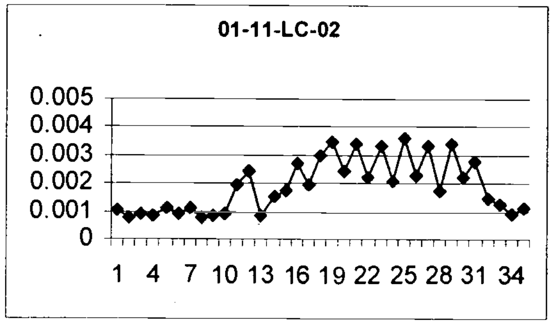

01-12-LC-17
0.005
0.004
0.003
0.002
0.001
0
1 4 7 10 13 16 19 22 25 28 31 34

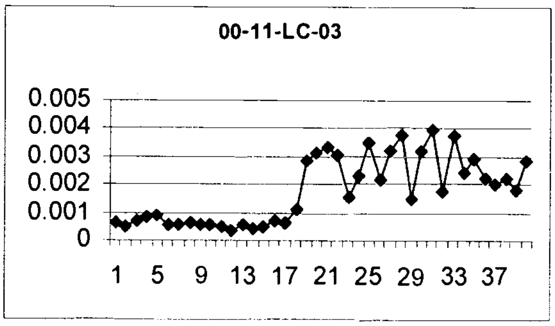
# Elson Lagoon

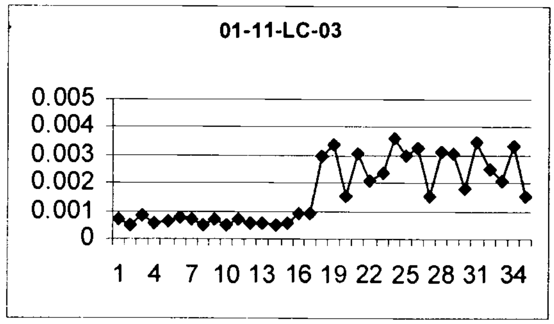


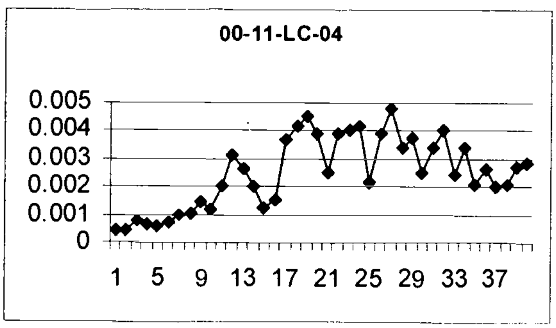



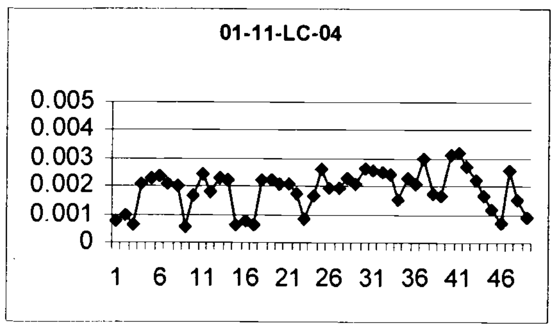



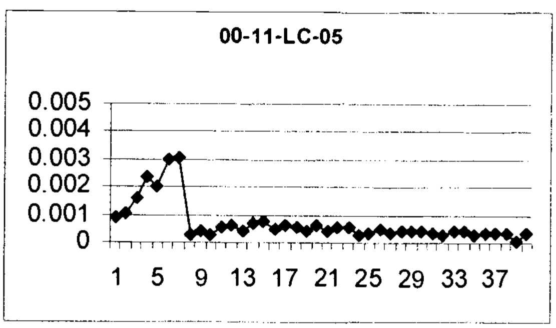



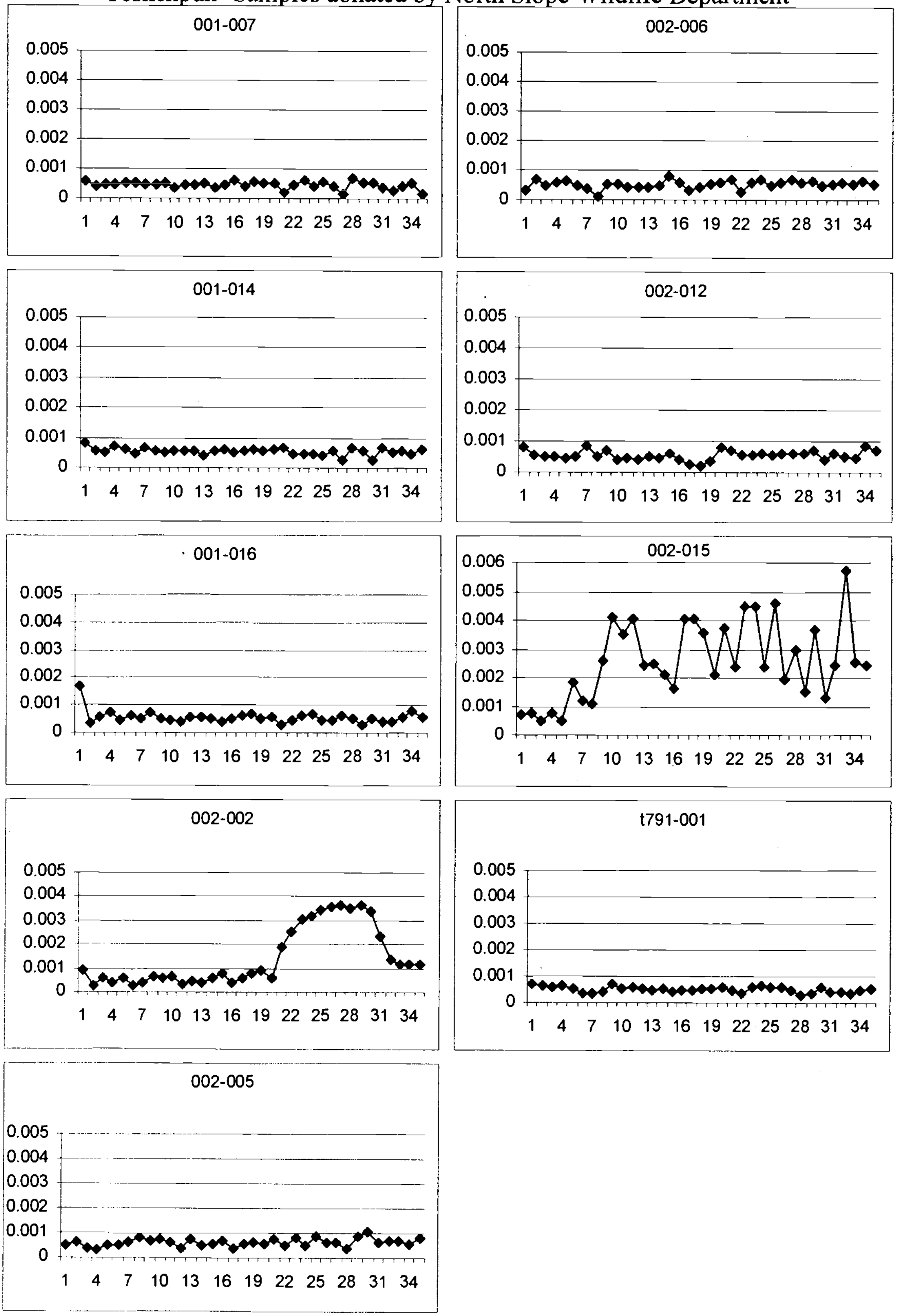



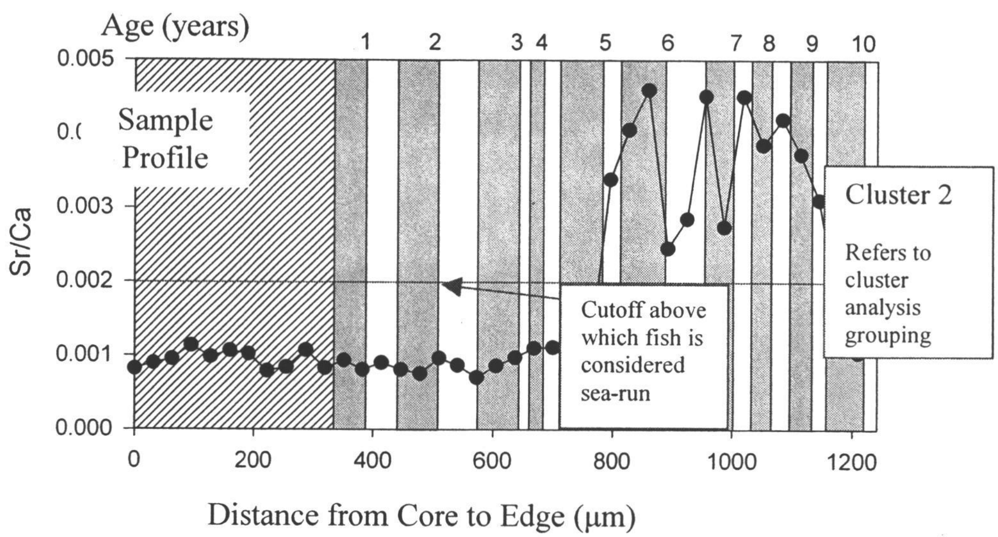



Teshekpuk- Samples donated by North Slope Wildlife Department



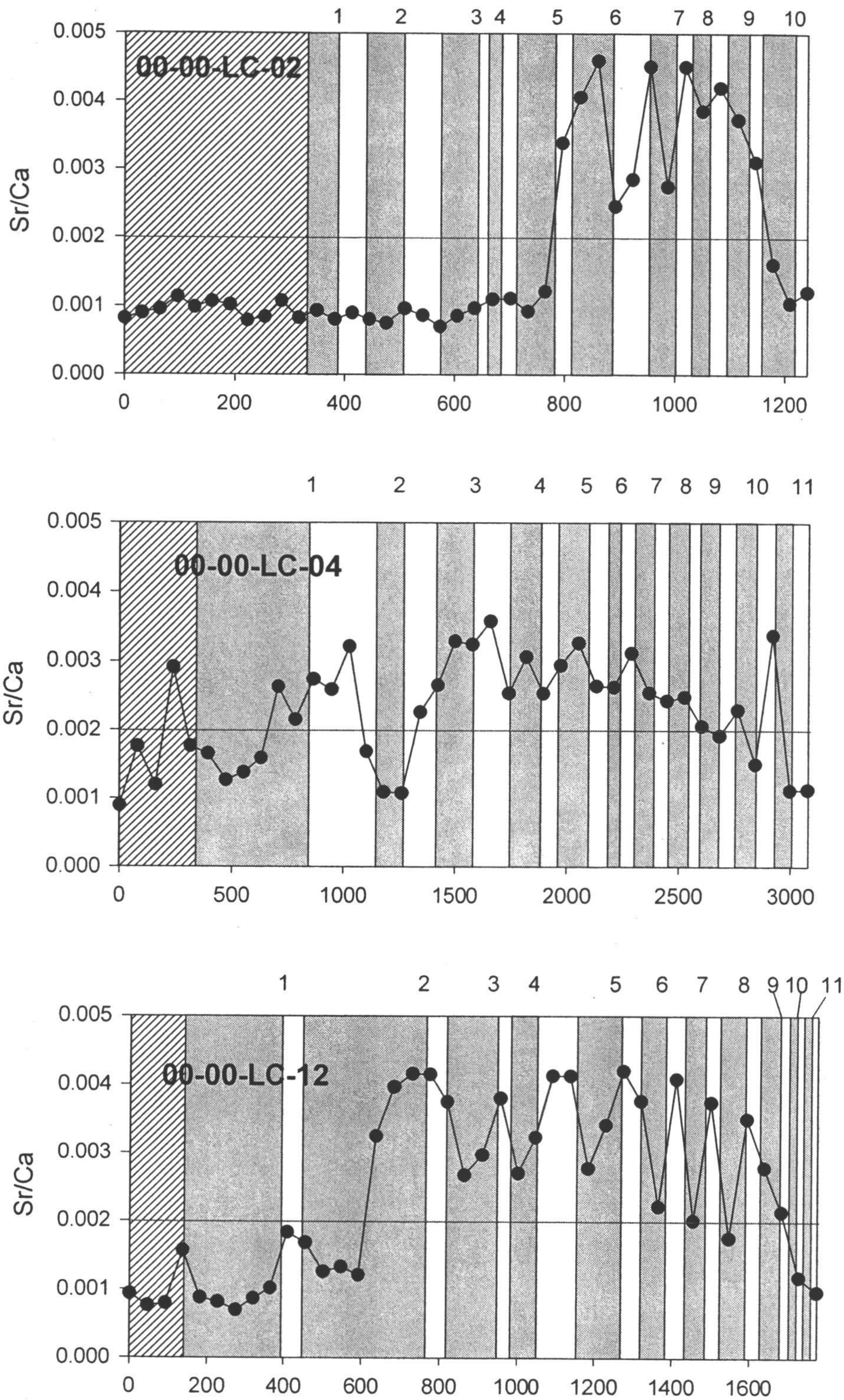
**Appendix D**
(pp. 121-133)
Age adjusted Sr:Ca profiles for sea-run least cisco



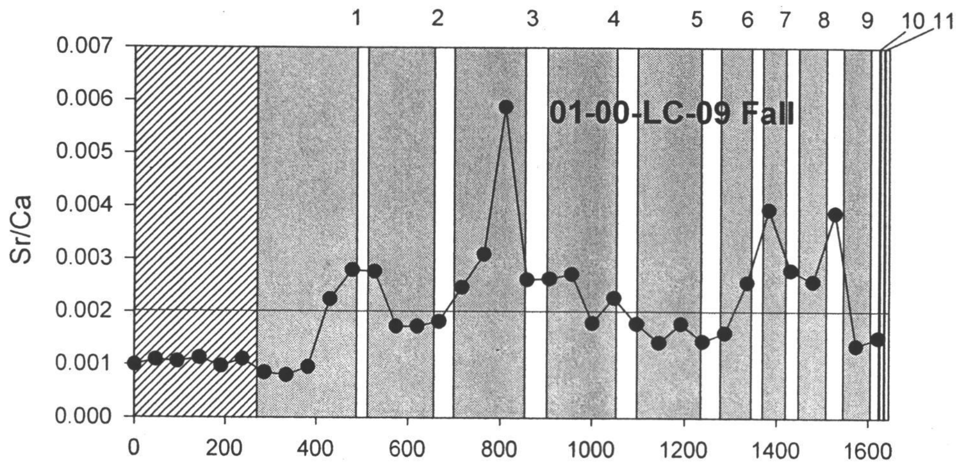

Key: = opaque or winter growth = hyaline or summer growth

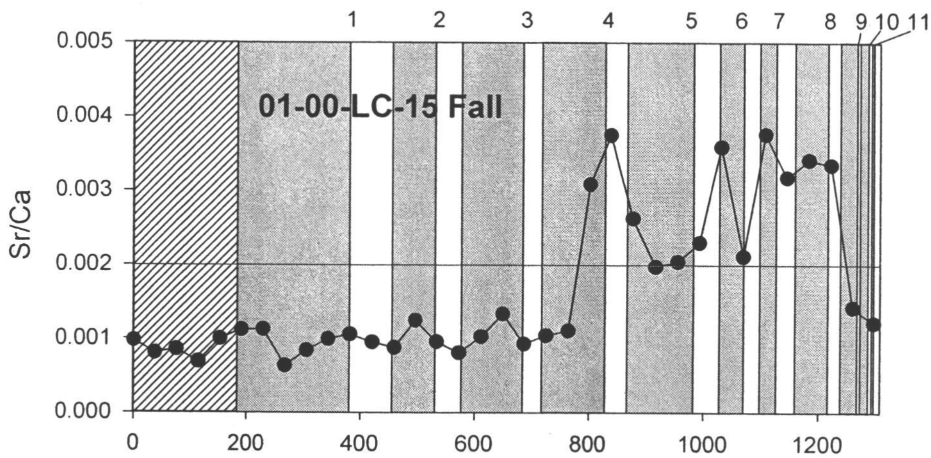
= core region

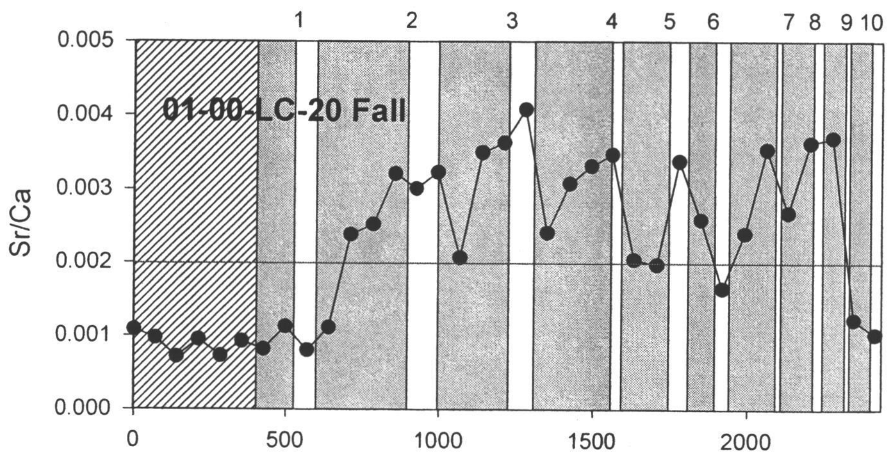
Ikroagvik


1 2 3 4 5 6 7 8 9 10
00-00-LC-02
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0 200 400 600 800 1000 1200
1 2 3 4 5 6 7 8 9 10 11
00-00-LC-04
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0 500 1000 1500 2000 2500 3000
1 2 3 4 5 6 7 8 9 10 11
00-00-LC-12
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0 200 400 600 800 1000 1200 1400 1600

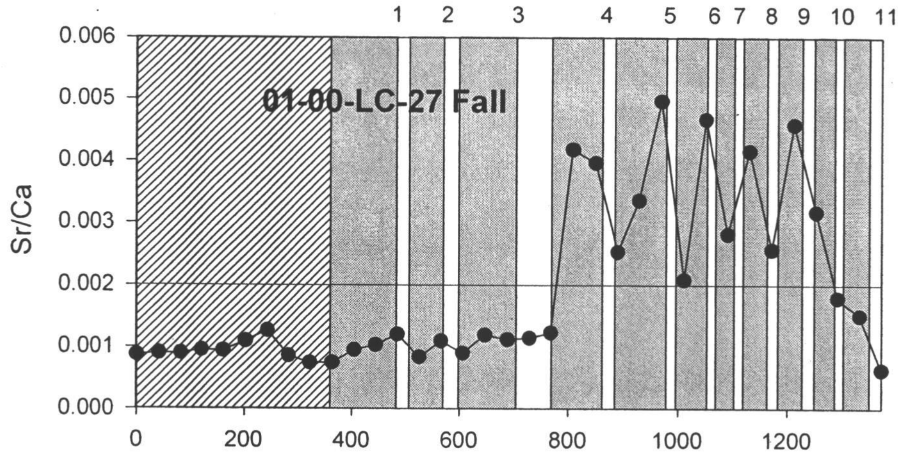
Ikroagvik

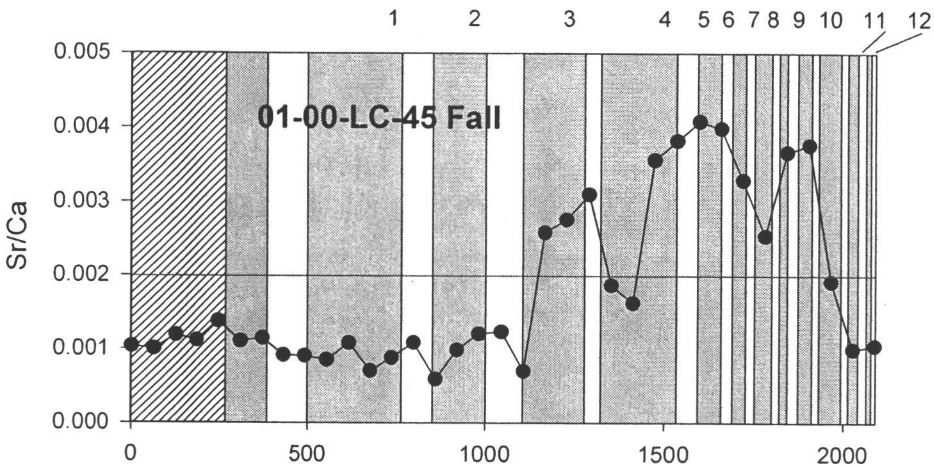

01-00-LC-09 Fall
Sr/Ca
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
1400
1600
1
2
3
4
5
6
7
8
9
10
11

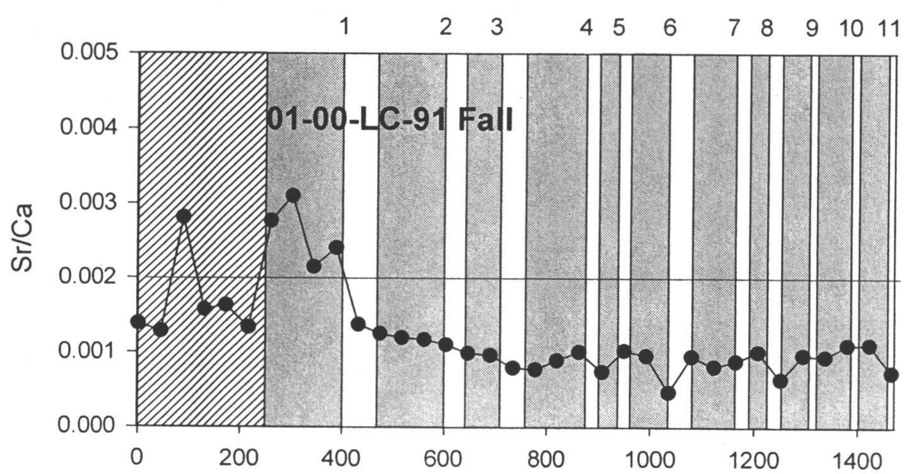

01-00-LC-15 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10
11


01-00-LC-20 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
500
1000
1500
2000
1
2
3
4
5
6
7
8
9
10

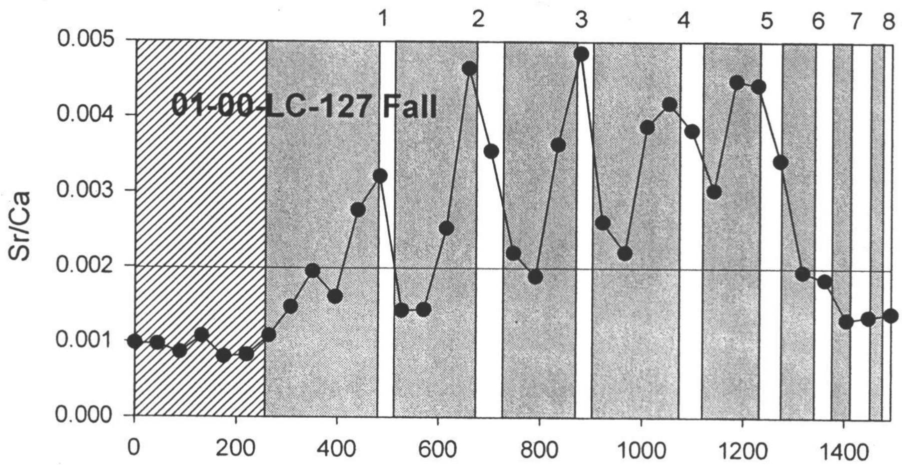
Ikroagvik


01-00-LC-27 Fall
Sr/Ca
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
1 2 3 4 5 6 7 8 9 10 11


01-00-LC-45 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
500
1000
1500
2000
1 2 3 4 5 6 7 8 9 10 11 12

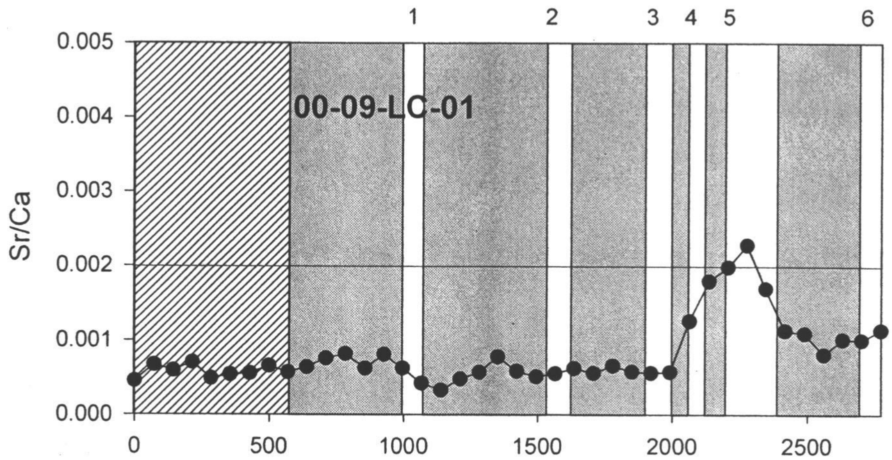

01-00-LC-91 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
1400
1 2 3 4 5 6 7 8 9 10 11

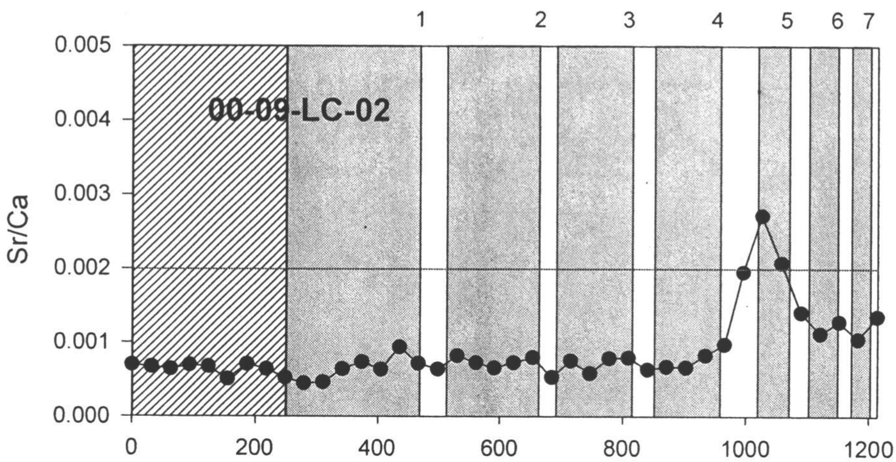
Ikroagvik

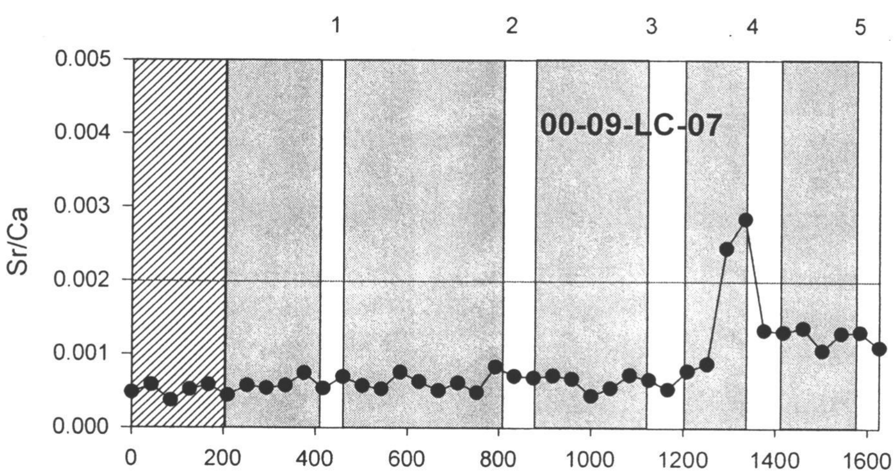


1
2
3
4
5
6
7
8
01-00-LC-127 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
1400

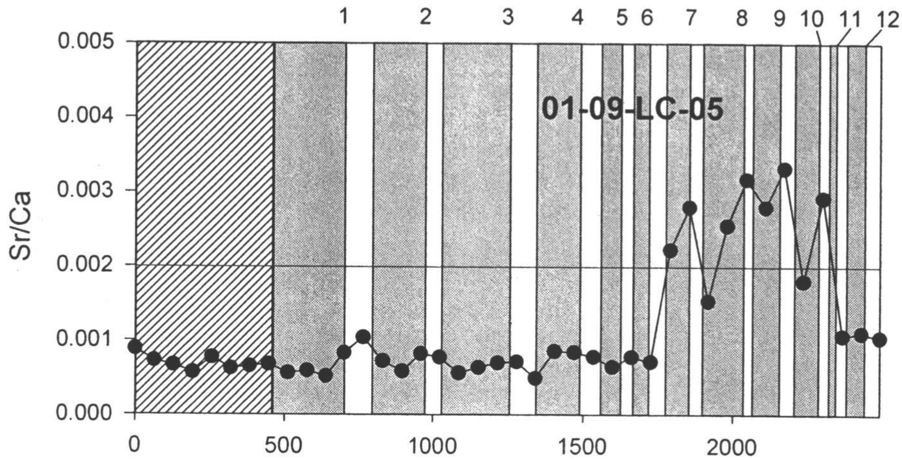
Joeb's

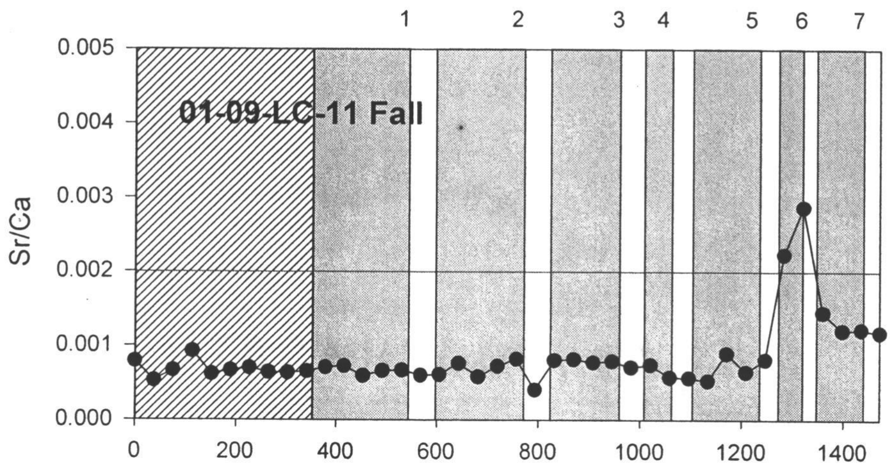

1
2
3
4
5
6
0.005
0.004
0.003
0.002
0.001
0.000
Sr/Ca
00-09-LC-01
0
500
1000
1500
2000
2500

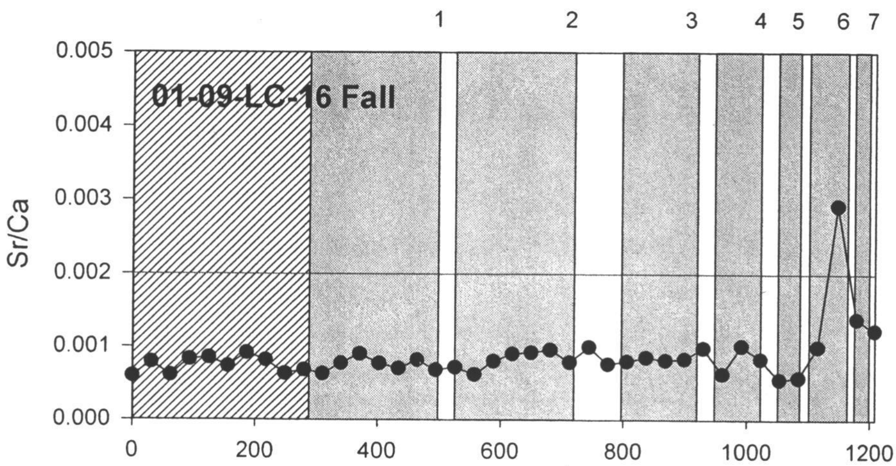

1
2
3
4
5
6
7
0.005
0.004
0.003
0.002
0.001
0.000
Sr/Ca
00-09-LC-02
0
200
400
600
800
1000
1200


1
2
3
4
5
0.005
0.004
0.003
0.002
0.001
0.000
Sr/Ca
00-09-LC-07
0
200
400
600
800
1000
1200
1400
1600

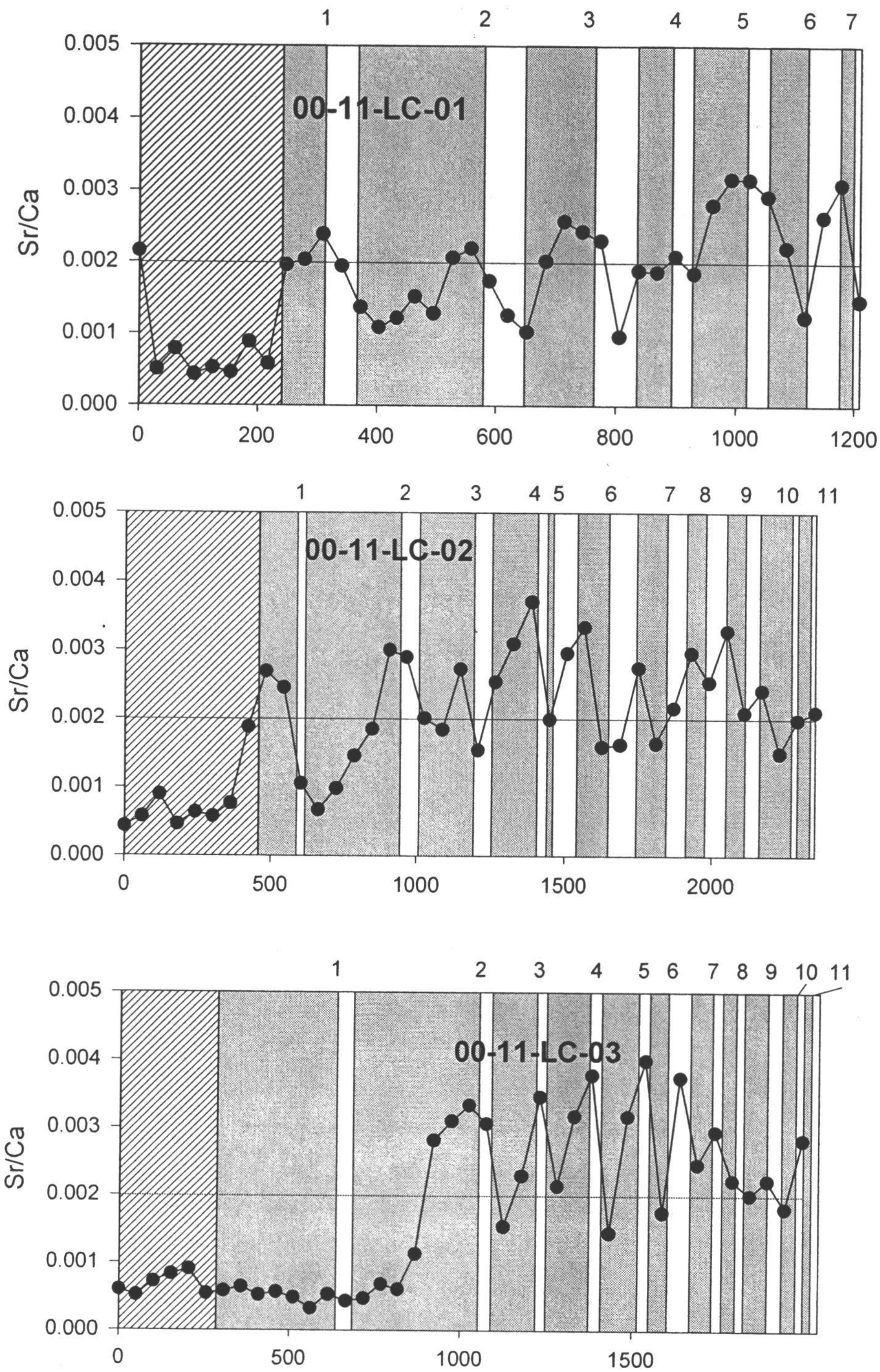
Joeb's


01-09-LC-05
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
500
1000
1500
2000
1 2 3 4 5 6 7 8 9 10 11 12

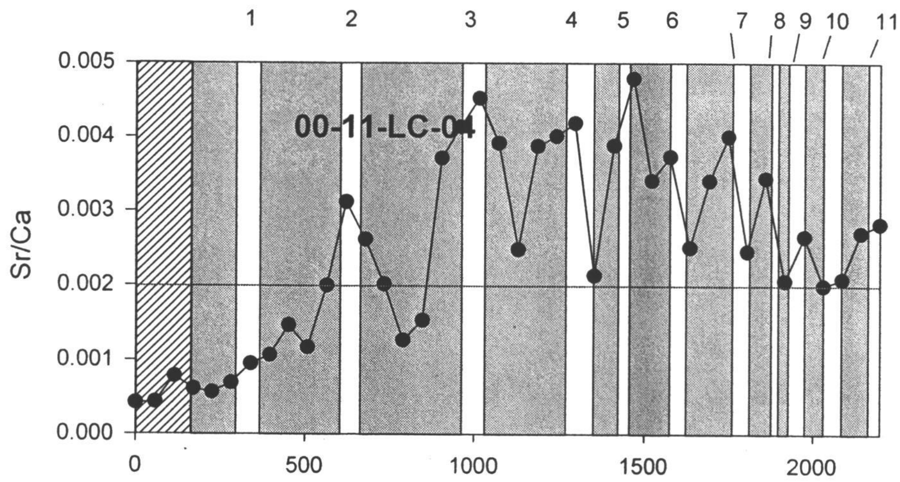

01-09-LC-11 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
1400
1 2 3 4 5 6 7

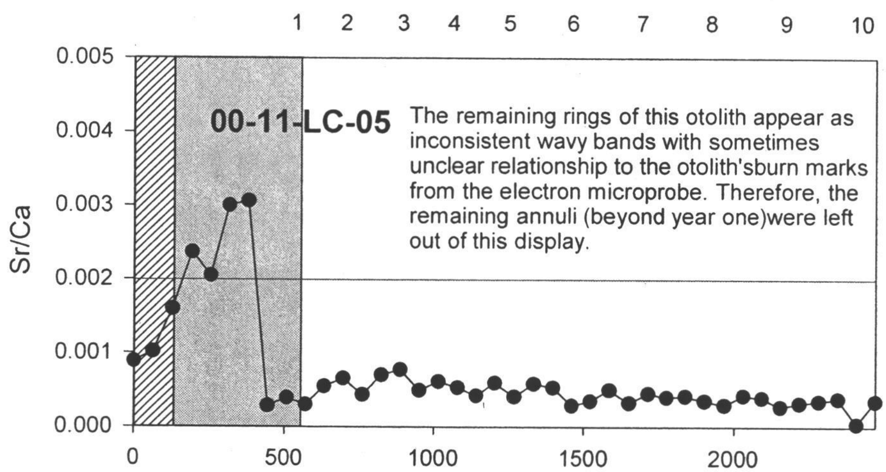

01-09-LC-16 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
1 2 3 4 5 6 7

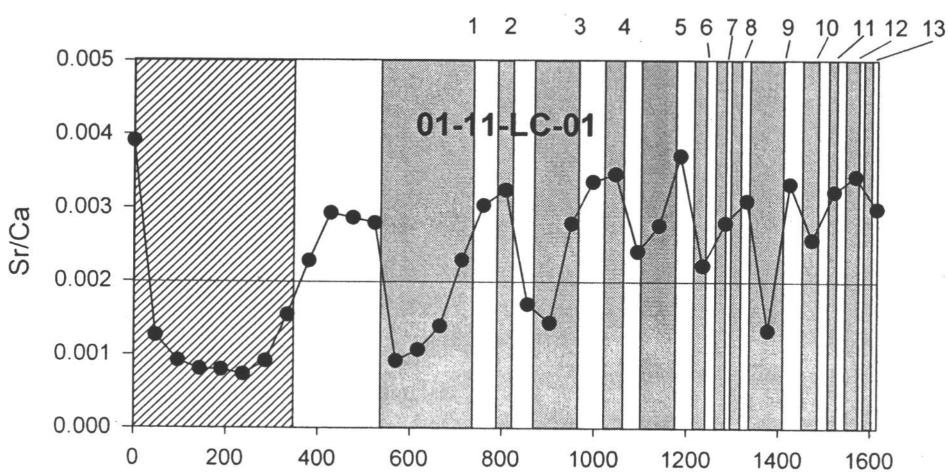
Elson Lagoon



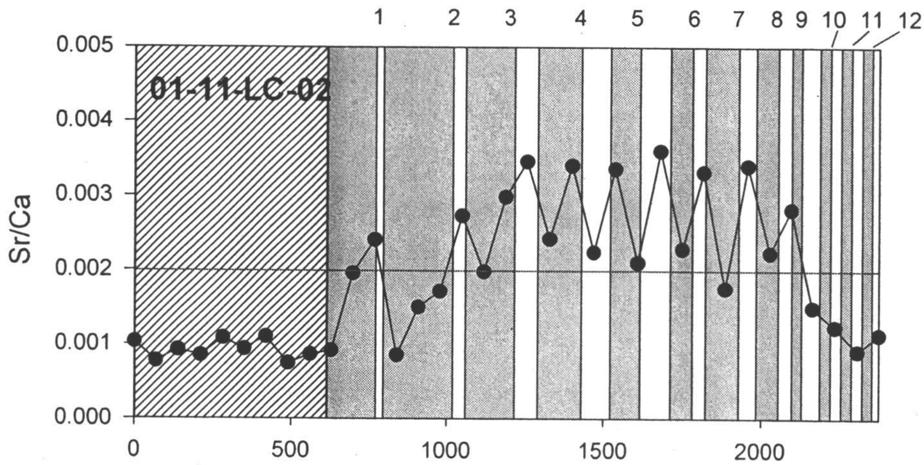
# Elson Lagoon

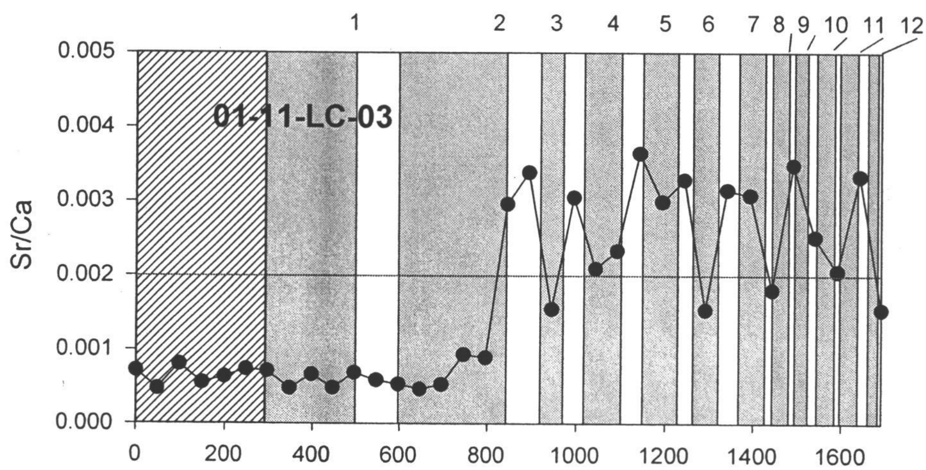


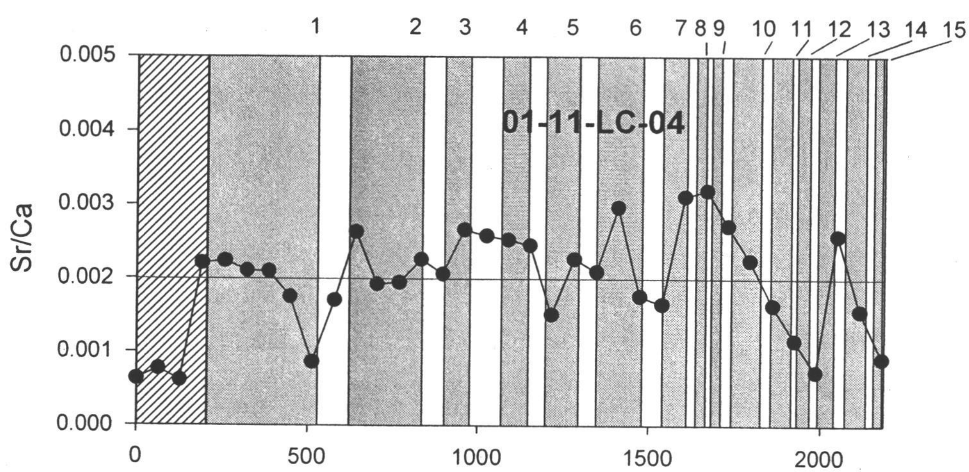



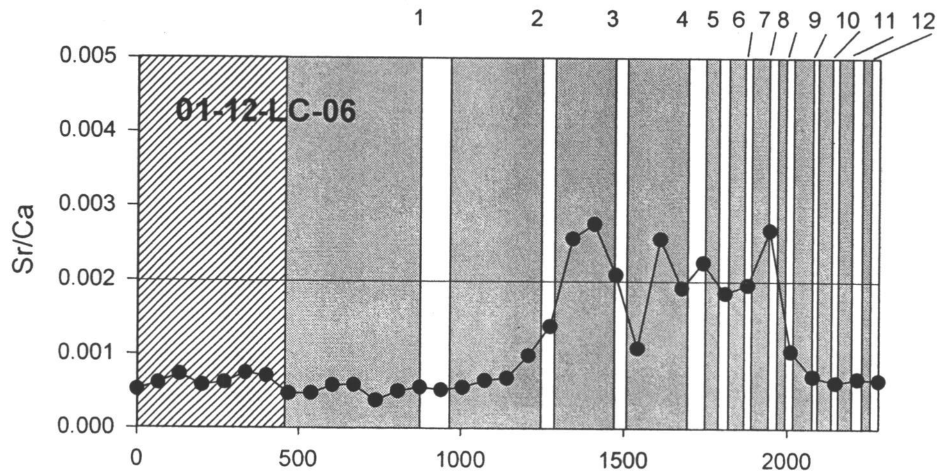
Elson Lagoon



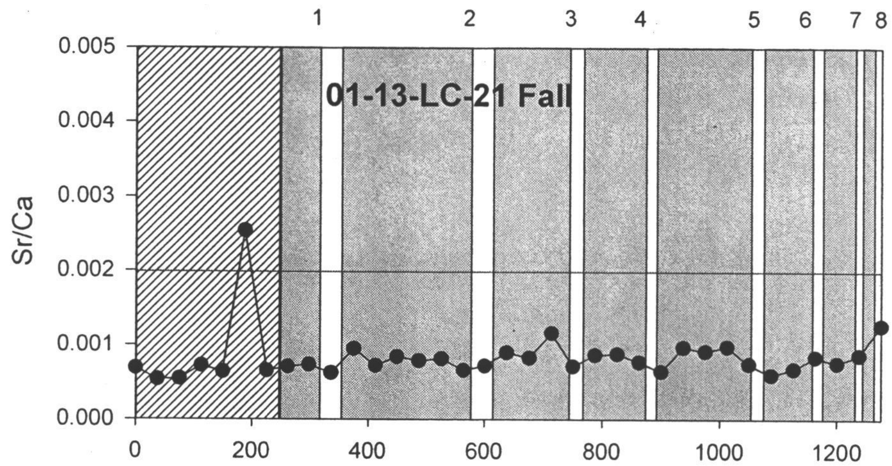



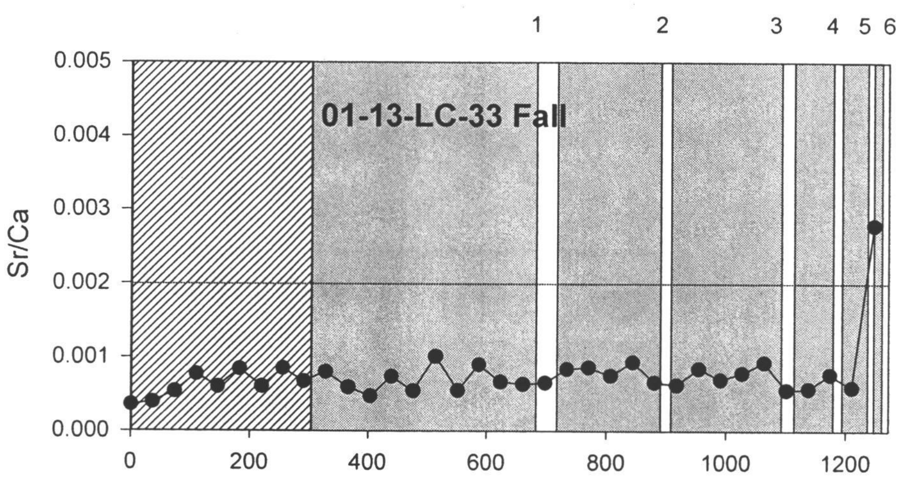
Joeb's 2nd


1
2
3
4
5
6
7
8
9
10
11
12
01-12-LC-06
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
500
1000
1500
2000

Joshua's 2nd



1 2 3 4 5 6 7 8
01-13-LC-21 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200

1 2 3 4 5 6
01-13-LC-33 Fall
Sr/Ca
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200

Teshekpuk- Samples donated by North Slope Wildlife Department