

Project No: F0522

Title: Reproductive ecology of Atka mackerel, *Pleurogrammus monopterygius*, in Alaska

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**Project Summary:** Atka mackerel support a multi-million dollar commercial fishery and play a key role in the marine ecosystem of the Aleutian Islands. This study represents an ongoing research effort examining aspects of Atka mackerel reproductive ecology which will be directly applicable to estimates of spawning biomass, recruitment, stock dynamics, and distribution patterns. In 2004, spatio-temporal patterns in distribution were examined with respect to spawning condition and habitat use for nesting sites. Additionally, Atka mackerel embryos were incubated at different temperatures at the Alaska Sea Life Center to allow the construction of developmental series. This information is essential since egg development at low temperatures in deeper waters could extend the spawning season dramatically and influence distribution patterns. Variability in female maturity schedule was examined and it is proposed to estimate variability of realized fecundity that also directly affects reproductive output and estimation of female spawning biomass. Male spawning biomass might influence reproductive success as much as female spawning biomass due to nest guarding. Egg cannibalism as a mating strategy could maximize individual reproductive success and minimize the energetic costs associated with nest tending in males.

**Specific objectives of this study are to:** 1) analyze additional years of spatio-temporal distributions by reproductive stage, 2) expand embryonic developmental series over finer sampling scales and broader temperature range; 3) determine parentage of egg batches 4) evaluate egg cannibalism using genetic techniques; 5) investigate spatio-temporal variation in reproductive output (maturity schedule, realized fecundity); 6) determine fecundity and egg caloric content of successive batches spawned in captivity

**Progress summary:** Following is summary of progress made for the specific objectives

1) *Analyze additional years of spatio-temporal distributions by reproductive stage.*  
In September 2005, 408 gonad samples were collected at Amchitka Island, Tanaga Pass and Petrel Bank, along with data on sex ratio and length frequency. Collections were made during the spawning season, since an analysis of previous data collected in 2002 at Seguam pass showed the greatest segregation by size and maturity stage during this time.

Spatio-temporal maturity patterns at Seguam pass in 2002 (NPRB project 417 final report) suggest most mature females depart the only area open to commercial fishing at Seguam Pass during the September fishing season.

Preliminary sex ratio and length frequency analysis from the September 2005 samples support the idea of a female spawning migration and indicate a lack of females from the area at Seguam pass open to commercial fishing. The ratio of males to females was 9:1 and the females that were present were smaller in length than the males (Figure 1). Similar patterns (Sex ratio males to females 8:1) and smaller lengths of females (Figure 2) were seen at Petrel Bank in September 2005. To complete this analysis, length frequency data from the fishery at Seguam pass and Petrel bank will be analyzed for additional years to examine whether the pattern of sex segregation is prevalent annually.

We are continuing the description of the male reproductive cycle using histological methodology, with the male Atka mackerel samples collected in March, May and June 2005.

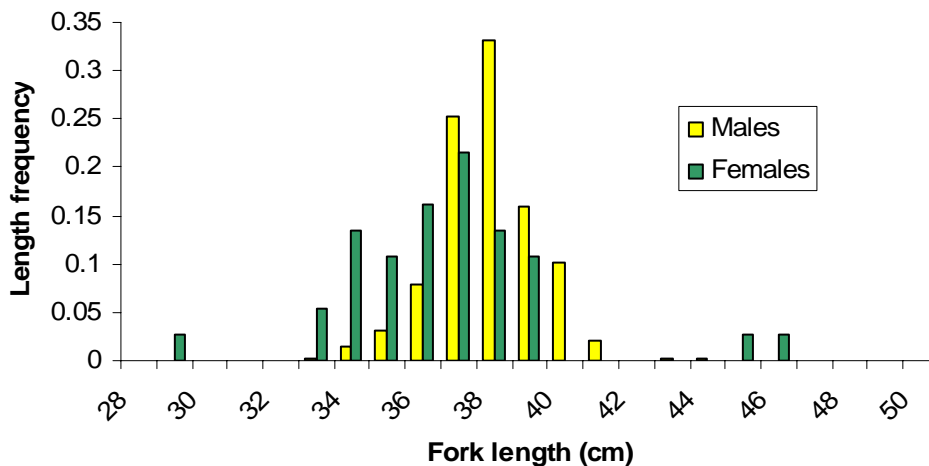


Figure 1. Length frequencies of males and females from Seguam pass in September 2005.

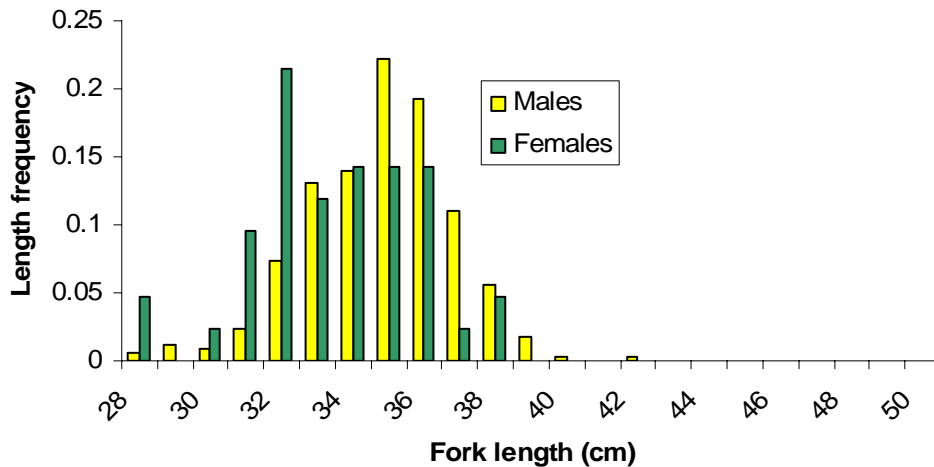


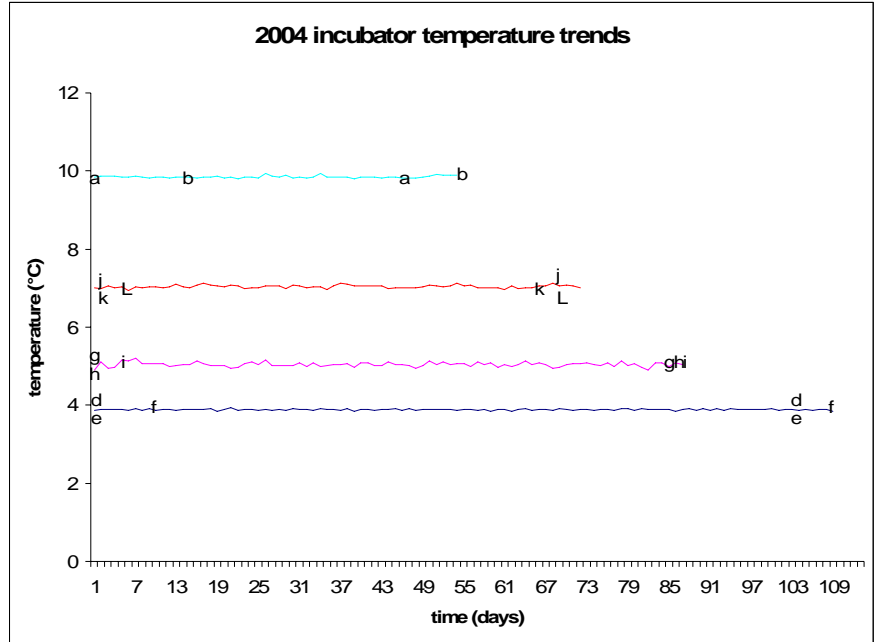
Figure 2. Length frequencies of males and females collected at Petrel bank in September 2005.

2) *Expand embryonic developmental series over finer sampling scales and broader temperature range.*

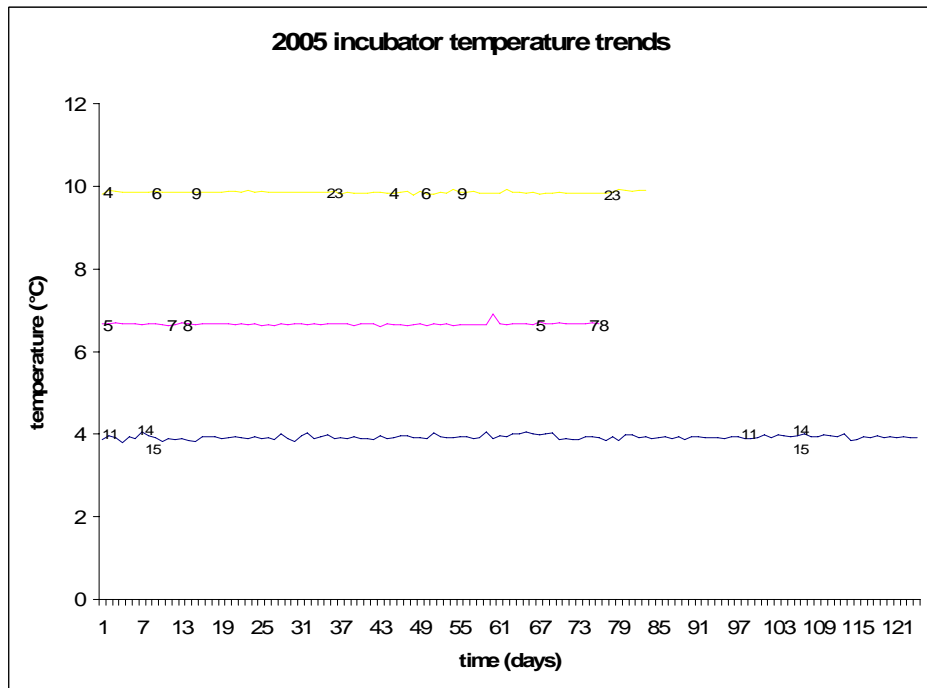
In 2004 and 2005, temperature varied little at all incubation experiments (Figure 3 & 4). A total of 21 incubation experiments at 7 temperature regimes were conducted in both years of our study (Table 1). Preliminary results indicate that time until first hatch decreases with increasing temperature from a maximum of 100.7 days at 3.89°C to a minimum of 40.0 days at 9.85°C (Figure 5).

Lengths and weights have been collected from 2.4.0 (ratio of male to female to unknown) Atka mackerel broodstock to be used in this study.

For the 2006 breeding season, submersible cameras and recording equipment have been reinstalled in the study aquarium at the Alaska SeaLife Center. Equipment was upgraded to better document Atka mackerel spawning behavior and now consists of two color cameras. Incubation regimes have been established at 2°C and 12°C to examine the effect of extreme temperatures on embryo development. Additional egg batches will be incubated at 7°C. An IACUC annual renewal for 2006 has been submitted to the Alaska SeaLife Center’s IACUC for review.



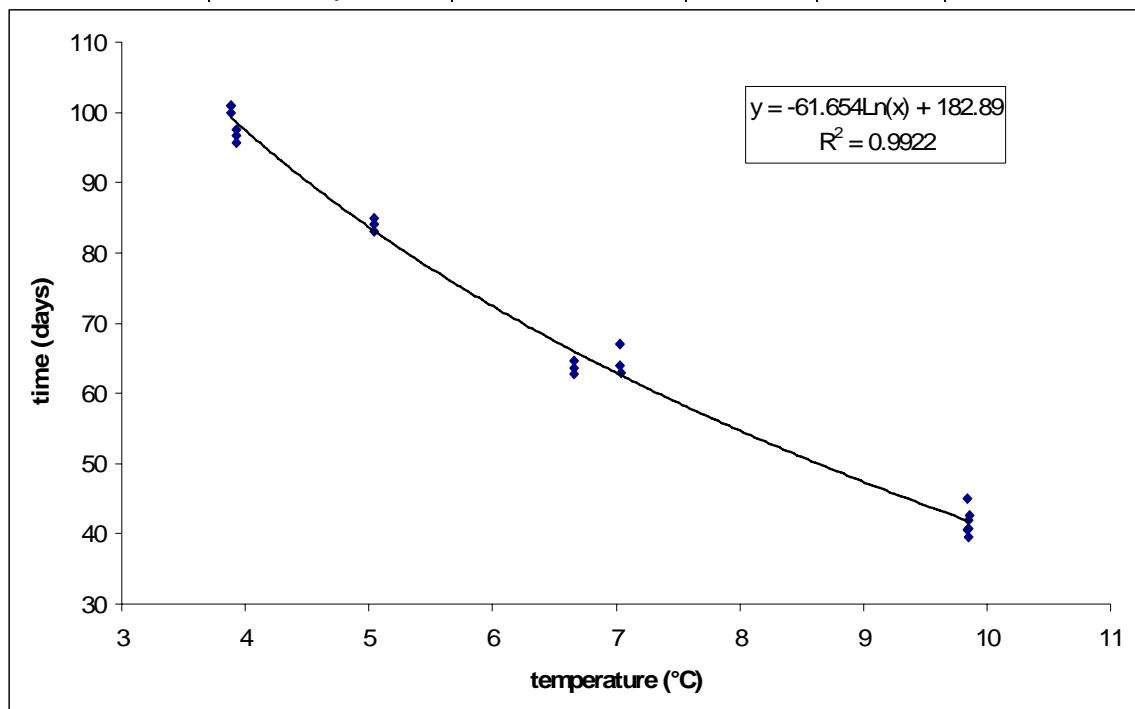
**Figure 3.** Graph showing egg mass temperature trends for each regime in 2004. Mean temperatures were 3.89°C, 5.08°C, 7.02°C, and 9.89°C. Paired letters indicate the duration of incubation for an individual egg mass with the first letter representing time of fertilization and the second representing time of first hatch



**Figure 4.** Graph showing egg mass temperature trends for each regime in 2005. Mean temperatures were 3.92°C, 6.66°C, and 9.85°C. Paired letters indicate the duration of incubation for an individual egg mass with the first letter representing time of fertilization and the second representing time of first hatch.

**Table 1.** Summary of temperature regimes for 2004 (yr04) and 2005 (yr05), corresponding mean time until first hatch and number of egg masses incubated.

Temperature Regime	Mean time until first hatch	Std. Error	n
3.89 yr04	100.7	0.333	3
3.92 yr05	96.6	0.559	3
5.03 yr04	84	0.577	3
6.66 yr05	63.7	0.523	3
7.02 yr04	64.7	1.201	3
9.85 yr05	40.9	0.61	4
9.89 yr04	43.5	1.5	2



**Figure 5.** Time until first hatch as a function of incubation temperature.

### 3) Determine parentage of egg batches.

Lengths and weights were collected for Atka mackerel broodstock. Natural markings from the 6 known males were documented to later be used for identification of males guarding territories.

#### Spawning event summer 2004

Thirteen egg masses, produced by two males and four females in captivity at the Alaska SeaLife Center in 2004, were genotyped using DNA microsatellite markers to determine parentage. We genotyped 96 eggs per clutch for the first two clutches and determined that a single pair of parents was responsible for each clutch and that a single male dominated spawning events (Table 2). These results were not consistent with those observed for egg masses collected in the field, where multiple parentage is very common, and we attribute them to the controlled conditions for mating in captivity (e.g. small tank,

limited numbers of parents). We elected not to exhaustively sample the remaining clutches and instead analyzed 24 embryos from each. Twelve of the 13 egg masses appeared to be produced by a single set of parents. The exception was a single egg mass that was primarily fertilized by Male 1, but had a small proportion (~10%) of eggs fertilized by Male 2. There was also some variation in the realized fecundity of the females; one female produced six of the 13 egg masses and the other three females produced one, two, and three batches, respectively.

Table 2. Parentage assessment of egg masses produced in captivity in 2004.

Egg mass	Parents
1	Female B, Male 2
2	Female B, Male 2
3	Female B, Male 2
4	Female B, Male 2
5	Female A, Male 2
6	Female A, Male 2
7	Female D, Male 1; Male 2 fertilized ~10% of the offspring
8	Female B, Male 2
9	Female D, Male 2
10	Female C, Male 2
11	Female B, Male 2
12	Female D, Male 2
13	Female A, Male 2

We have collected 15 egg masses produced in the bird exhibit at the Alaska Sea Life Center produced in 2005 and have fin clip samples from all possible parental fish. We anticipate the larger size of the exhibit and more natural conditions may have allowed more polygamous matings, as observed in field collections. We will determine parentage of some subset (up to five) of these egg masses to evaluate whether polygamous matings occurred. An additional five egg masses collected from natural populations during summer, 2006 will also be analysed.

#### *4) Evaluate egg cannibalism using genetic techniques.*

Highly polymorphic DNA markers were used to assess parentage of embryos consumed by five adult Atka mackerel of each gender. Gut contents contained both single eggs and one or two partial egg masses (Table 3). Most of these egg masses consisted of batches of developing full and half-sib embryos produced by multiple (3 - 8) parents. All female cannibals were excluded as the mother of embryos they had eaten, thus indicating heterocannibalism. Similarly, four of five males in spawning coloration were excluded as sires of cannibalized embryos, with the exception of one male cannibal, determined to be the sire of two half-sib families detected in one egg mass, thus documenting filial cannibalism by male Atka mackerel. However, this male sired only 22 % of the embryos genotyped in the egg mass, which contained a minimum number of eight parental genotypes. It is unknown if he was the attendant male or an adjacent territory holder. The complex polygamous mating system inferred from preliminary analyses of partially

cannibalized egg clutches suggest that sneaked fertilizations and nest raiding by males may be common behaviors in this species. It seems highly improbable that females would exhibit filial cannibalism so we will focus on parental determination of 10 partial egg masses from male cannibals to get a better estimate of the frequency of this behavior in natural populations.

Table 3. Genetic assessment of patterns of cannibalism in male and female Atka mackerel.

Cannibal	# partial egg masses consumed	minimum # of parents			cannibalism type H = heterocannibalism F = filial cannibalism
		mass 1	mass 2	indeterminate*	
♂ 1	2	8	4		H, F. ♂ 1 sired two half-sib families (22% of all cannibalized embryos)
♂ 3	indeterminate			?	H
♂ 5	indeterminate			?	H
♂ 6	2	3	3		H
♂ 8	2	2	3		H
♀ 1	2	6	5		H
♀ 3	1	8			H
♀ 4	indeterminate			2	H
♀ 5	indeterminate			6	H

5) Investigate spatio-temporal variation in reproductive output (maturity schedule, realized fecundity).

Maturity at age and length analysis for the 146 samples collected in 2004 has been completed. The results were compared with results from previous years (1992-1994, 2002, and 2004). The data were compared using a generalized Linear model with area and time period as factors (S-Plus, Venables and Ripley, 1994).

When comparing all years, maturity at age did not vary by INFPC area ( $p = 0.40$ ) (Figure 6). Maturity at age was marginally significantly different by time period ( $p=0.053$ ; Figure 7). However, maturity at length varied significantly by area ( $p \ll 0.0001$ ; Figure 8) and time period ( $p \ll 0.0001$ , Figure 9).

It appears that female maturity for Atka mackerel is determined by age and not size. At age 4, most females will be mature (50% age at maturity is 3.5 years) regardless of their size at this age. A model that predicts changes in year class strength was developed in collaborations with Jim Ianelli (AFSC). It showed that changes in year-class strength cause annual variation in length at 50% maturity of up to 2cm, even if maturity at age and growth remains constant (Fig 10). A manuscript of these results is in internal review.

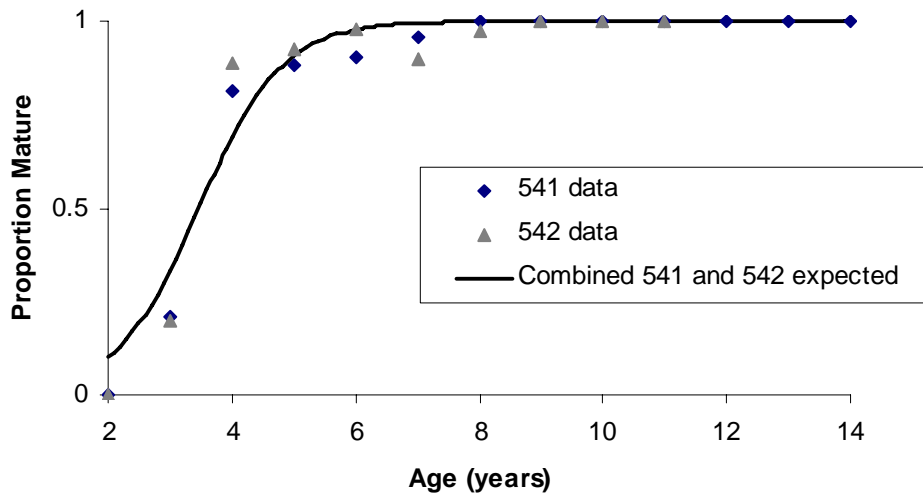


Figure 6. Proportion mature at age by INFPC area.

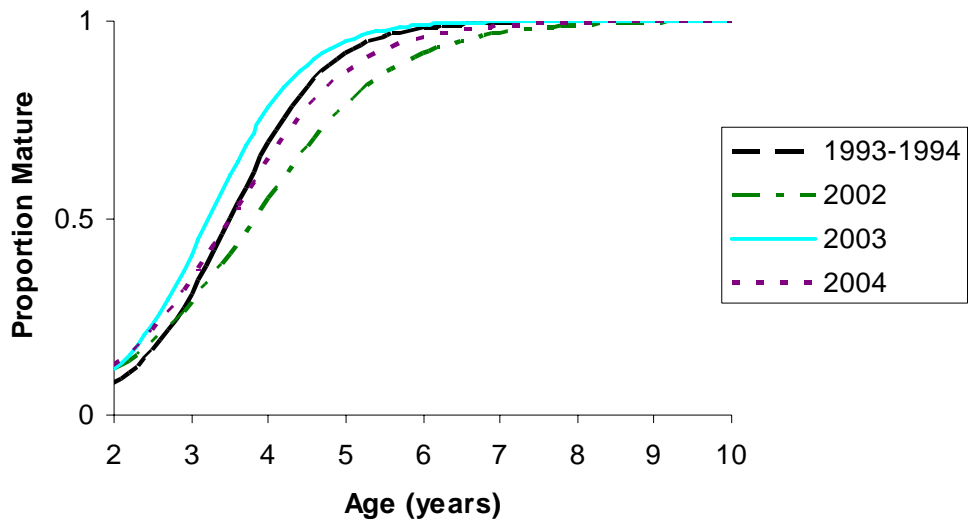


Figure 7. Proportion mature at age (INFPC areas 541 and 542 combined) by time period.

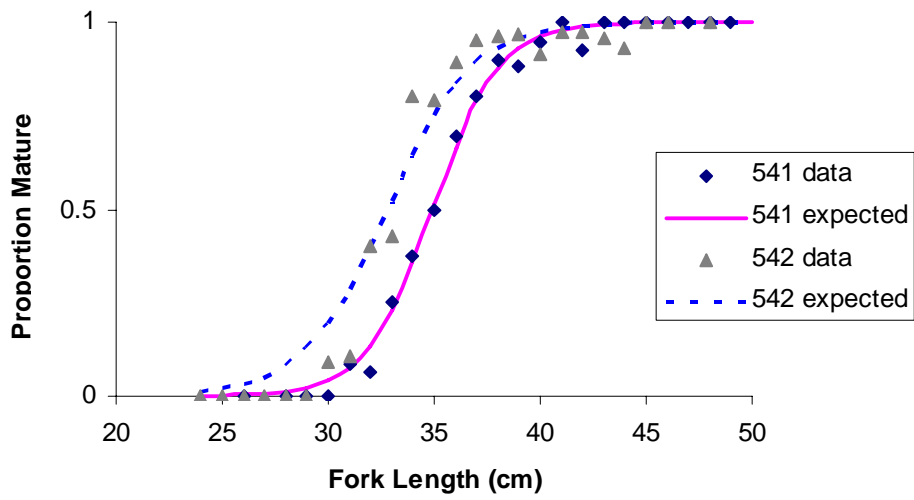


Figure 8. Proportion mature at length for INFPC areas 541 and 542.

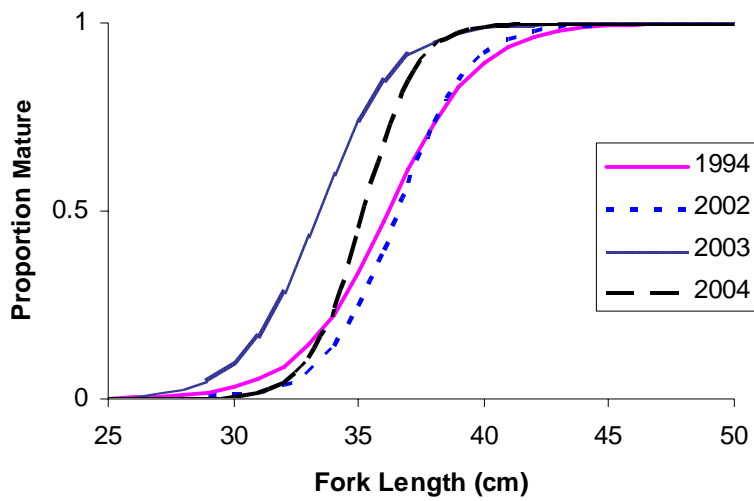


Figure 9. Proportion mature at length over time for INFPC area 541.

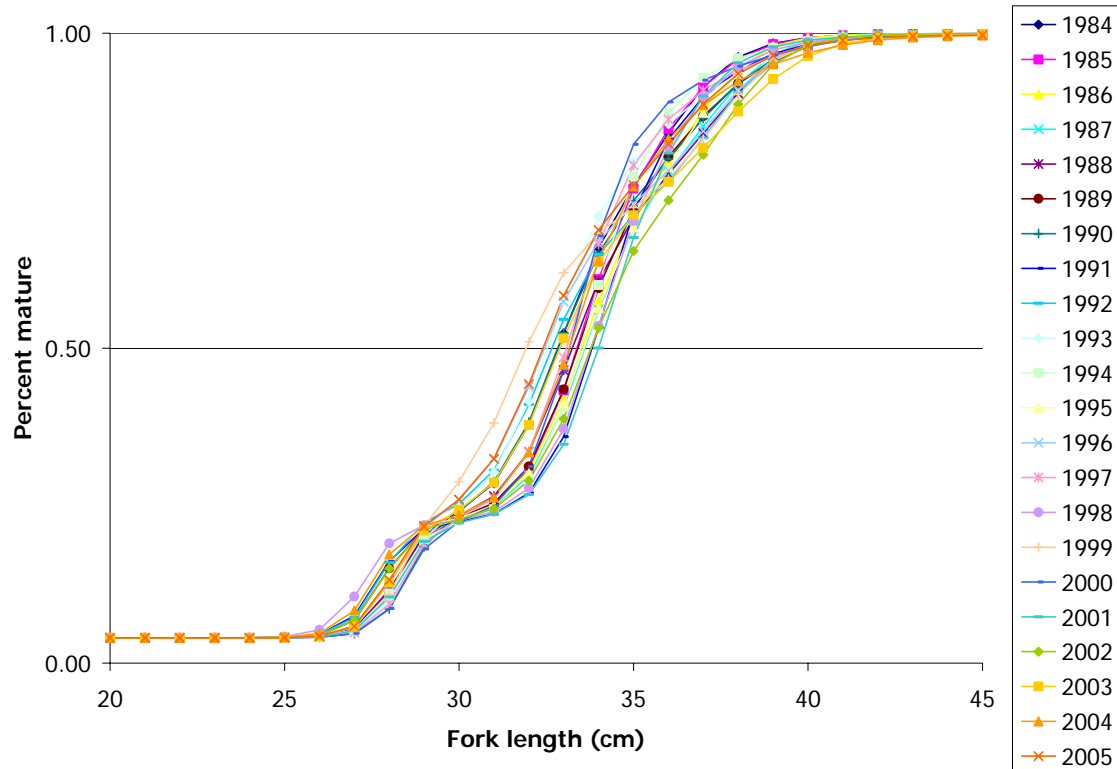


Figure 10. Model predicted proportion mature by length for 1984 – 2005.

6) *Determine fecundity and egg caloric content of successive batches spawned in captivity.*

Female gonad samples were collected from the 2005 Gulf of Alaska trawl survey, and from September in 2005 aboard the FV *Seafisher*. Those samples will be used to determine the methodology for estimating egg energetic content.

Researchers at the Alaska SeaLife center collected samples for fecundity and egg caloric analysis and shipped subsamples to Seattle. Spawning of eight (3.5.0) captive Atka mackerel began 7/13/05 at the Alaska Sealife Center and yielded forty separately deposited egg masses. Lengths and weights have been collected from 2.4.0 Atka mackerel broodstock. Gravimetric sampling was performed on each egg mass to determine number of eggs per egg mass. Sub samples for each egg mass were preserved for genetic analysis which will be used to determine maternal parentage. Analysis of maternal parentage, number of eggs per egg mass, and time order of egg deposition is planned.

Outreach:

Guthridge, J. L., N. Hillgruber, and R. Lauth (2006). Embryonic development of Atka mackerel and the effect of temperature. AFS Juneau Student Symposium. April 2006 (Oral presentation)

Guthridge, J. L., N. Hillgruber, and R. Lauth (2006). The effect of temperature on hatch time for Atka mackerel. 14<sup>th</sup> Western Groundfish Conference, Newport, Oregon. January/February 2006 (Poster)

Guthridge, J. L., N. Hillgruber, and R. Lauth (2006). The effect of temperature on hatch time for Atka mackerel. Marine Science in Alaska: 2006 Symposium. January 2006, Anchorage, Alaska. (Poster)

Cooper, D., and S. F. McDermott (2006). Atka mackerel reproductive biology, Temporal and spatial variation in Atka mackerel maturity schedule. Marine Science in Alaska: 2006 Symposium. January 2006, Anchorage, Alaska. (Poster)

McDermott S. F. (2006). Current research of Atka mackerel at the Alaska Fisheries Science Center. Multicultural Initiative in the Marine Sciences (MIMSUP event), Alaska Fisheries Science Center.

Spies, I.S. and M. Canino. (2006) Atka mackerel reproductive biology, Genetic assessment of cannibalism and the mating system of Atka mackerel. Marine Science in Alaska: 2006 Symposium. January 2006, Anchorage, Alaska. (Poster)

Spies, I.S. and M. Canino. (2006) "Its elementary, dear Watson"; How genetics can provide clues to population structure, cannibalism, and the mating system of Atka Mackerel. Science in the Sound Speaker Series, Highline Community College. May, 2006, Seattle, WA. (Oral presentation; [http://flightline.highline.edu/mast/06-Speaker\\_listing.htm](http://flightline.highline.edu/mast/06-Speaker_listing.htm)).