Working Document to WKARMAC2 – Workshop on Age estimation of Mackerel (Scomber scombrus). Pasaia, San Sebastian, Spain, 22-26 October 2018

Study of seasonal formation of growth rings in the otoliths of the NEA Mackerel (*Scomber scombrus*) in ICES Divisions 8c and 9a North

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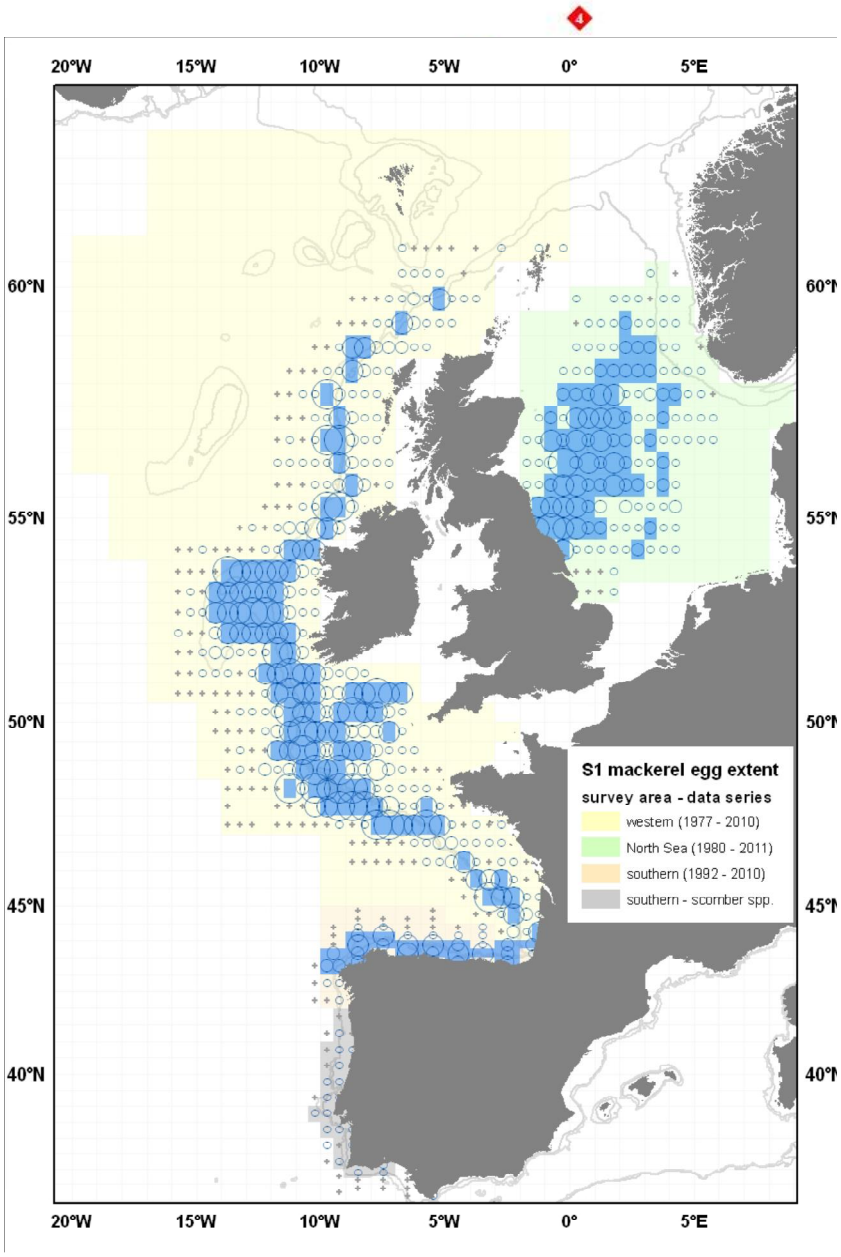
Background

- The Northeast Atlantic Mackerel is a migratory species (Uriarte et al., 2001) and therefore the mixture of the stock should always be considered when reading the otoliths.

- Mackerel spawns from January in Portuguese waters and Bay of Biscay until August in the North Sea. (ICES WGMEGS)

- As spawning occurs at different times in different zones, otoliths can show different sizes in the first year of growth and the growth of any given annual class is variable.

- The edge of the otolith can also be variable due to this, since growth will start at different times of the year



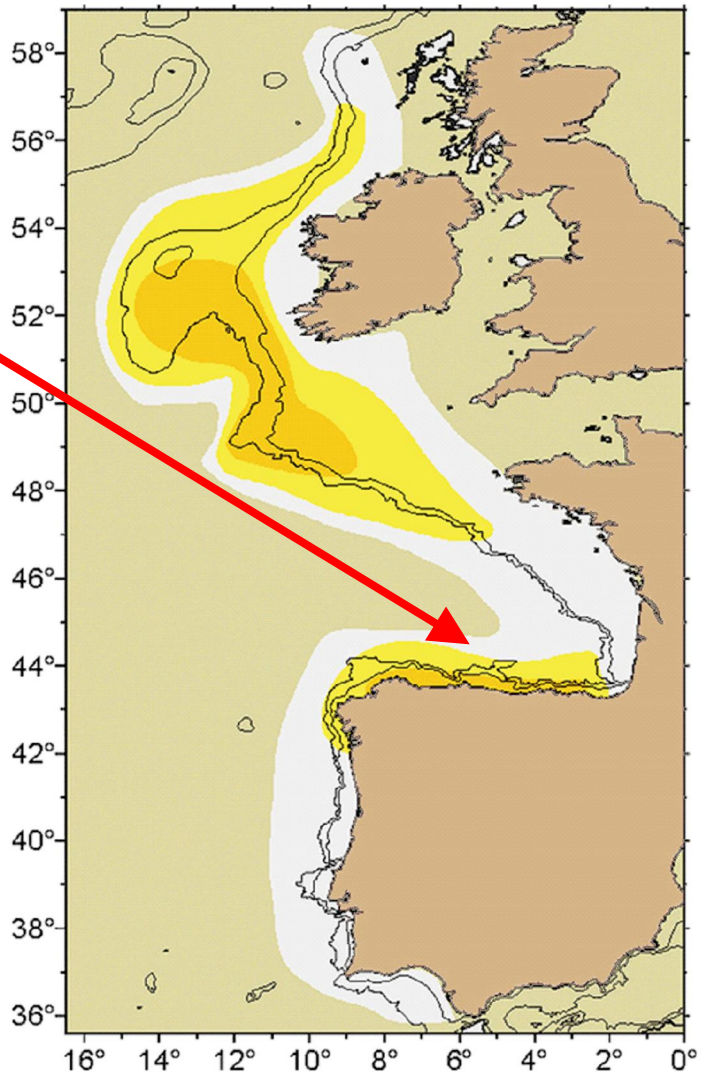
Background

- **Mackerel migrate to the spawning ground** of the **Southern area** in the first half of the year (Uriarte et al., 2001). In this season the greatest mackerel concentrations are found in the Cantabrian Sea, as this is the main spawning ground of the Southern area (ICES, 2010).

- In Cantabrian Sea spawning takes place from February to June, reaching its maximum in March-April.

- The annual start of the Spanish mackerel fishery in the Cantabrian Sea and northwest of the Iberian Peninsula is determined by this migration (Villamor et al., 1997; Punzón et al., 2004; Villamor, 2007; Punzón and Villamor, 2009).

- Historically, mackerel reaches these areas between the end of February and March, and the fishing activity then begins.



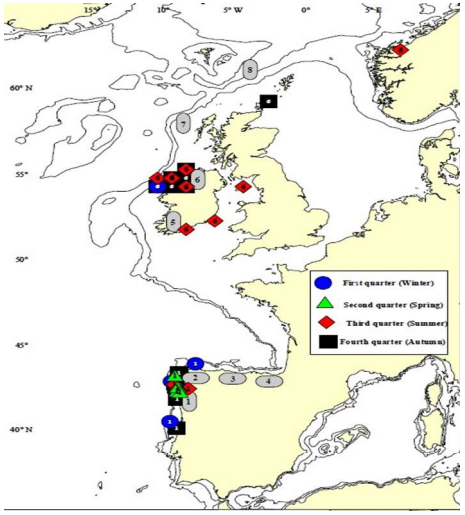
Background

- The growth of mackerel is very fast in the first months, reaching 22 cm at the end of the year in which they were born, age group 0 (Villamor et al., 2004).

- The growth rate of mackerel is high during the first year of life (reaches 25 cm at age 1) and then slows down rapidly (29 cm and 32 cm at ages 2 and 3 respectively). Maturity is normally reached at 2-3 years and growth slows drastically at this point (Villamor *et al*., 2011).

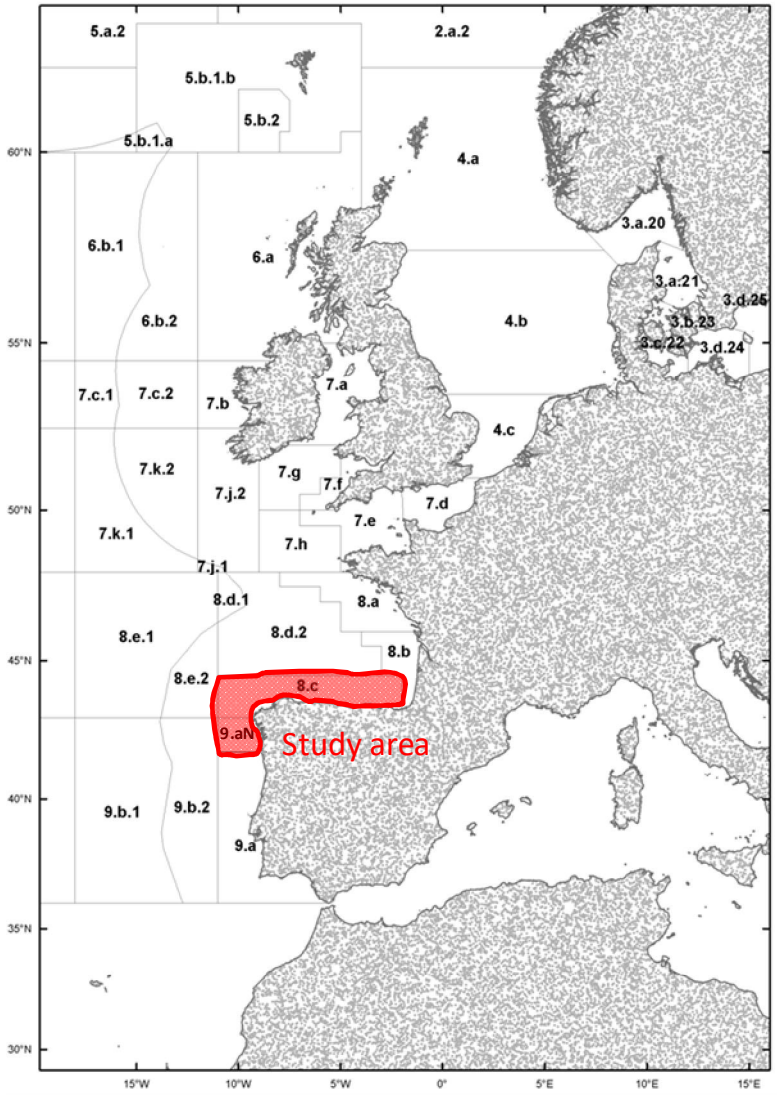
- Mackerel can reach a maximum size of 70 cm (Navarro *et al*., 2012), although commonly the maximum size reached is 45 cm. The maximum age reported has been 23 years in northern Europe (ICES, 1995). In the Southern area, the maximum size recorded for this species is 59.2 cm with a maximum age of 20 years (Navarro *et al*., 2012).

- Tag-recapture studies showed that juveniles tend to remain in nursery areas until maturity (3 years), then join the migratory route of the adult population (Uriarte et al., 2001).



Objetives

Main purpose of the following work is to establish seasonal formation of growth rings in the otoliths of the NEA Mackerel (*Scomber scombrus*) in ICES Divisions 8c and 9a North, in relation to environmental and biological parameters.



Biological Sampling Scheme & Protocols for Mackerel

Historical series (data-base): Since 1982 onwards.

Sampling frequency: One commercial sample by month/quarter by area (8c east, 8c West and 9a North). Additional samples from Acoustic and Egg surveys (March-April) and from Bottom-trawl (September-October) annual surveys, are also analyzed**.**

Sampling scheme at lab: On every sampling the following tasks are carried out:
1) Simple Random Sampling 100 individuals.
2) Otoliths are mounted whole in transparent resin (previously in Eukitt; since 2017 in a substitute for xylene) on black slides with the sulcus facing down.
3) Aged under reflected light at 20x.
4) Otolith edge and quality (or credibility) of each age estimation (AQ1, AQ2 & AQ3) are registered since 2013.

The available information for each fish is:
- Sampling/Catch date.
- Total individual length [PTL (Pinched Tail Length), mm].
- Total individual weight (0.00 g).
- Sex and sexual maturity stage (Walsh 1990 scale)
- Gonad and eviscerated weight (0.00 g) of the first 40 specimens (since 2010).
- Visceral fat stage (4 stage-scale) (Since 2006).
- Age.

Validation of the ageing method following the marginal otolith structure development throughout the year

Monthly monitoring of the otolith edge was carried out during 2013-2017 in order to determine the seasonality in the formation of rings.

Number of otoliths examined monthly by year:

Month/Year	2013	2014	2015	2016	2017	Total
Jan	0	0	0	64	0	64
Feb	393	115	77	279	0	864
Mar	1176	960	479	411	892	3918
Apr	429	576	807	1135	632	3579
May	0	72	65	166	217	519
Jun	76	0	62	57	2	197
Jul	174	275	103	202	151	905
Aug	183	6	97	164	81	531
Sep	225	551	292	419	202	1689
Oct	245	323	296	127	442	1433
Nov	78	0	183	98	97	456
Dec	66	0	88	0	0	154
Total	3045	2878	2549	3121	2716	14309

Number of otoliths examined monthly by age group:

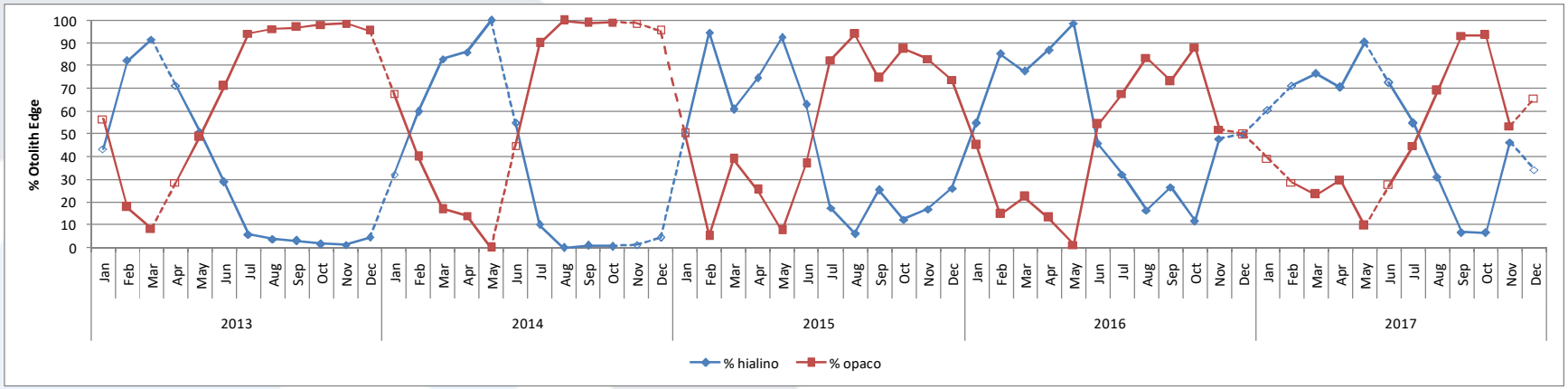
Month/age	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7+
Jan	2	56	4	0	0	0	0
Feb	17	335	222	73	43	75	94
Mar	707	414	194	253	528	646	1130
Apr	308	67	77	267	613	767	1418
May	0	30	111	40	39	67	205
Jun	2	9	53	18	8	23	84
Jul	288	198	169	61	58	39	53
Aug	203	77	89	49	46	30	28
Sep	431	335	177	58	16	11	12
Oct	203	132	57	26	8	10	8
Nov	136	167	57	32	27	9	16
Dec	91	39	18	3	0	0	0
Total	2388	1859	1228	880	1386	1677	3048

It was estimated the percentage of **hyaline edge** (**HE%**) and **opaque edge** (**OE%**) by month and the average per year to find out the annual pattern.

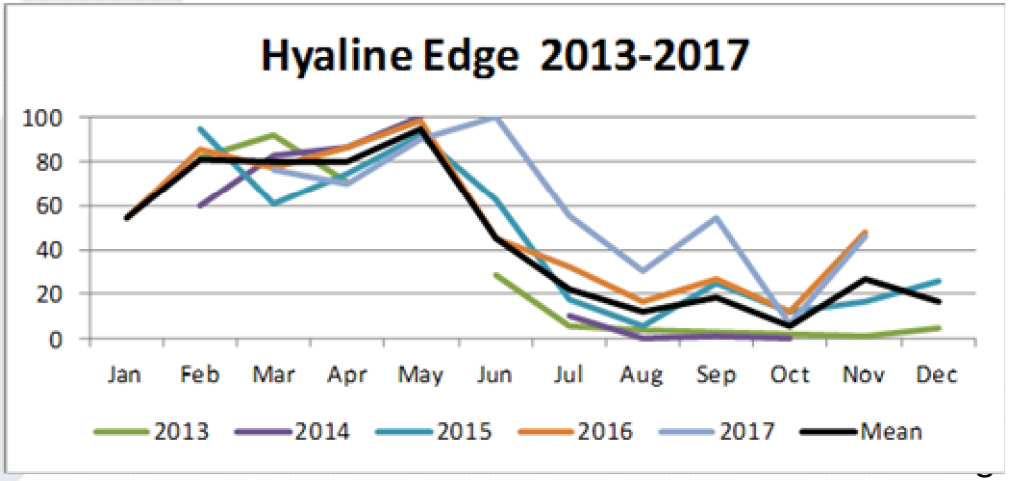
It was also calculated the **average temperature of the seawater** (SST, upper 30m and Tº from 30m to 180 m), **gonad somatic index** (GSI) and **Condition Factor** (CF) in order to get a yearly pattern for these parameters.

Nature of the otolith edge

The monthly proportion of edge type of mackerel indicates an annual periodicity in the formation of the hyaline and opaque annuli, appearing the **opaque edge mainly from June to December.** The **winter (hyaline) annulus** seems to be **entirely formed in May**.

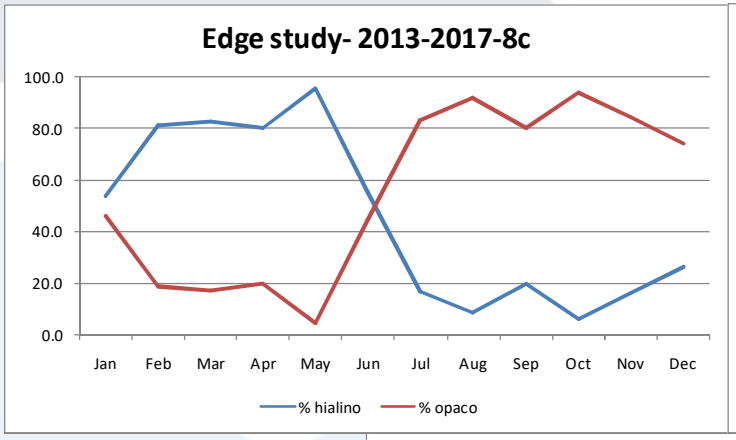


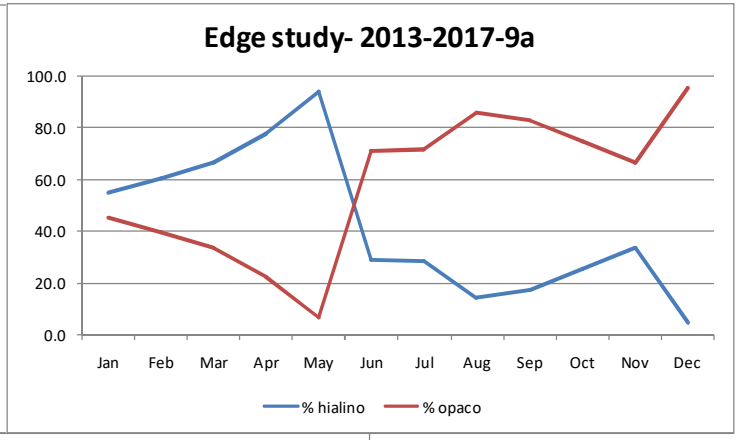
The **highest percentage of hyaline edge occurs between January and June, with a maximum in May** every single year. **The minimum occurred between August and October.**

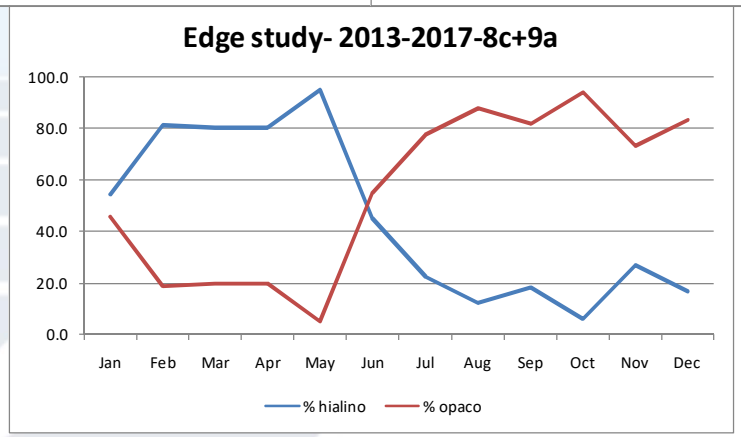


Nature of the otolith edge

The same results are obtained for each area (8c and 9a North) as for the total area (8c + 9a North) for the whole period studied.

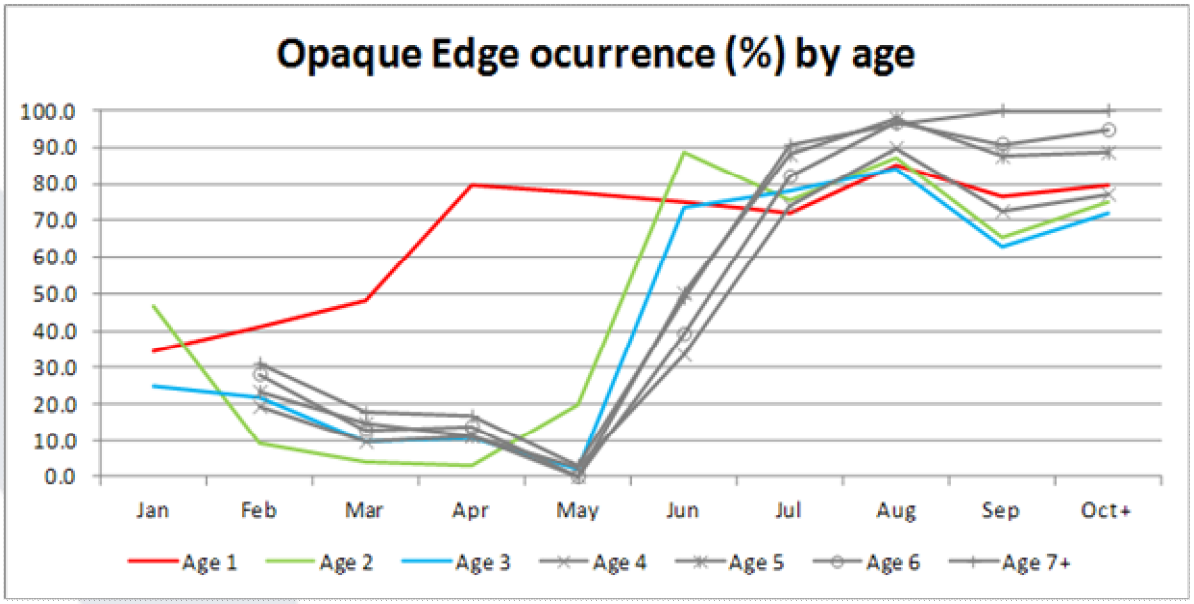






Mackerel Seasonal growth pattern of otoliths by ages

The timing of formation of the opaque edges by age is summarized in the Figure.



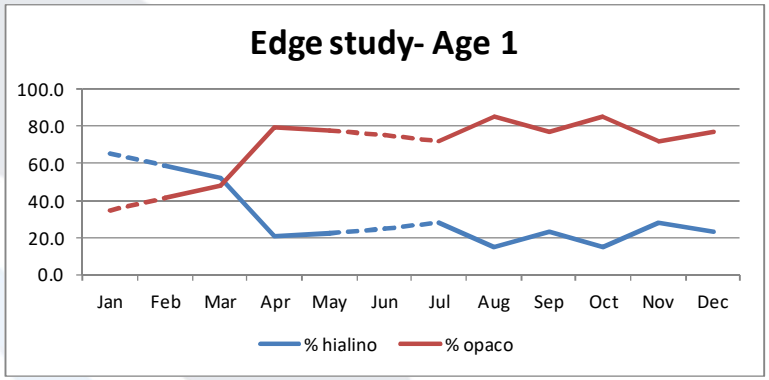
✓**For age-1**, growth resumes usually during March, and by April most show marginal opaque growth

✓**For the age-2** group, only a few individuals start laying down the marginal opaque growth by May, and most have already resumed opaque growth by June.

✓**For age-3 and older**, it is only in June when some individuals start showing marginal opaque growth, whereas by July most of them will have resumed otolith opaque growth and by August-October most of individuals show opaque edges.

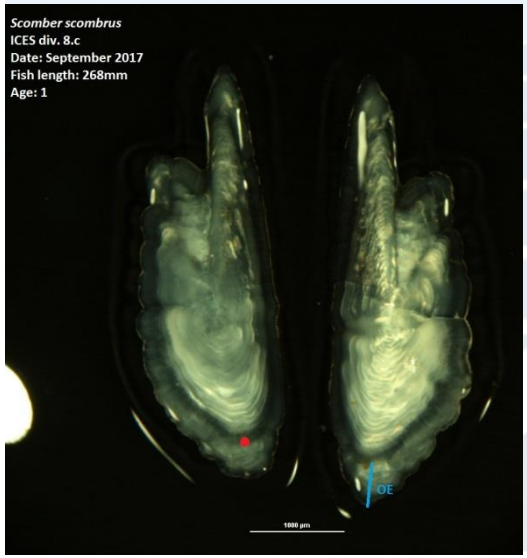
Expected growth pattern for age 1

First quarter (Jan-Mar)



Second quarter (Ap-Jun)

Third quarter (Jul-Sept)

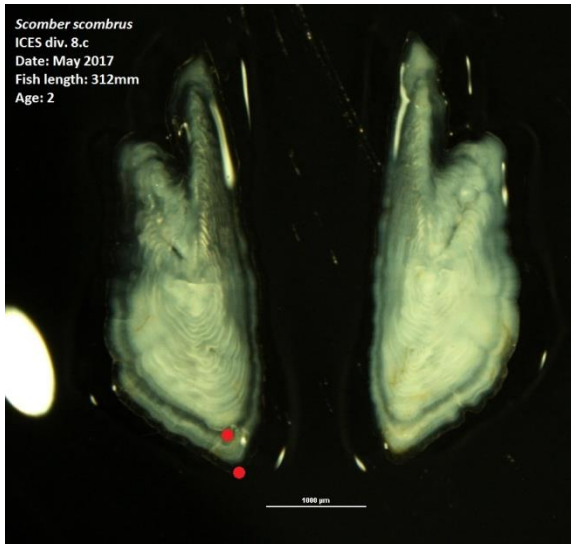


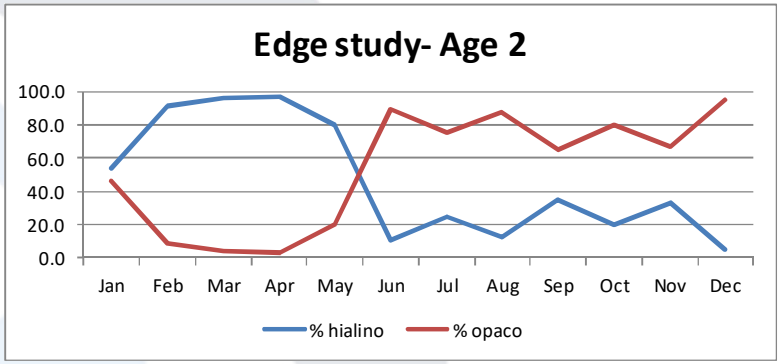
Fourth quarter (Oct-Dec)

Expected growth pattern for age 2

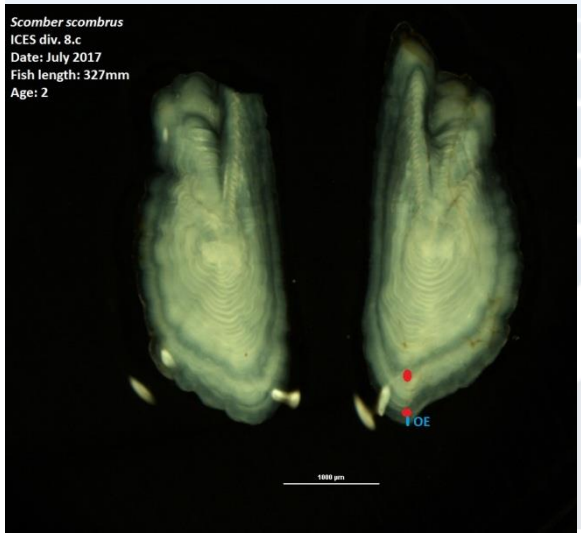
First quarter (Jan-Mar)

Second quarter (Ap-Jun)

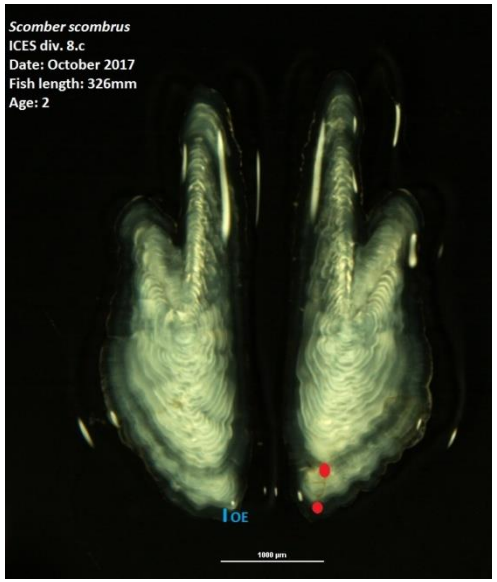




Third quarter (Jul-Sept)



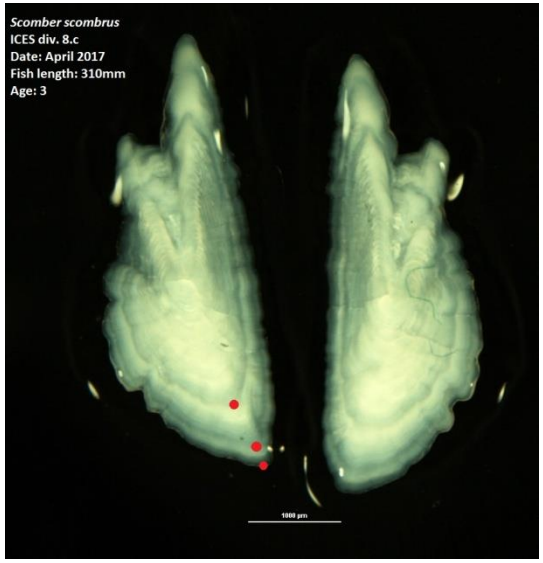
Fourth quarter (Oct-Dec)

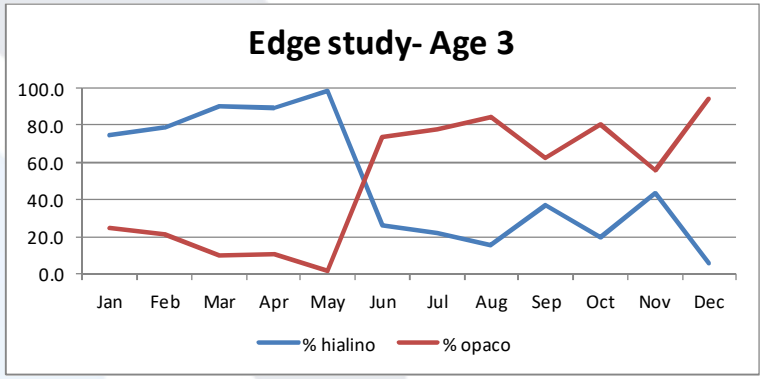


Expected growth pattern for age 3

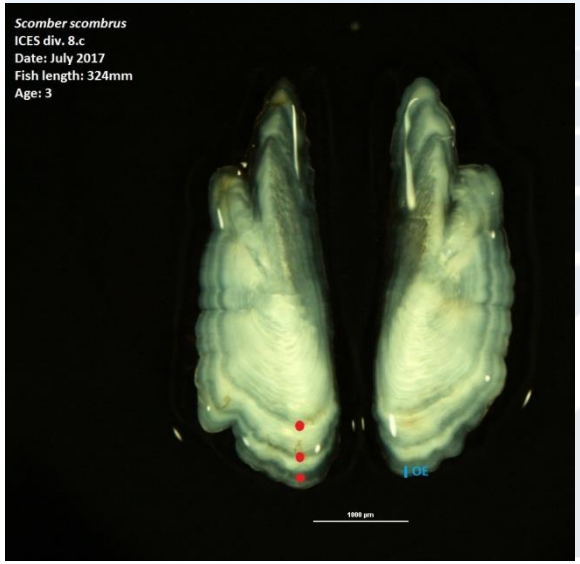
First quarter (Jan-Mar)

Second quarter (Ap-Jun)

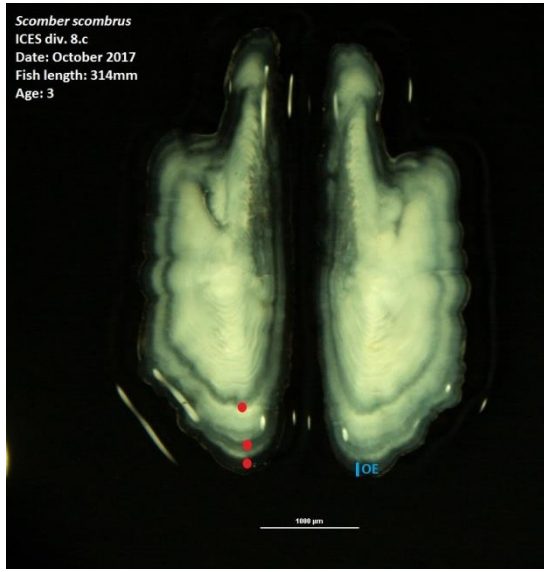




Third quarter (Jul-Sept)



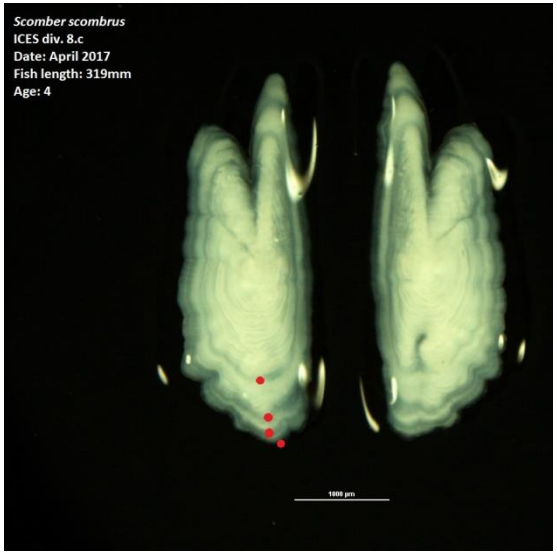
Fourth quarter (Oct-Dec)

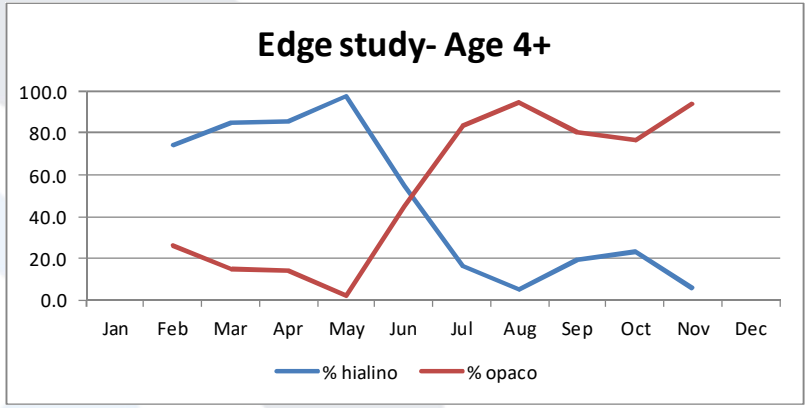


Expected growth pattern for age 4 and older

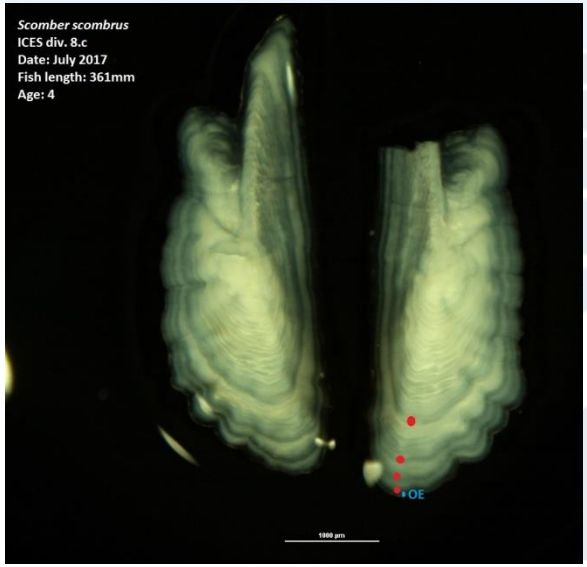
First quarter (Jan-Mar)

Second quarter (Ap-Jun)

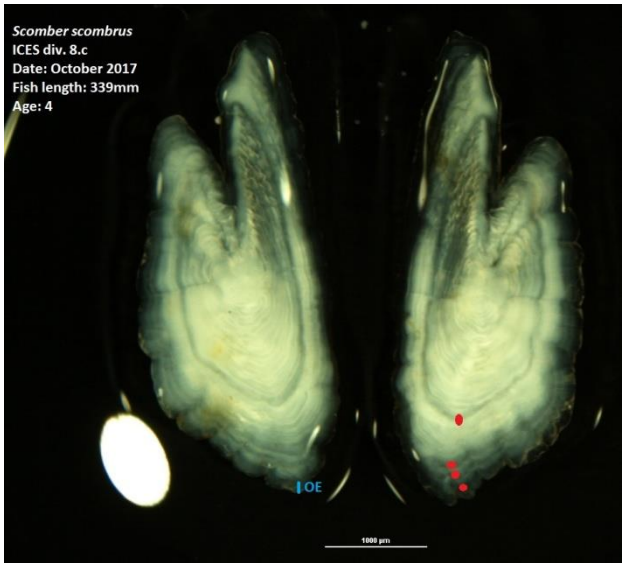




Third quarter (Jul-Sept)

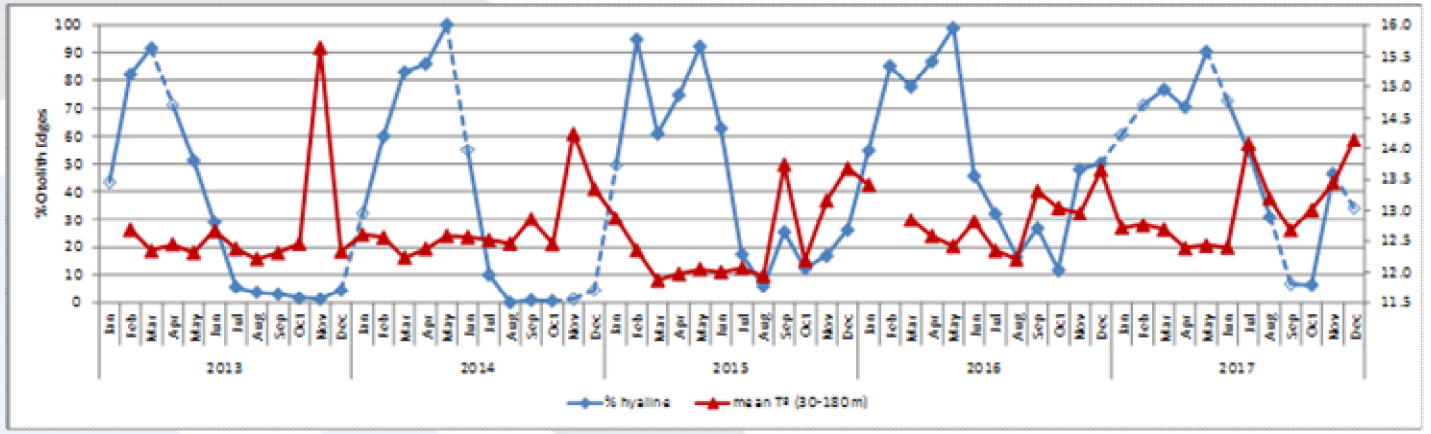


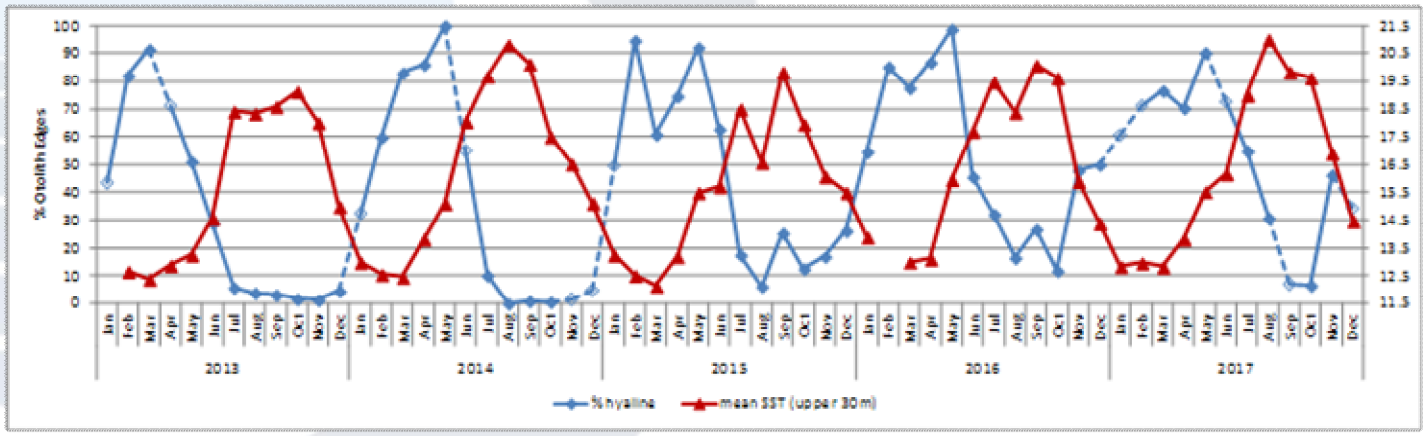
Fourth quarter (Oct-Dec)



Edge relationships with Temperature

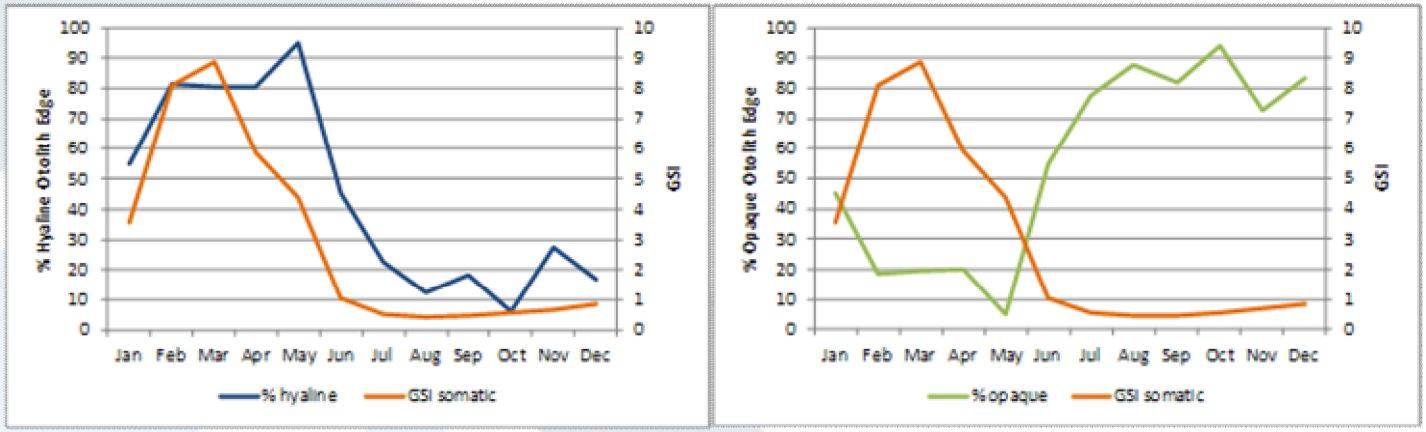
Monthly evolution of percentage of Hyaline edge formation and average monthly seawater temperature 30-180 m deep (top panel) and SST (bottom panel) from 2013 to 2017.



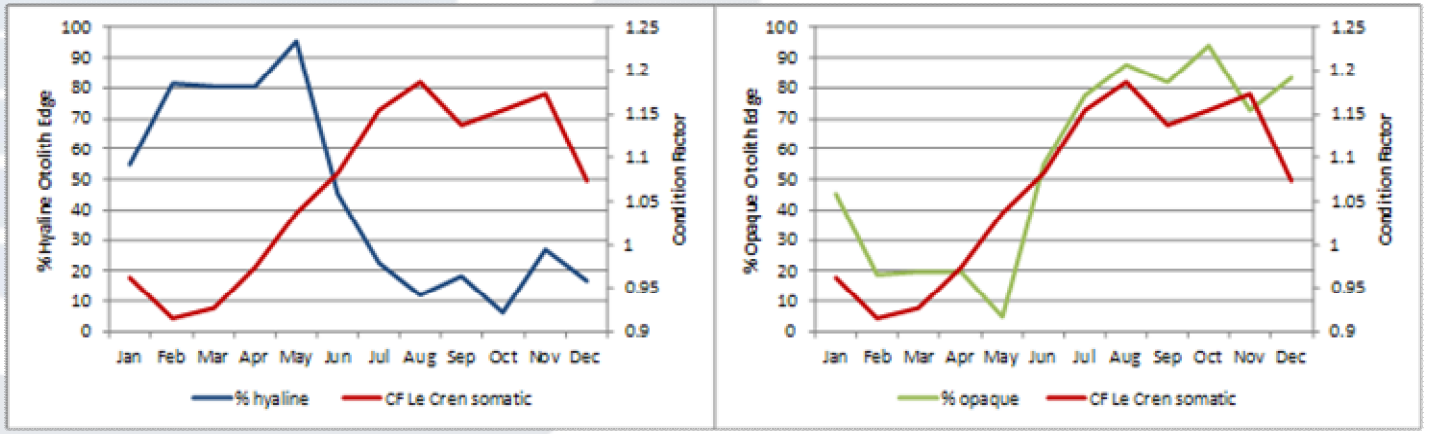


Edge relationships with GSI and CF

Evolution of percentage of hyaline edge formation (left panel) and opaque edge formation (right panel) and **gonad somatic index (GSI)** for the entire study period. Opaque edge formation do not coincide with the spawning season (February-May).



For months with lower HE%, that is to say, during opaque edge formation, mackerel shows a higher **CF** (better nutrition status). This suggests that the formation of the opaque edge is, in part, related to the period of fast growth of the fish.



Conclusions

✓ The **highest percentage of hyaline edge** occurs between **January and June**, with a maximum in May every single year. **The minimum** occurs **between August and October**.

✓ The **variation in the proportion of hyaline edges was gradual over months** and so was the delay in the formation of the opaque edge with age; in general the minimum proportion of hyaline edges was observed around April at age 1, June at age 2 and August at ages 3 and older.

✓ **Temporal delay in opaque-zone formation increase with age**, in younger mackerels, of age-1 (all immature), the otolith edge growth resumes usually during March, mackerels of age-2 (already mature) start laying down the marginal opaque growth by May-June, and in mackerels of age-3 (totally matures) and older it is in June when individuals start showing marginal opaque growth.

✓ From these results, we are to **take into account the delay in opaque edge formation with age for the Southern area** (ICES Division 8c and 9a).

✓ It would be desirable to analyze the seasonality of the edge in other areas more thoroughly and to find out alternatives to the use of otolith edge type in age determination.

Conclusions

✓ The timing in the **formation of rings in mackerel otoliths seems to link the temperature** and **food resources** (CF) to the fast growth of the fish.

✓ Based on the temperature, it **could be assumed that relatively high seasonal temperature is the driving force behind the opaque band formation** in the NEA mackerel in the Southern area (ICES Divisions 8c and 9a).

✓ Fish feeding is another factor influencing opaque edge growth in otoliths. NEA mackerel main feeding season starts in summer and ends in autumn (Olaso *et al*., 2005), coinciding with the same time of opaque otolith growth of this work. **Opaque otolith band at the end of spring is laid down during a period of rapid growth and feeding**.

✓ The formation of the otolith zones in relation to reproductive activity is controversial. In this work **spawning occurs when the translucent zone is well into the process of formation**.

✓The maximum of the somatic index of the gonad (**GSI) coincides when the majority of mackerel individuals are forming the hyaline edge**, **except for the younger individuals of age-1 (all immature) that are forming the opaque edge**.

Remarks and further works

✓ **The season of formation of opaque and translucent zones may change during development** and **in relation to geographical distribution**, as in the Atlantic cod (Høie et al., 2009) and *Sebastes* in the Pacific coast (Pearson, 1996).

✓ In our study, **no geographical differences are found between areas 8c and 9a N,** and nor with the one performed on the Portuguese coasts (ICES Subdivisions 9a Central-North and South) by Gordon and Martins (1982). **All these areas belong to the same Southern Component of the ANE mackerel**

✓**It is advisable to make this type of study for all distribution areas of mackerel in the Northeast Atlantic, from the south of the Iberian Peninsula to northern Europe (Norwegian and Icelandic coasts) to test whether or not there are seasonal differences in the formation of opaque-hyaline zones in otoliths and to study that factors influencing variation in otolith opacity**