Implementation of a gross anatomical maturity key for the study of spawning phenology and geography of Pacific cod (*Gadus macrocephalus*

NOAA FISHERIES
Alaska Fisheries Science Center

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Presentation outline

- Project background
- Research objectives
- Maturity key
  - implementation
  - histological stage comparison
- Maturity data analysis
  - geography
  - phenology
- Implications
  - biological
  - fishery management

Background: Pacific cod spawning behavior

- Form large spawning aggregations
- Site fidelity; returning to spawning grounds year after year
- Synchronous, single batch spawners
- Eggs are demersal and slightly adhesive
- Few eggs are retained in ichthyoplankton research nets
- Little is know about spawning and dispersal patterns

Background: Pacific cod are ecologically and economically important species

Top predator and an important prey species for sea lions

Supports the 2nd largest commercial fishery in the Bering Sea

Fishery targets spawning aggregations

Research objectives

- Maturity key
  - Development
  - Implementation
  - Validation
- Analyze observer maturity data to identify:
  - Spawning locations
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  - Fishery management
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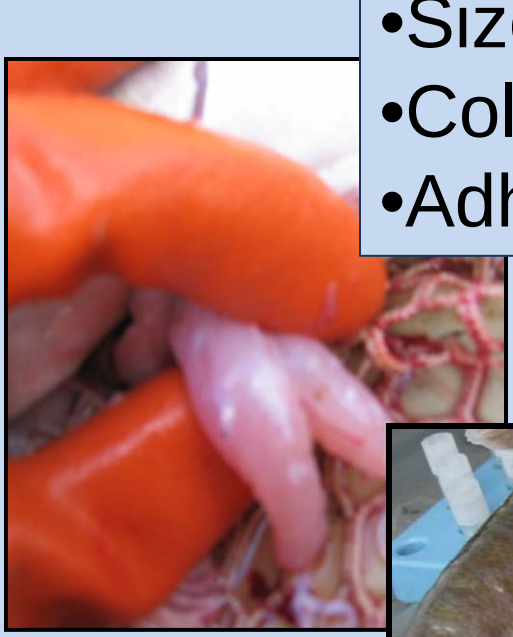
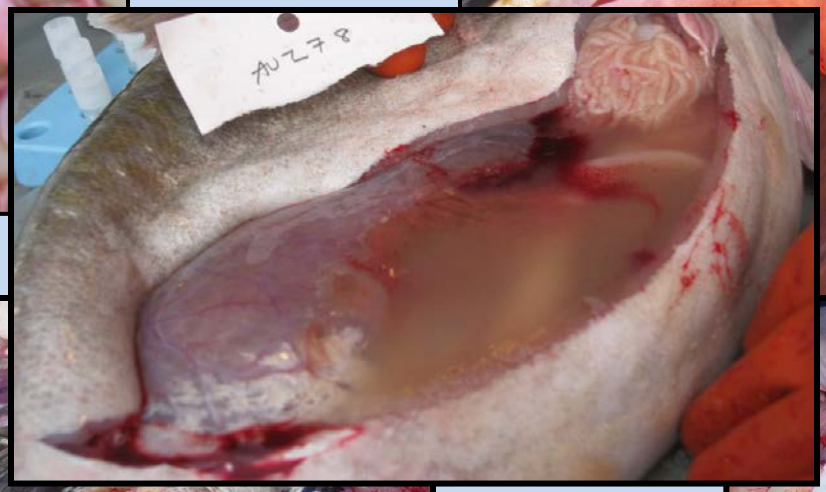
Background: Maturity keys provide an inexpensive and easily applied tool for extensive data collections

- Developed a gross anatomical maturity key based on morphological changes that occur in the ovary during maturation
- Maturity keys are easily deployed and applied in the field
- Maturity keys are often subject, particularly for ovaries in transitional stages of development
- Histological processing is often used to validate maturity key assignments

Key characteristics used in determining spawning stage

- Size
- Color
- Adhesiveness





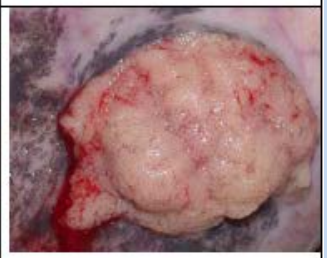
PACIFIC COD MATURITY CODES (FEMALES)

1. Immature
Gonads small, close to vertebral column, may be difficult to sex. Ovaries appear as pink or transparent paired sacs, no oocytes are visible to the eye.

* Look for transparent or pinkish coloration. There may be slight silver or dark blotching on the surface, but the ovary should be small and new looking as shown.

2. Developing
Gonads small, to about ½ the length of body cavity. Ovaries form 2 tapered, distinct lobes having well-developed blood vessels. Transparent and/or opaque orange oocytes are distinct and visible through the ovary wall. Oocytes stuck together forming a solid mass.
* The ovary shown is fairly small, as stated above the developing ovary can be up to half of the body cavity

3. Pre-Spawn
Ovaries form 2 large distinct lobes. Most eggs appear as mature clear ova, some oocytes remain interspersed throughout the ovary. Ova are less adhesive resembling the consistency of pudding.

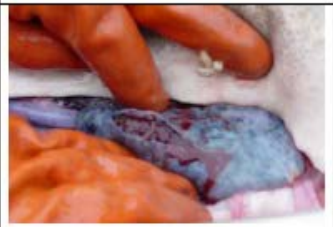


4. Spawning
Eggs run under slight pressure to the body. Ova are loose in the ovary.

* No photo available for spawning females though the ovaries look very much like the stage 4 ovary shown above. Spawning fish often release their eggs as they die in fishing gear.

* To differentiate ovary stages 2 through 4 look at the adhesive quality of the eggs. Stage 2 eggs form a solid mass while stage 3 eggs are looser and stage 4 eggs flow freely.

5. Spent
Gonads are still large, but appear flaccid and watery. Ovaries may contain remnants of disintegrating ova and associated structures.



* Spawning females who have released their eggs (as mentioned above) should still have some loose eggs in the ovary, with the ovary very flaccid. The ovary starts to shrink, looking wrinkled or bumpy as in the example. Disintegrating ova and structures look bloody.

6. [Resting]
Ovaries small, firm, may have some black or silver color. No oocytes are visible to the eye.

* Look for small ovaries (as shown or slightly larger) in larger fish. The surface will be dark or silver and fibrous. The shape is more triangular and thicker than an immature ovary.

- **Immature**: small and transparent
- **Developing**: up to ½ length of abdominal cavity, orange, tightly bound
- **Prespawning**: greater than ½ length of abdominal cavity, opaque, loosely bound
- **Spawning**: free flowing under light pressure
- **Spent**: small, flaccid, and bloody
- **Resting**: Small, dense, dark

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Data collection: two separate data collections used for project

- Research tagging cruises 2003-2005
  - Fishery biologists collaborated on changing key characteristics for maturity stage assignments
  - Collections limited to research cruise dates and locations

- NMFS Commercial Fishery Observer 2005-2007
  - Observers work independently to apply key descriptions to assess maturity
  - Collections limited to areas fished during open seasons

Results: Data tables

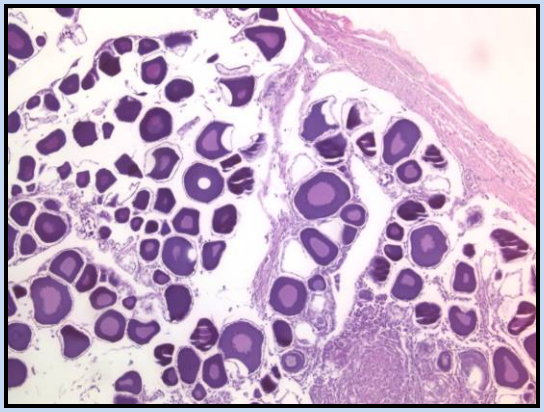
Year	Visual Maturity	Histological Specimens
2003	6,046	380
2004	7,415	407
2005	6,596	515

Research Cruise Collections

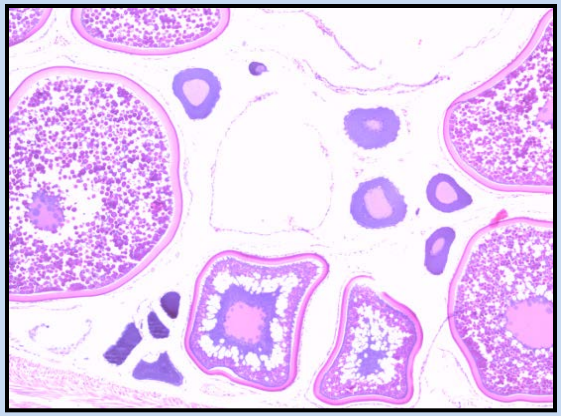
NMFS Fishery Observer Collections

Year	Visual Maturity	Histological Specimens
2004	4,600	
2005	32,500	
2006	30,000	
2007	27,900	600
2008	8,000	430

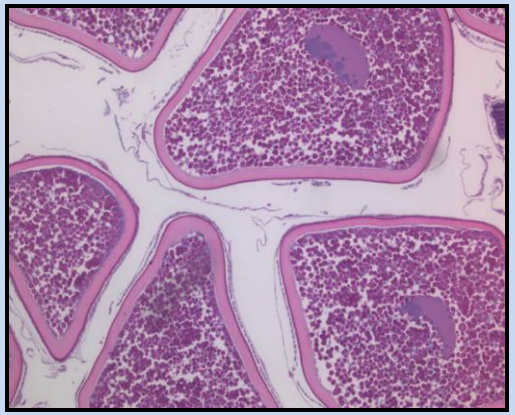
Pacific cod histology



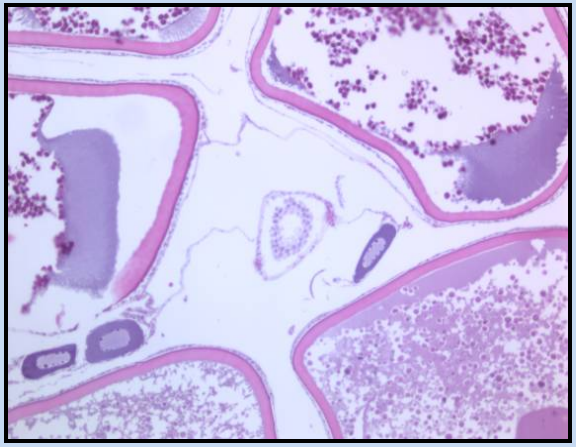
Perinuclear (NYolk)



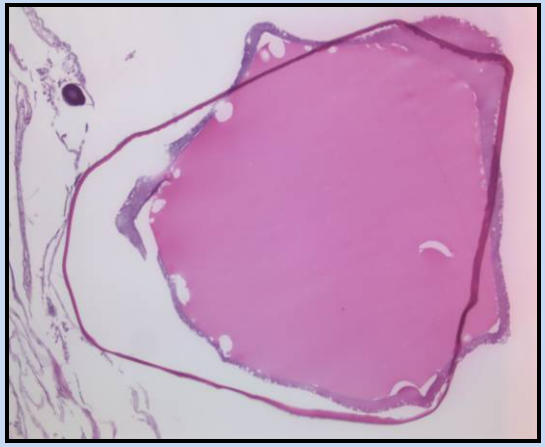
Cortical alveoli (EYolk)
Early vitellogenesis



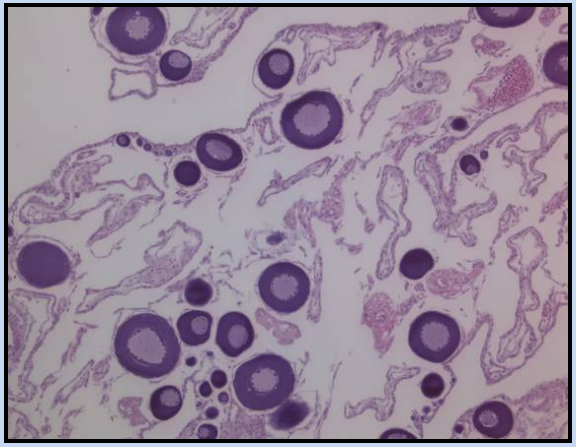
Med vitellogenesis (MYolk)
Nuclear migration



Late vitellogenesis (LYolk)
Yolk fusion YC



Hydration (HYD)



Post-ovulatory
Follicles (POF)

Maturity key conclusions

- This inexpensive tool is easy to train, and has a distribution potential on a scale far greater a than histological specimen collections

- Validation is essential, though correct calibration between measures of maturity is important

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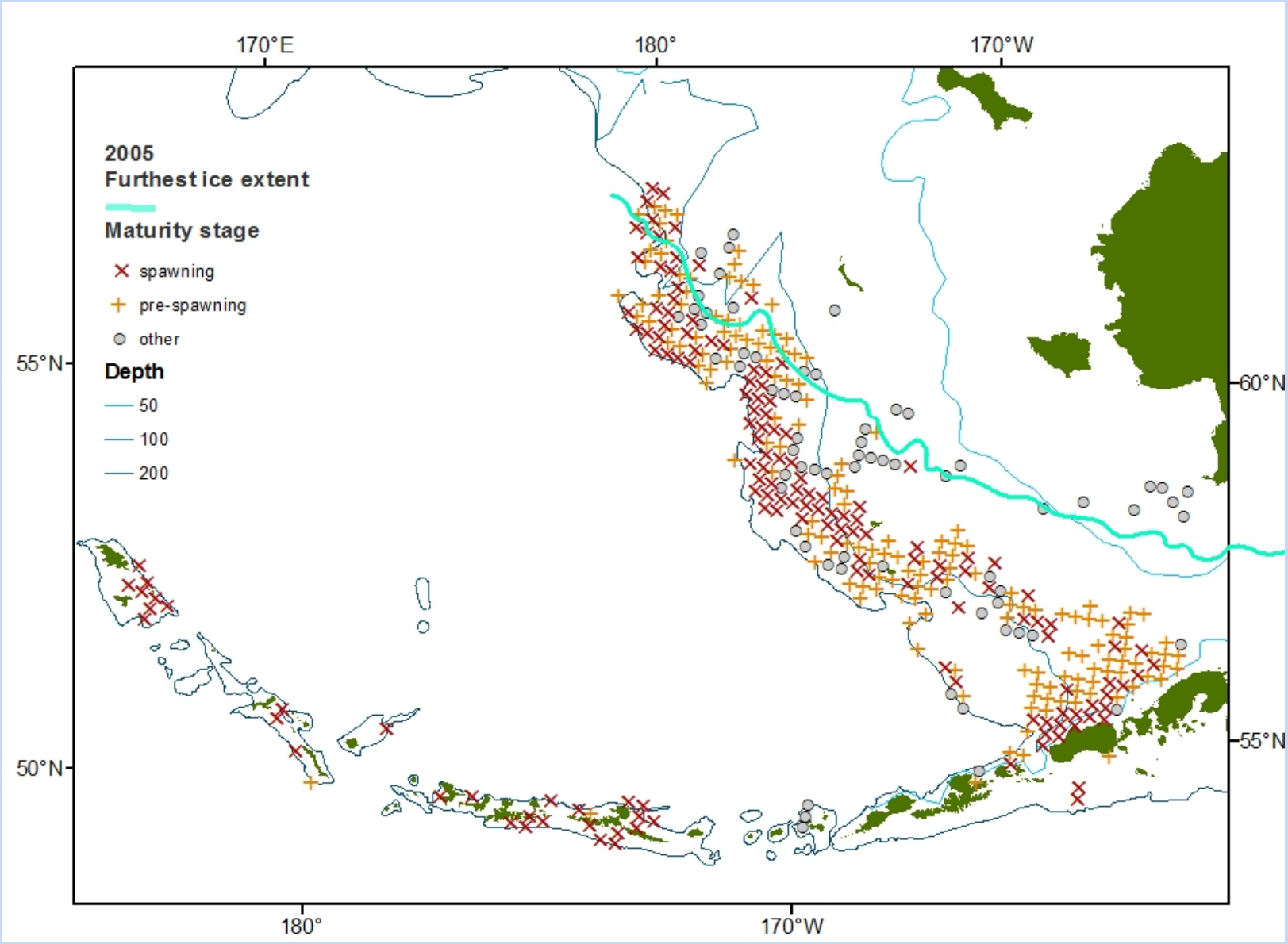
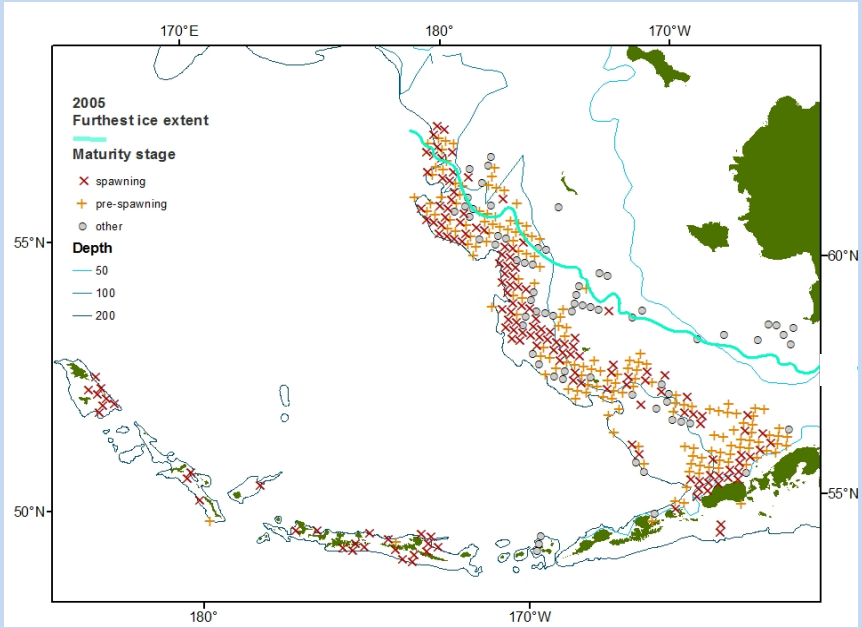
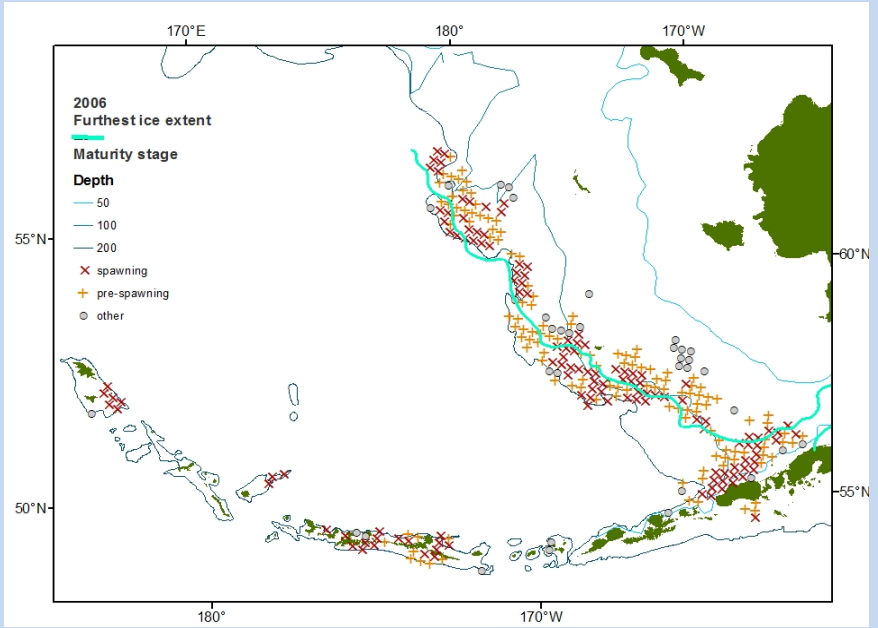
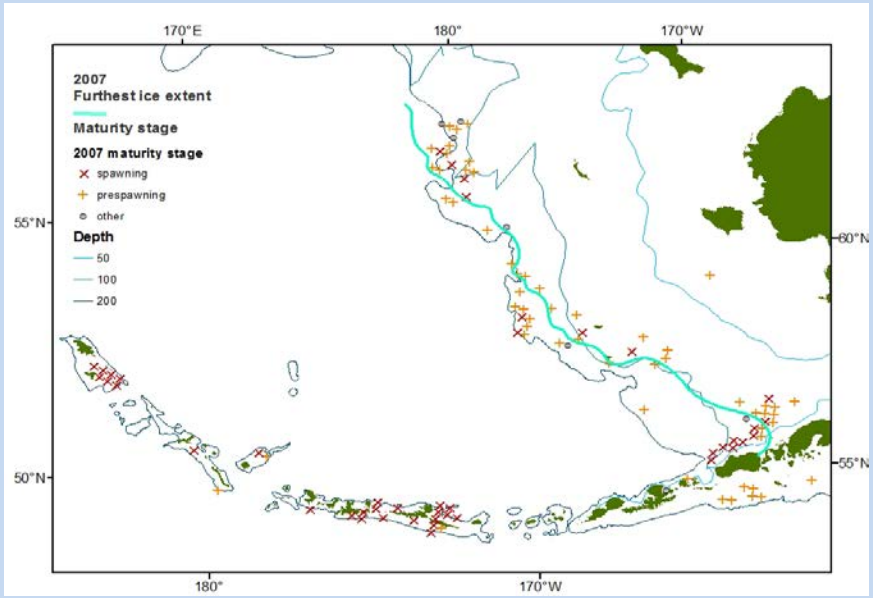
Observer maturity spawning and prespawning stages show spawning distributed along the BS outer shelf and AI



Spawning and prespawning locations for years of varying climate conditions







Spawning occurs along the outer continental shelf between 100 and 200 isobaths in the Bering Sea and Aleutian Islands

Ice coverage may prevent access to the fishing grounds in very cold years

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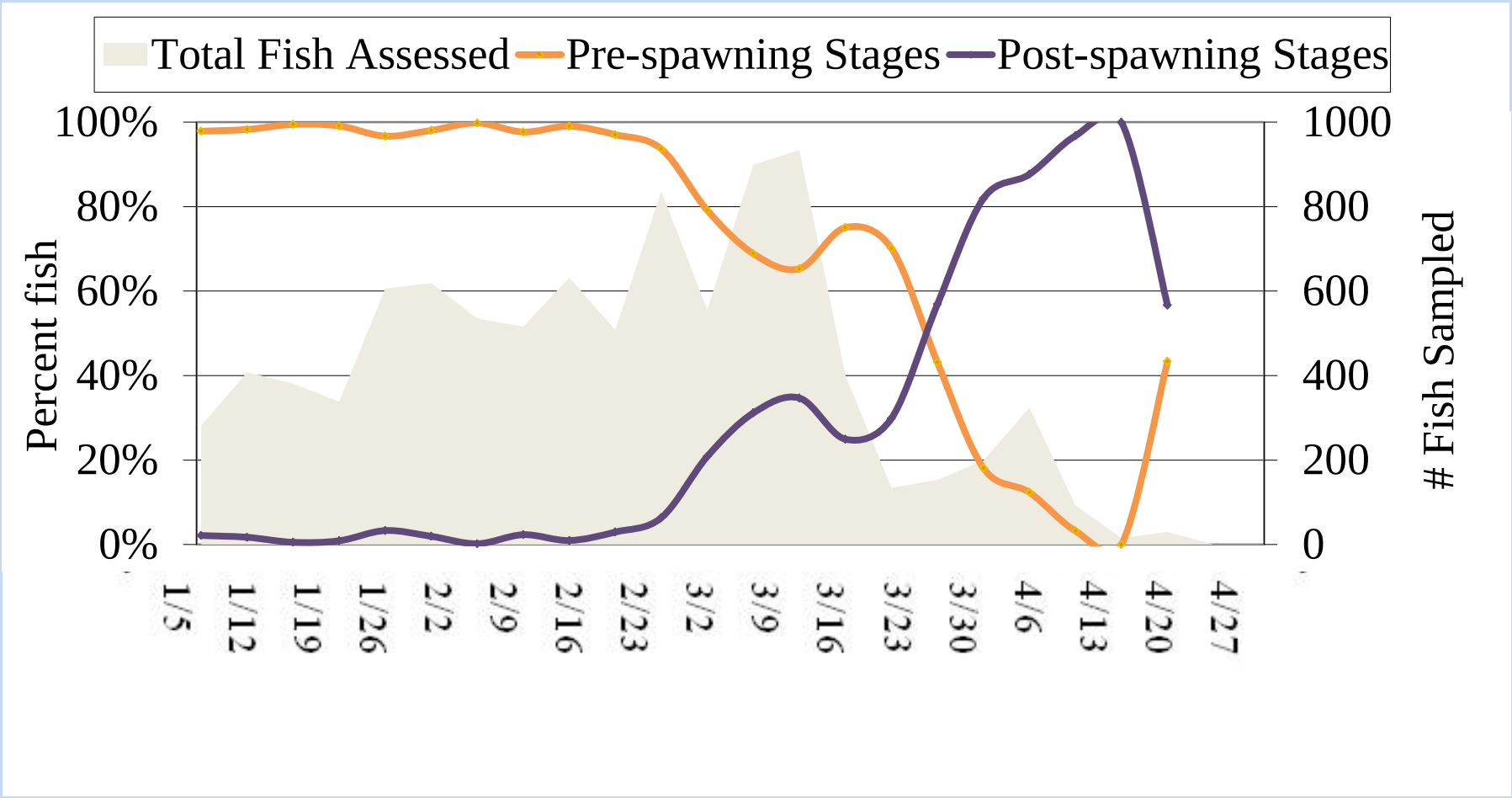
Spawning phenology

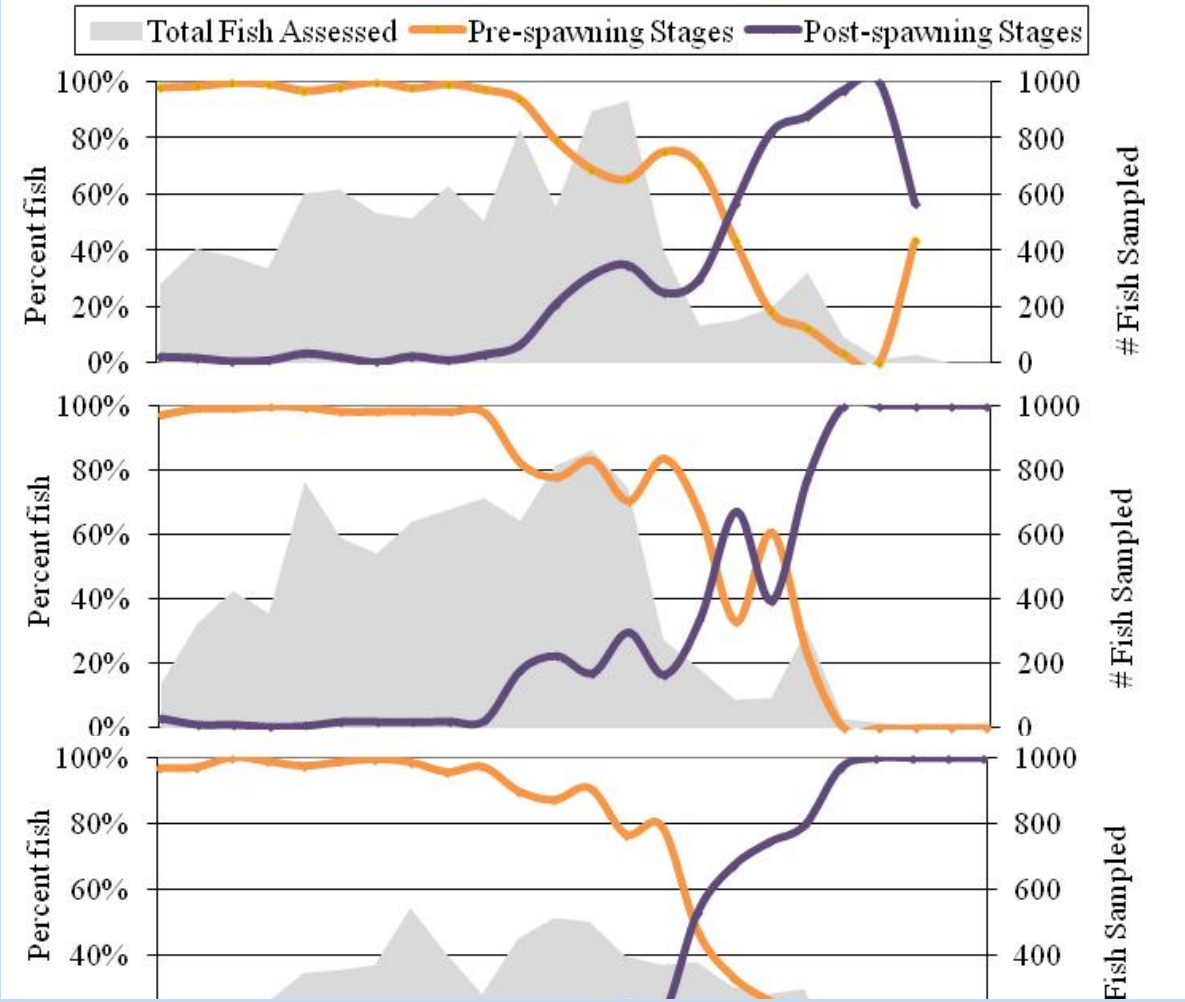


Spawning phenology variation among study years

2005 (warmer year)
Earlier start to spawning

2006 (transition year)
Longer spawning season

2007 (colder year)
Delayed start and shorter



Neidetcher, S.K., et al., Spawning phenology and geography of Aleutian Islands and eastern Bering Sea Pacific cod (*Gadus macrocephalus*). Deep-Sea Res. II (2014)

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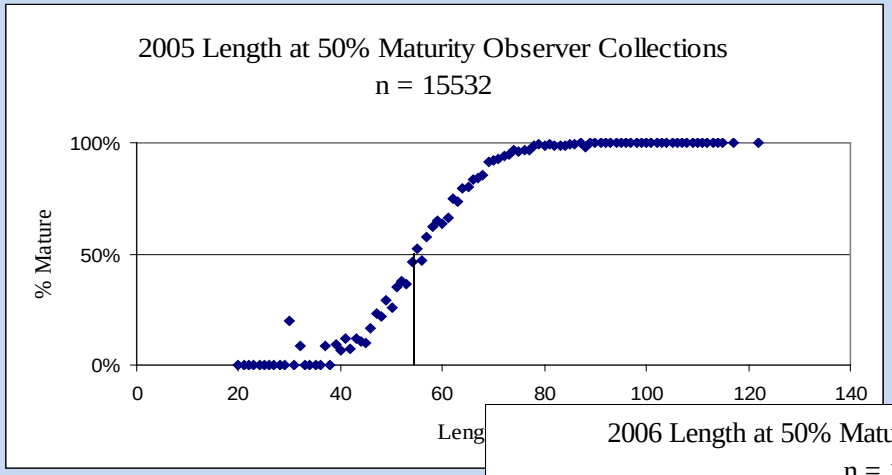
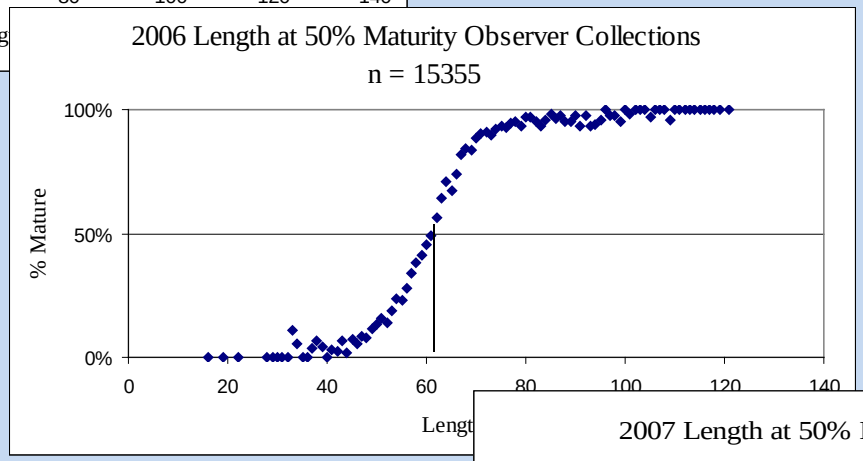
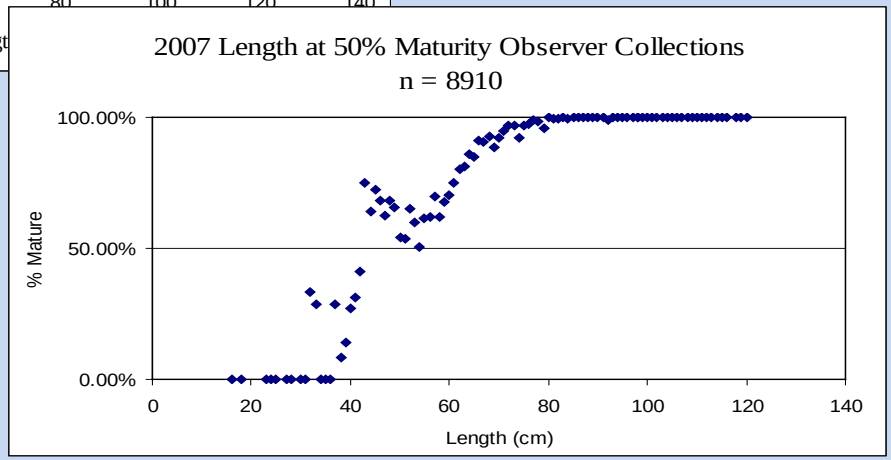
Additional results







Length at 50 % Maturity
56 – 62 cm

Stark, 2007 L_{50} = 58.0 cm

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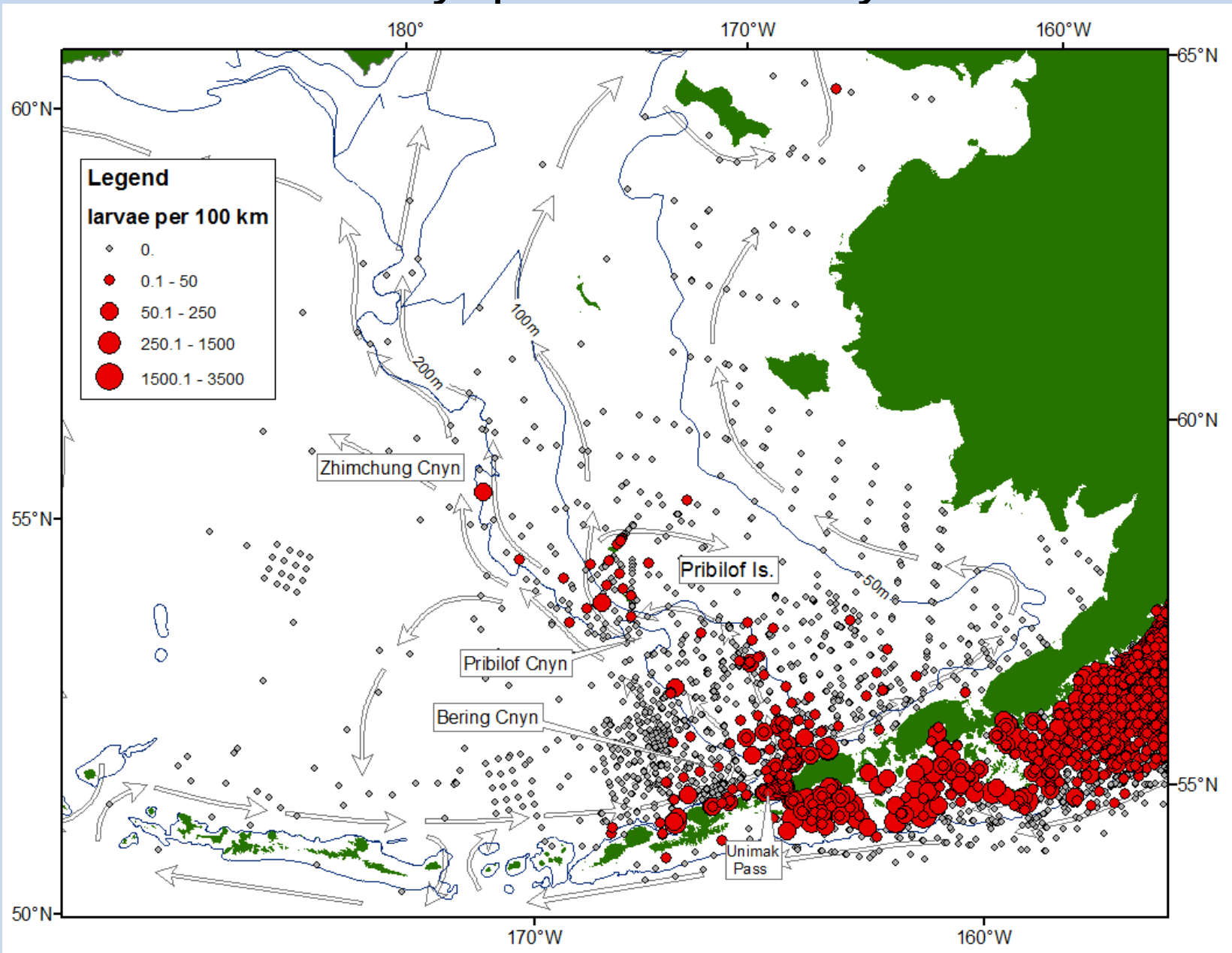
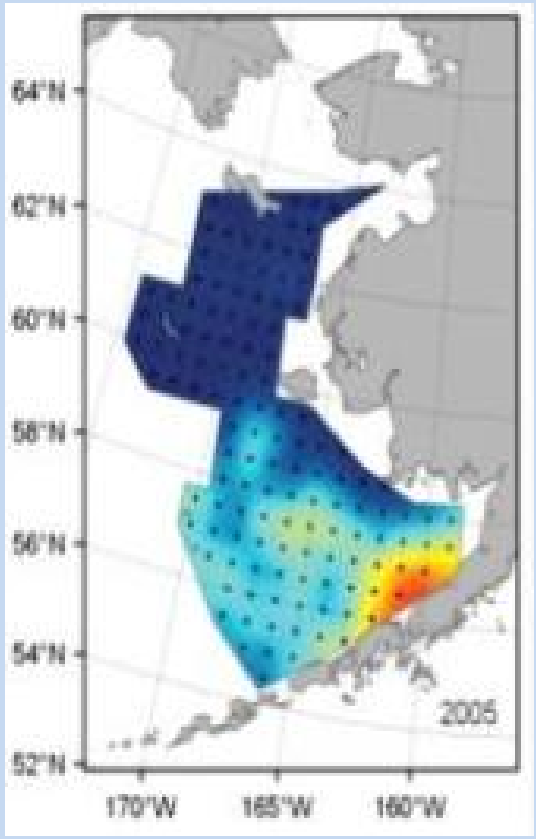
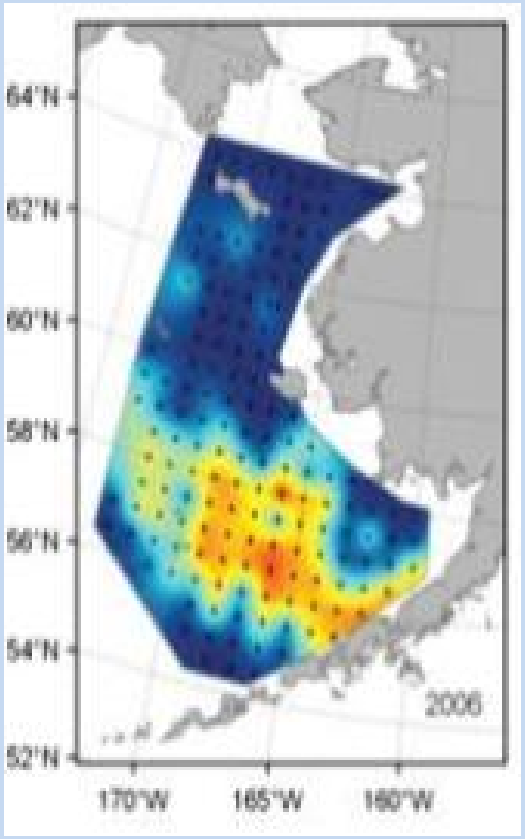
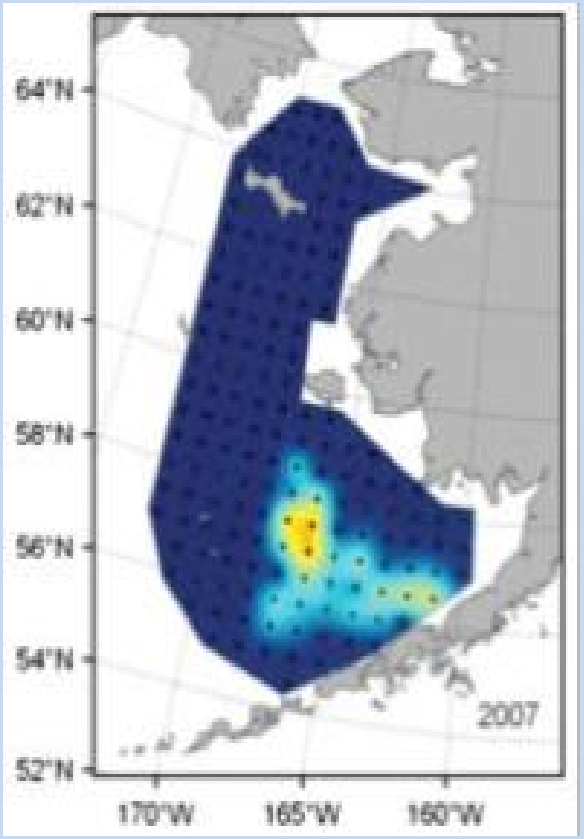
AFSC FOCI ichthyoplankton surveys



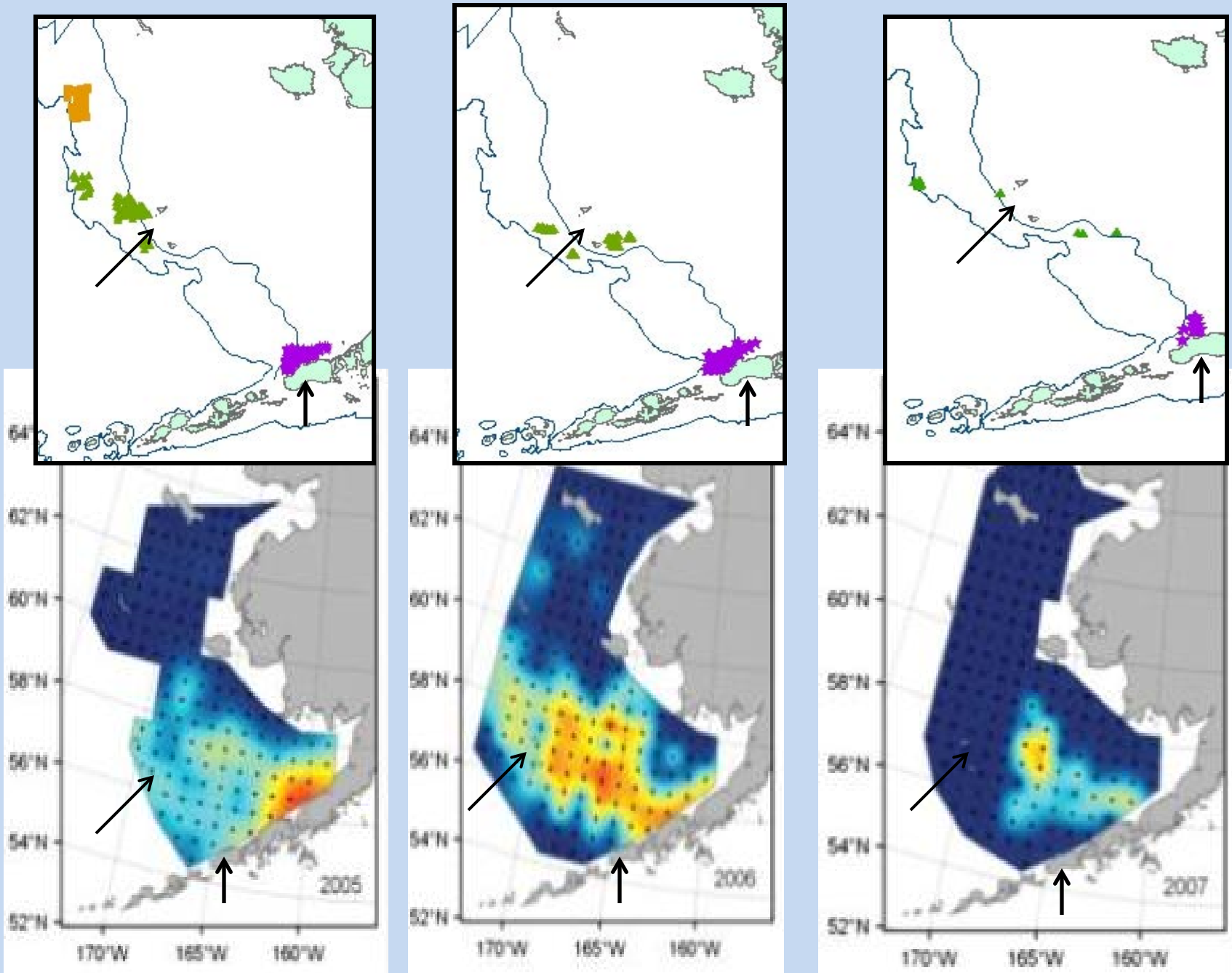
Age 0 Pacific cod CPUE







Hurst , 2012


64°N
62°N
60°N
58°N
56°N
54°N
52°N
170°W
165°W
160°W
2005
2006
2007

Acknowledgments

Alaska Fisheries Observers

Fit: Libby Logerwell, Susanne McDermott, Peter Munro, Liz Conners, Kim Rand, Olav Ormseth, Anne Hollowed

COAS community, lab members, and Corvallis friends

Committee Members

Mark Harmon- GCR

Ed Dever

Grant Thompson

Tom Hurst

Libby Logerwell

Lorenzo Ciannelli

Thank you

Maturity Key Assumptions

- We assume morphological changes seen at the gross visual scale correspond to changes occurring with individual oocytes at the cellular level.

- We use histology processing to stain and isolate ovary tissue to examination of cellular structures present through individual oocyte development

Background: Knowledge of location and timing of spawning provides insight in how a species interacts with its environment

Location provides the oceanic landscape where topography and bathymetry interact with currents and hydrography

Provide a basis for understanding patterns for dispersal, migration, and population connectivity

Provides reproductive conditions of stocks and a means to evaluating changes in abundance and distributions

Provides fishery managers knowledge of fishing fleet dynamics with regard to spawning patterns

Provides an opportunity to make informed decisions regarding future research

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Misclassification tables: cruise collections used to analyze key design

	Immature	Develop	Prespawn	Spawn	Spent	Rest	Total
N Yolk	93	1	1	0	3	0	98
E Yolk	1	100	0	0	0	3	104
M Yolk	0	103	38	0	0	0	141
L Yolk	0	76	186	3	1	0	266
YolkC	0	7	16	2	0	0	25
HYDR	0	0	4	23	2	0	29
POF	3	1	1	4	31	0	40
TK NY	2	0	0	0	0	1	3
Total	99	288	246	32	37	4	706
% mis	6%	30%	18%	28%	16%	75%	22%

Key validation: sources of error

- Key design: gross visual changes accurately and consistently represent ovary maturation

- Key use or subjectivity: key adequately describe developmental characteristics to allow multiple users to consistently identify distinct stages

Misclassification tables: observer collections used to analyze interpretation of the key

	Immature	Develop	Prespawn	Spawn	Spent	Rest	Total
N Yolk	143	17	0	0	2	31	193
E Yolk	0	2	1	0	0	0	3
M Yolk	0	37	25	4	0	0	66
L Yolk	1	100	50	20	0	0	171
Yolk C	0	23	40	6	2	0	71
HYD	0	0	1	26	3	0	30
POF	0	1	0	1	32	2	36
TKNY	11	2	0	0	0	3	16
Total	155	182	117	57	39	36	586
% mis	8%	79%	23%	54%	18%	92%	43%

Mapping prespawn and spawn stages = 18%

Mapping develop+prespawn and spawn+spent stages = 14%

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Potential bias

- Observer use of the key may underestimate maturity level for vitellogenesis stages and may over estimate late hydration as spawning stage fish
- Observer sampling is are restricted to fished areas; commercial vessels may have limited access to areas with rough bottom, high current, and by sea ice
- Gear types requiring active feeding may capture less spawning which tend to feed less
- Barotrauma associated with gear retrieval may cause early release of eggs