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DIFFERENT TOOLS TO OPTIMIZE THE WELFARE AND THE MORPHOLOGICAL QUALITY OF REARED FINFISH LARVAE

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INTRODUCTION

- The morphological quality of species considered as 'consolidated' for aquaculture is far to be "wild-like", so determining economic losses and inducing diffidence in consumers for aquaculture products.
- Available data in literature are still unsatisfactory: e.g., the same anomalies are ascribed to many different causes.
- Actual knowledge seems to indicate that anomalies are the consequence of so many factors acting and interacting among them that probably multidisciplinary and multilevel studies seem to be necessary.

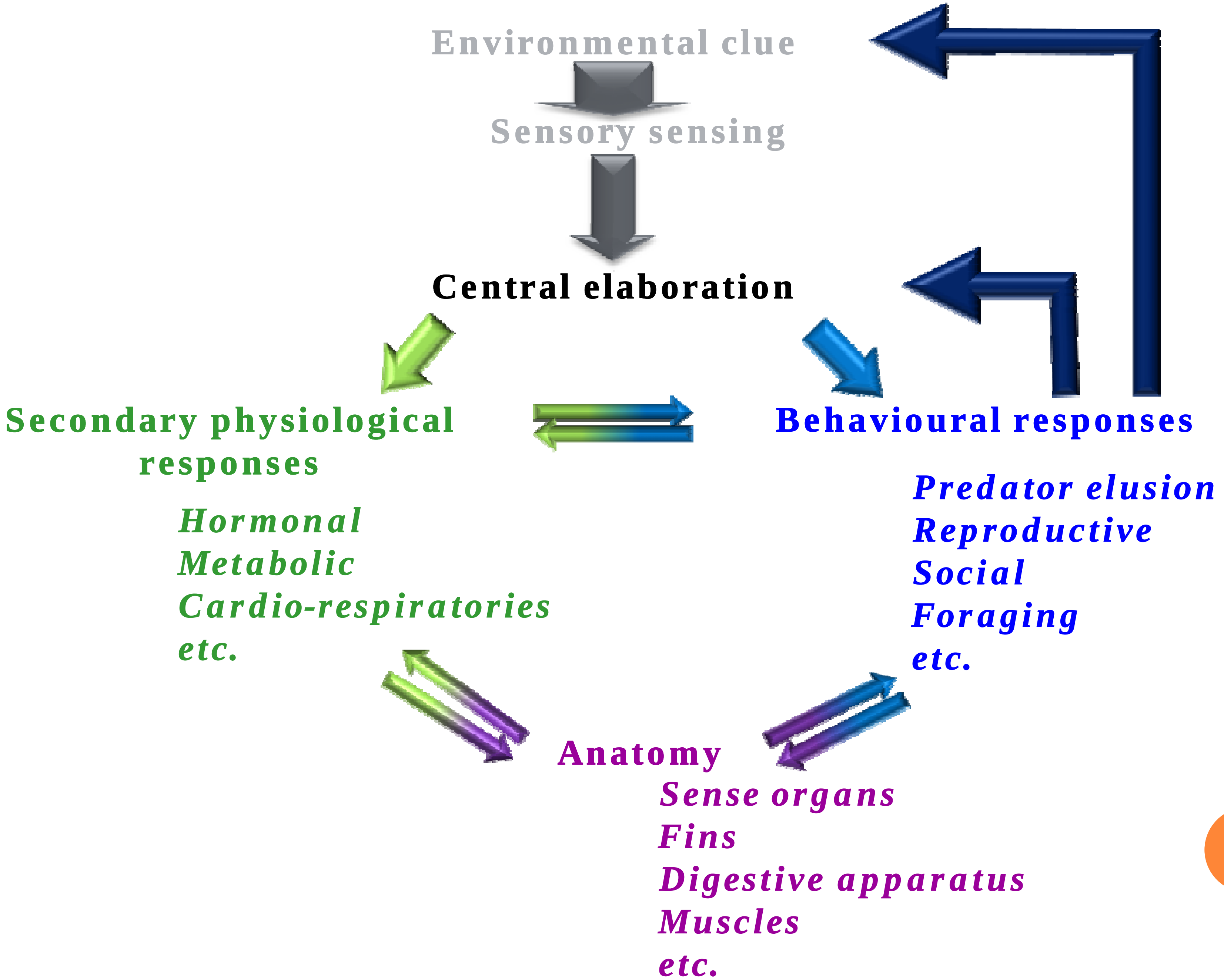
INTRODUCTION

- In particular, if we considered that vertebral malformations may now be the norm in hatchery lots, we should begin to take into consideration that all reared fish in each developmental stage are probably 'distressed' fish, in which epigenetic and genetic factors try to buffer the environmental noises effects.
- The setting up of proper rearing protocols in a framework of a responsible aquaculture should take into account what is the larval behaviour in wild instead of what happens in 'forced' environment.

In our Lab, we are facing the problem of developmental anomalies by means of three approaches:

- **the widening of knowledge on the development of locomotor, sensorial and digestive organs in the different reared species**, considered as an essential tool to properly fit the rearing methodology to the species' and developmental stages' needs.
- **the monitoring of morpho-anatomic quality in mass produced gilthead seabream, from different Mediterranean hatcheries and larval rearing methodologies**. This activity is actually carried out in the framework of a EU research Project (SSP-2005-44483 "SEACASE - Sustainable extensive and semi-intensive coastal aquaculture in Southern Europe"), and it's directed to the individuation of rearing methodology able to produce *wild-like* juveniles.
- **the development of a model of the occurrence of skeletal anomalies in reared juveniles of different species, both in terms of type and quantity**.

- **the widening of knowledge on the development of locomotor, sensorial and digestive organs in the different reared species**



- May developmental intervals be different in the same species?

- Are developmental intervals different in the same family?

- Do all the larvae actually reared exhibit the same feeding behaviour?

- Do similar rearing methodologies return the same morphological quality of juveniles?

Developmental intervals may be different in the same species?

Evidences available from literature reinforce the idea that in the same species some heterochronies are induced by rearing temperatures

HETEROCHRONY (introduced by Ernst Haeckel in 1875[1])

Bertolini *et al*., (1986)
Boglione *et al*., (1989)
Marino *et al*., (1991)
Seikai *et al*. (1986)
Batty *et al*. (1993)
Fuiman *et al*. (1998)
Koumoundouros *et al*. (2001)
Sfakianakis *et al*. (2004)

[1] *Horder, T. (2006) Heterochrony. In: Encyclopedia of Life Sciences. John Wiley & Sons, Ltd: Chichester.*

So the answer at this question is YES!

Developmental intervals/patterns are different in the same family?

Species	Authors	Sequence of the first appearance of skeletal elements in some Sparids
S. aurata	Faustino and Power 1998, 1999, 2001	mouth , gills and pectoral girdle; caudal; vertebral column; notochord flexion; vertebrae ossification; dorsal and anal; pelvic; ribs
P. major	Matsuoka, 1987	pectoral; mouth & gills; caudal; vertebral column; *lack data on notochord flexion*; vertebrae ossification; anal; pelvic; dorsal; *lack data on ribs*
A. rhomboidalis	Houde and Potthoff 1976	mouth & gills; pectoral; caudal; vertebral column; notochord flexion; vertebrae ossification; dorsal and anal; pelvic; ribs
D. puntazzo	Sfakianakis *et al.*, 2005	*lack data on cranium*; pectoral; caudal; vertebral column; notochord flexion; vertebrae ossification; dorsal and anal; pelvic; ribs
P. erythrynus	Sfakianakis *et al.*, 2004	*lack data on cranium*; pectoral; caudal; vertebral column; dorsal; anal; notochord flexion; vertebrae ossification; pelvic; ribs
P. pagrus	Çoban *et al.*, 2009	pectoral; caudal; dorsal; notochord flexion; *lack data on vertebrae ossification*; vertebral column; anal; pelvic; *lack data on ribs*
D. dentex	Koumoundourous *et al.*, 1999; 2000; 2001a	mouth , gills and pectoral girdle; caudal; vertebral column; notochord flexion; vertebrae ossification; dorsal and anal; pelvic; ribs
*D. sargus**	Koumoundourous *et al.*, 2001b	*lack data on cranium*; pectoral; caudal; vertebral column; dorsal and anal; notochord flexion; vertebrae ossification; pelvic; ribs

** indicates that some data were extrapolated from figures in the article.*
when some elements start to differentiate at the same time, they are put together.

Boglione & Costa (in press) Skeletal deformities and juvenile quality. In: *Sparidae: biology and aquaculture*
Pavlides M. and Mylonas C.C. (editors). Elsevier

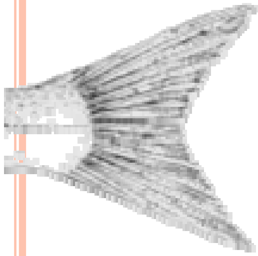
- Developmental intervals/patterns are different in the same family?

Species	*Authors*	*Skeletogenic sequence of final number of lepidotrichia achievement in Sparids fins*				
S. aurata	Faustino and Power 1998, 1999	caudal	dorsal	anal	pelvic	pectoral
P. major	Matsuoka, 1987	caudal	pectoral	dorsal, anal and pelvic		
D. puntazzo	Sfakianakis *et al.*, 2005	caudal	anal	pelvic	dorsal	pectoral
P. erythrynus	Sfakianakis *et al.*, 2004	caudal	dorsal	anal	pelvic	pectoral
P. pagrus	Çoban *et al.*, 2009	caudal	dorsal	anal	pectoral	pelvic
P. pagrus	Machinandiarena *et al.*, 2003	caudal, dorsal and anal			pectoral and pelvic	
D. sargus	Koumoundourous *et al.*, 2001b	caudal	anal	dorsal	pectoral	
D. dentex	Koumoundourous *et al.*, 2000; 2001a	caudal	anal	dorsal*	pelvic	pectoral

** indicates that some data were extrapolated from figures in the article; when some elements start to differentiate at the same time, they are put together.*

Boglione & Costa (in press) Skeletal deformities and juvenile quality. In: Sparidae: biology and aquaculture Pavlides M. and Mylonas C.C. (editors). Elsevier

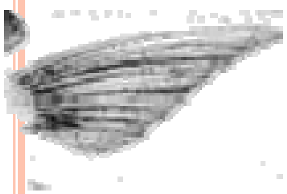
THE FIN DIFFERENTIATION PATTERN IS LINKED TO BEHAVIOUR/REQUIREMENTS OF LARVAE AND JUVENILES



Transmitting muscular force for propulsive tail strokes, used in escape or attack responses (Kohno *et al.* 1984, Hale, 1999)

the precocious caudal fin development is linked to the pelagic larval niche, where the needs for prolonged swimming against water currents dominate

the **precocious presence of the caudal fin in Sparids gives to larvae the capability not only of feeding on encountered preys but also of actively capturing (and selecting) preys through fast-start movements.**



The differentiation of the **pectoral fin** may facilitate **grazing**

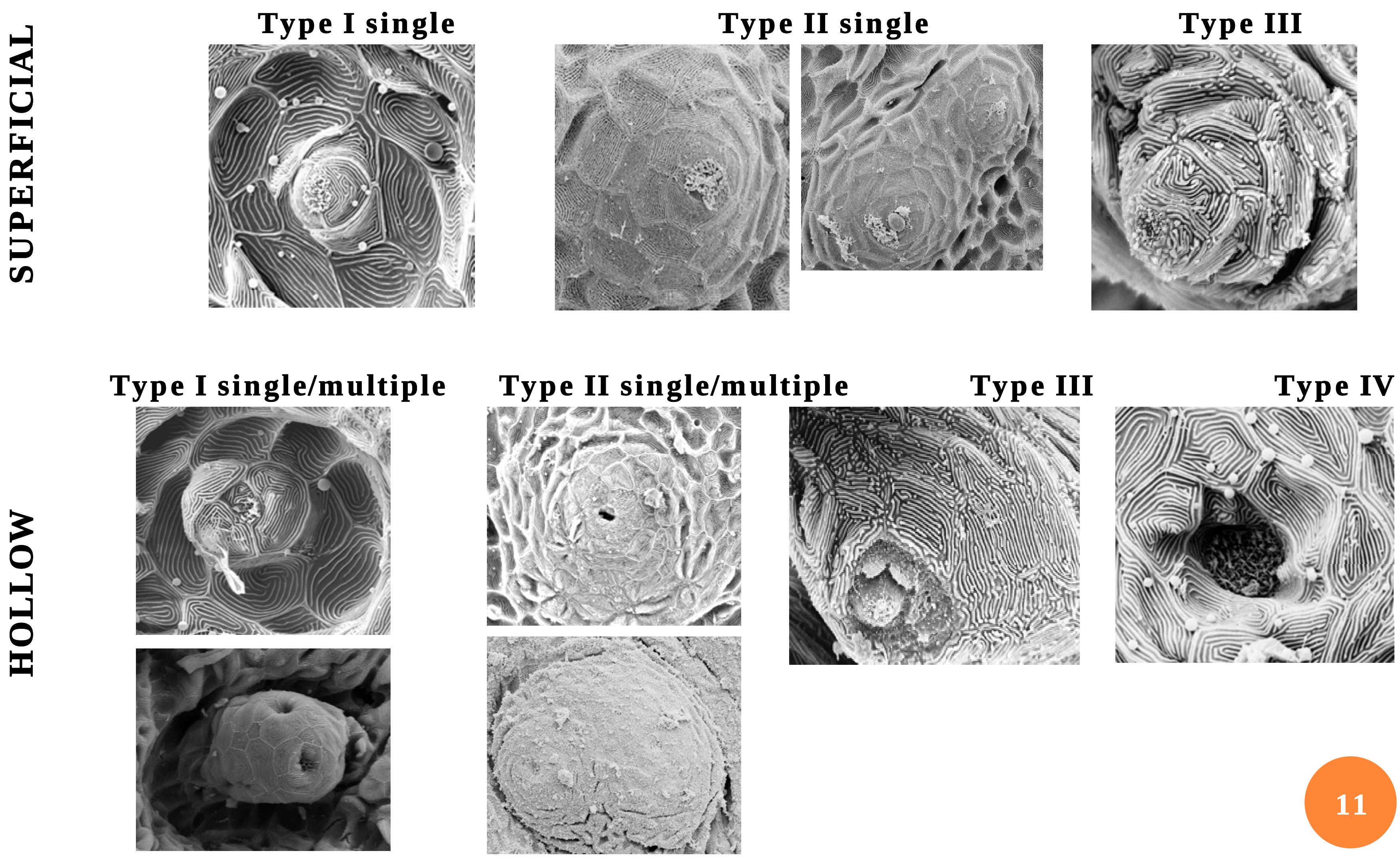
the prolonged and delayed pectoral fin development in *S. aurata* was linked to the **transition of to the demersal juvenile environment** where manoeuvrability is considered an advantage.

In higher Teleosts, the anterior spinous **dorsal fin** is use to slice though water whilst the soft, posterior, part plays an anti-pitch function during forward movement, or acts in synergy with the anal one, in braking, crawling along the underwater-floor, aiding in propulsion during slow swimming or in backing-up motions, allowing the fish to turn sharply

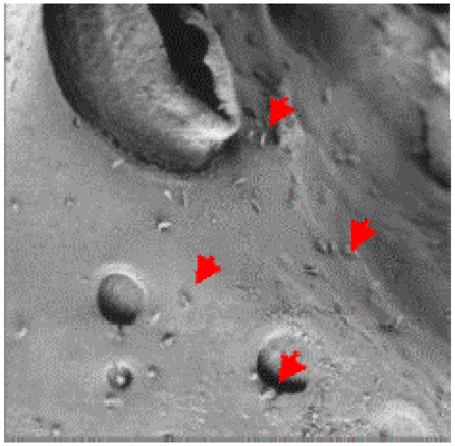
(Harder, 1975; Koumoundouros et al. 2001).

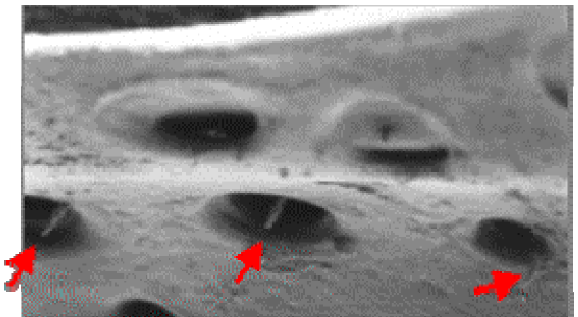
- Sense organs are similar in fish?

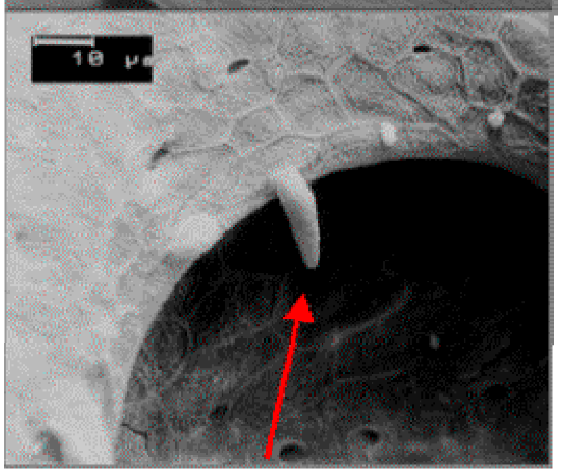
Variety of TB typologies in the oro-pharyngeal cavity

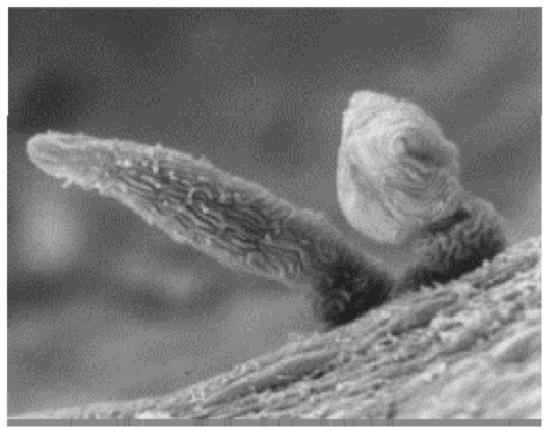


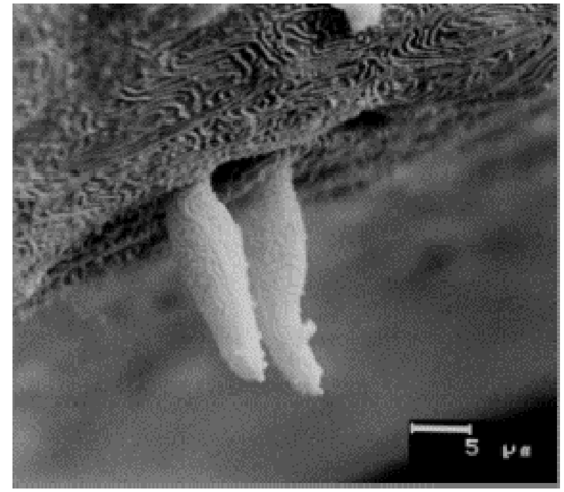
Pulcini D., Boglione C., Cataudella S. (2007). XII European Congress of Ichthylogy, Cavtat (Dubrovnik), Croatia, 9-13/09/07

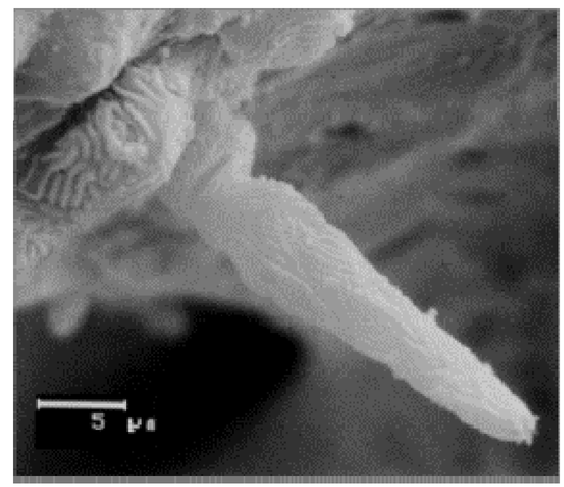





10 μm




5 μm

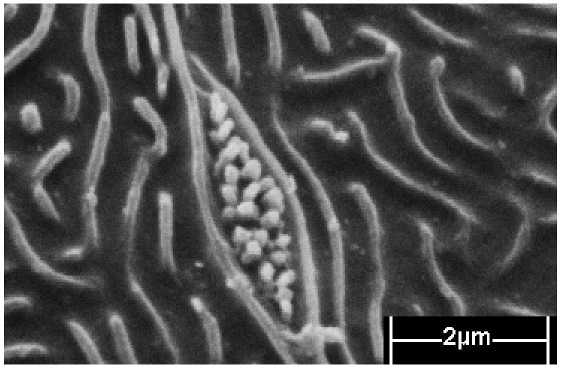

5 μm

?

Chemoreceptive solitary cells

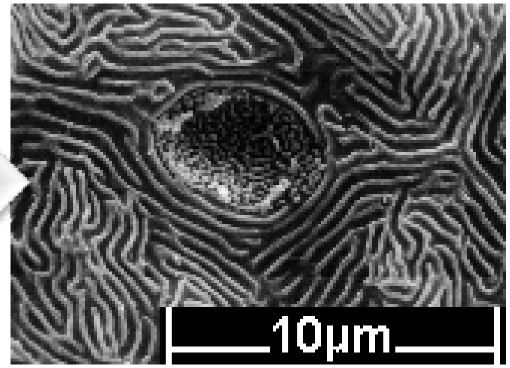
Salmo trutta macrostigma, Dumeril 1858 (unpublished data)

27 days post fecundation



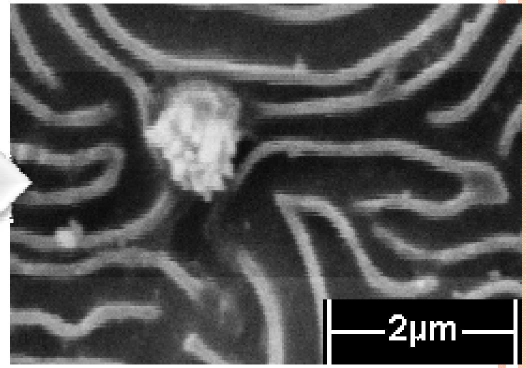
Oligovillous cell

25 days post hatching
(TL = 2,22 cm)

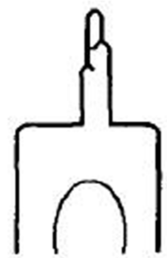


Degeneration

50 days post hatching
(TL = 2,71 cm)

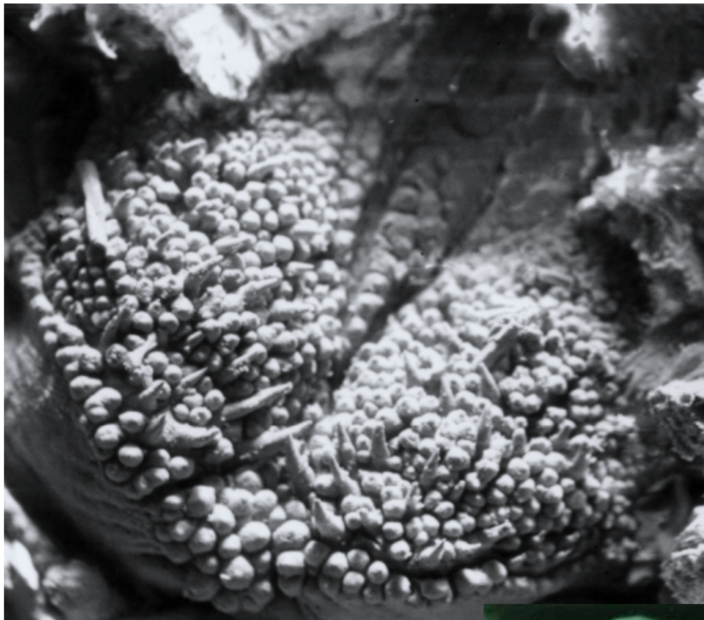


Monovillous
ramified cell



- Recognition and elusion of predators
- Food searching (?)
- Gas-receptors (?)

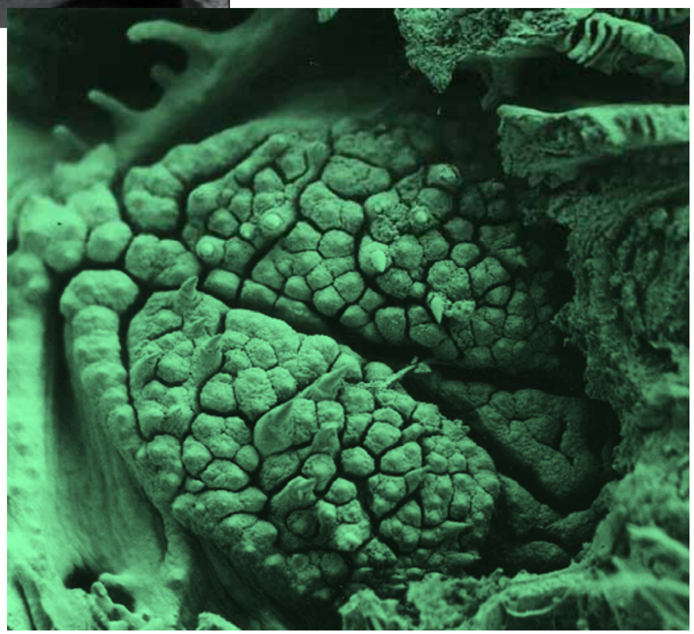
Morphological and functional differences of the same organ occur among Sparids



P. erythrinus
27 mm SL
80 DPH

S. aurata 17.9 mm SL
89 DPH

DORSAL
PHARYNX



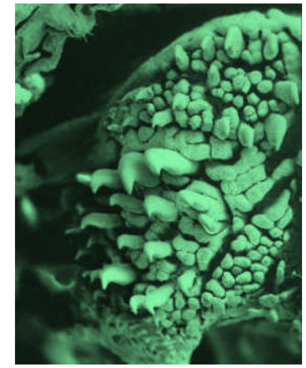
D. puntazzo 12.2 mm SL - 51 DPH

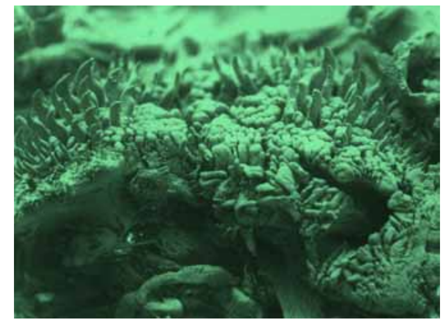
….. and during the development in the same species

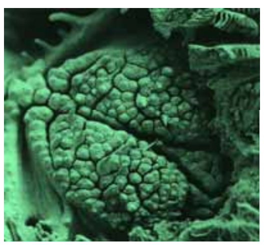
Aquaculture International **11:** 17–41, 2003.

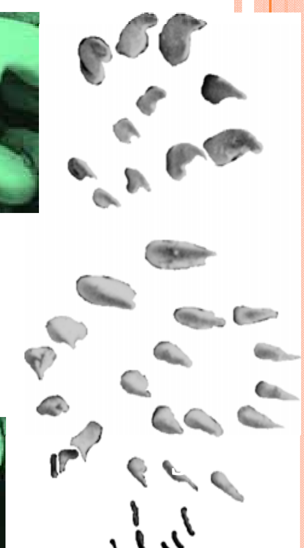
Morphoecology in larval fin-fish: a new candidate species for aquaculture, *Diplodus puntazzo* (Sparidae)

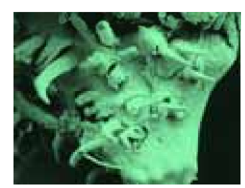
C. BOGLIONE*, M. GIGANTI, C. SELMO and S. CATAUDELLA





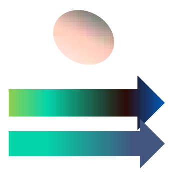
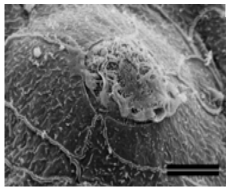
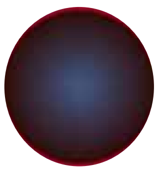
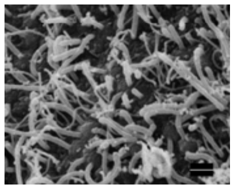
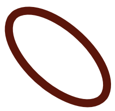
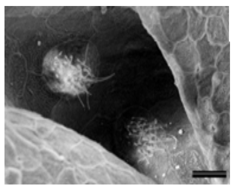
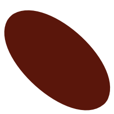
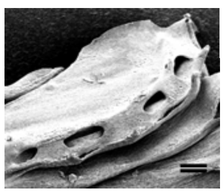
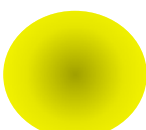
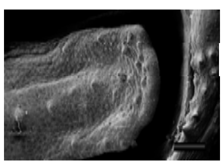
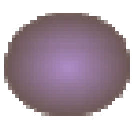
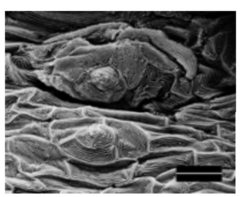




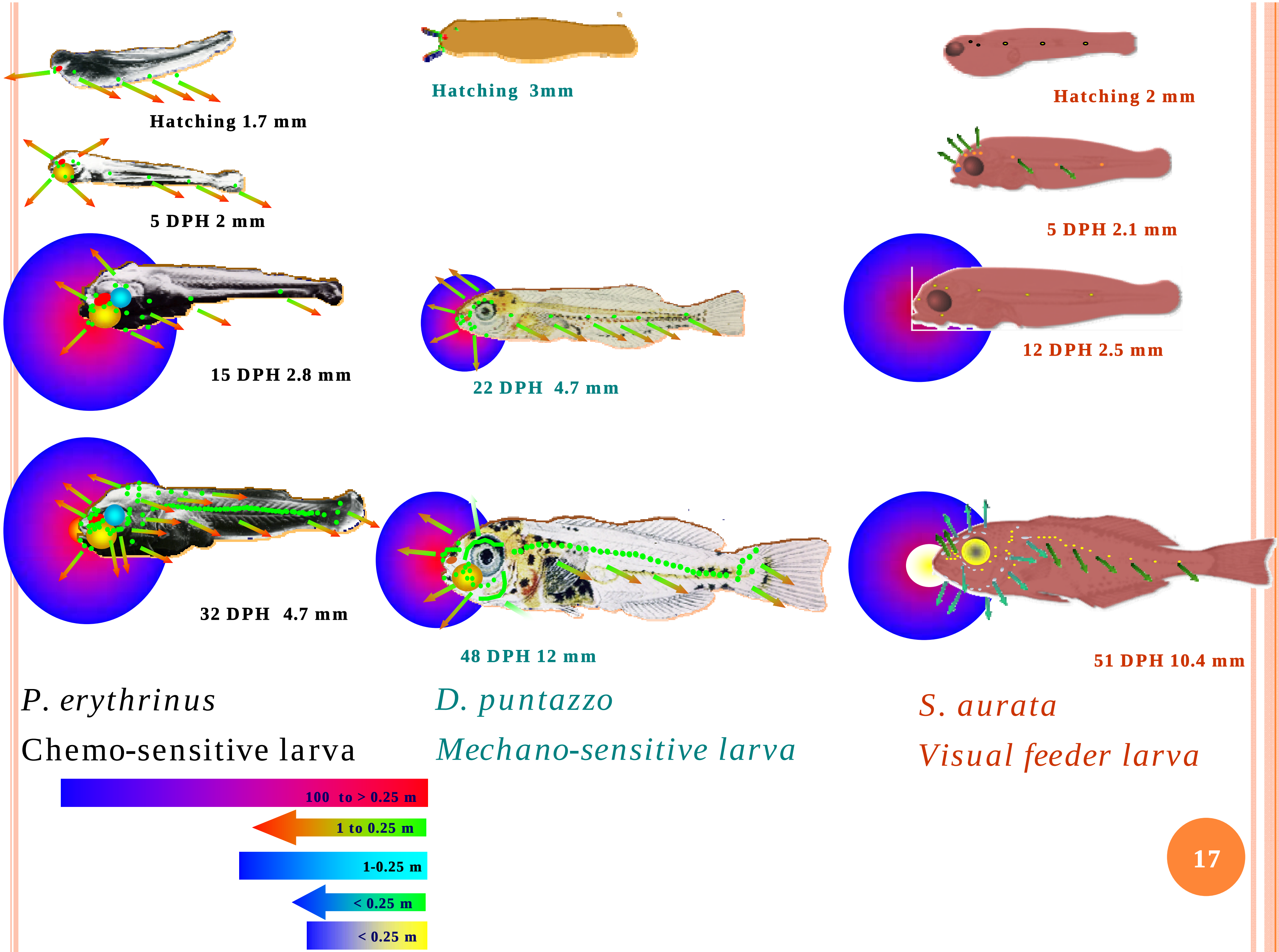


14.2 mm **28.5 mm** **58 mm** **62.9 mm**

- Do all the larvae actually rear exhibit the same feeding behaviour?

Graphic symbol	Structure	Function
	 ***Free neuromast with cupola*** (bar = 10µm)	Reotaxis
	 ***Olfactory sensorial cells*** (bar = 1 µm)	Long range search
	 ***Outset of canalization of the cephalic lateral line*** (bar = 10 µm)	Perception of water acceleration
	 ***Completion of canalization of the cephalic lateral line*** (bar = 100 µm)	Perception of water acceleration
	 ***Inner taste buds*** (bar = 100 µm)	Ingestion and protective reflexes
	 ***Outer taste buds*** (bar = 10 µm)	Selection and evaluation of food; mechanoreceptive function

Functional interpretation of sense organs in fish, according to Pavlov and Kasumyan (1990).


Hatching 1.7 mm
5 DPH 2 mm
15 DPH 2.8 mm
32 DPH 4.7 mm
Hatching 3mm
22 DPH 4.7 mm
48 DPH 12 mm
Hatching 2 mm
5 DPH 2.1 mm
12 DPH 2.5 mm
51 DPH 10.4 mm
P. erythrinus
Chemo-sensitive larva
D. puntazzo
Mechano-sensitive larva
S. aurata
Visual feeder larva
100 to > 0.25 m
1 to 0.25 m
1-0.25 m
< 0.25 m
< 0.25 m

MONITORING AND MODELLING: THE RATIONALE BEHIND OUR APPROACH

- The study of fish larvae comprises several tasks, each one characterized by a different methodology and therefore resulting in different kind of data
- Is it possible to build a model which is able to compare data from these different tasks?
- Is this model useful in investigating both theoretical and applied aspects of larval ecology of fish?

THE TOOLS

There is a new generation of powerful computational tools: the unsupervised artificial neural networks (ANN), have been used in fishery and aquatic sciences for:

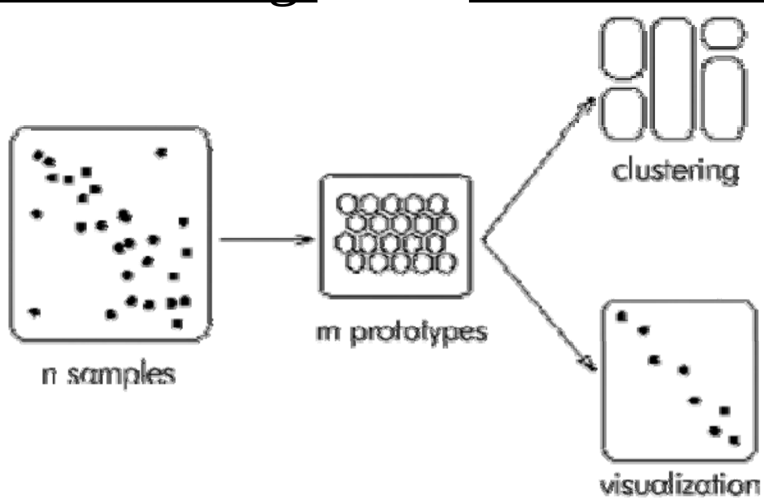
- classification,
- pattern recognition,
- empirical modeling

These tools are particularly effective and sound for analysis of ecological and biological data, which are frequently characterized by non linearity, internal redundancy and noise

A BRIEF INTRODUCTION TO SOM

Kohonen's Self-Organising maps (SOMs) are a data visualization technique which reduces the dimensions of data and generates a model in which the information stored in the original data is exemplified by "prototypes".

Further, SOMs allow the analysis of correlations among the data used for training with other external sources of information



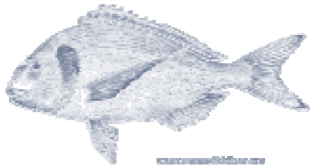
OUR APPLICATION OF SOM

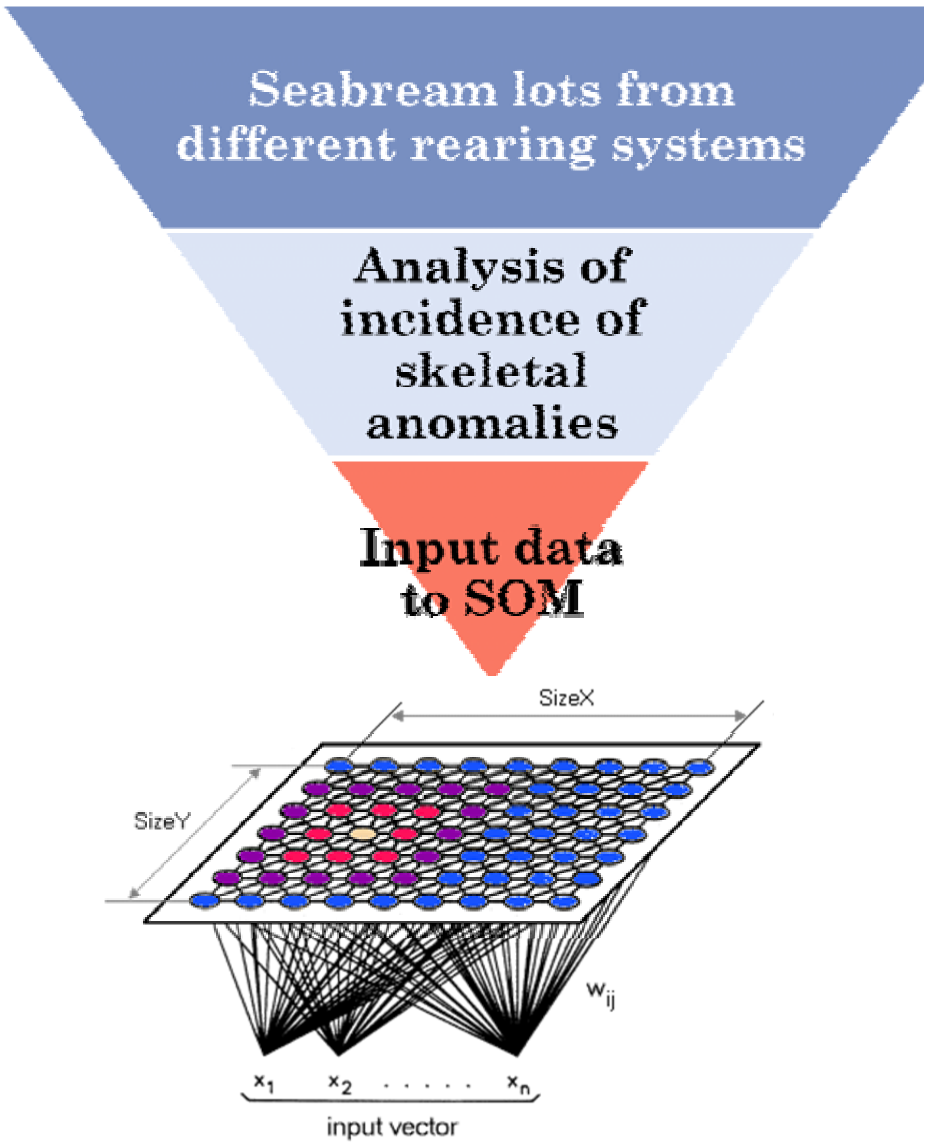
- to develop a model of the occurrence of skeletal anomalies in reared fish, both in terms of type and quantity. This model can correlate data on deformities and any other external source of information (growth performance, survival rates, densities,….), and having forecast and validation capabilities

- to investigate correspondence between different types of developmental anomalies (skeletal, meristic counts, pigmentation,…);

- to set up a method for an objective evaluation of morphological quality of cultured lots of juveniles

MONITORING THE INCIDENCE OF SKELETAL ANOMALIES IN GILTHEAD SEABREAM

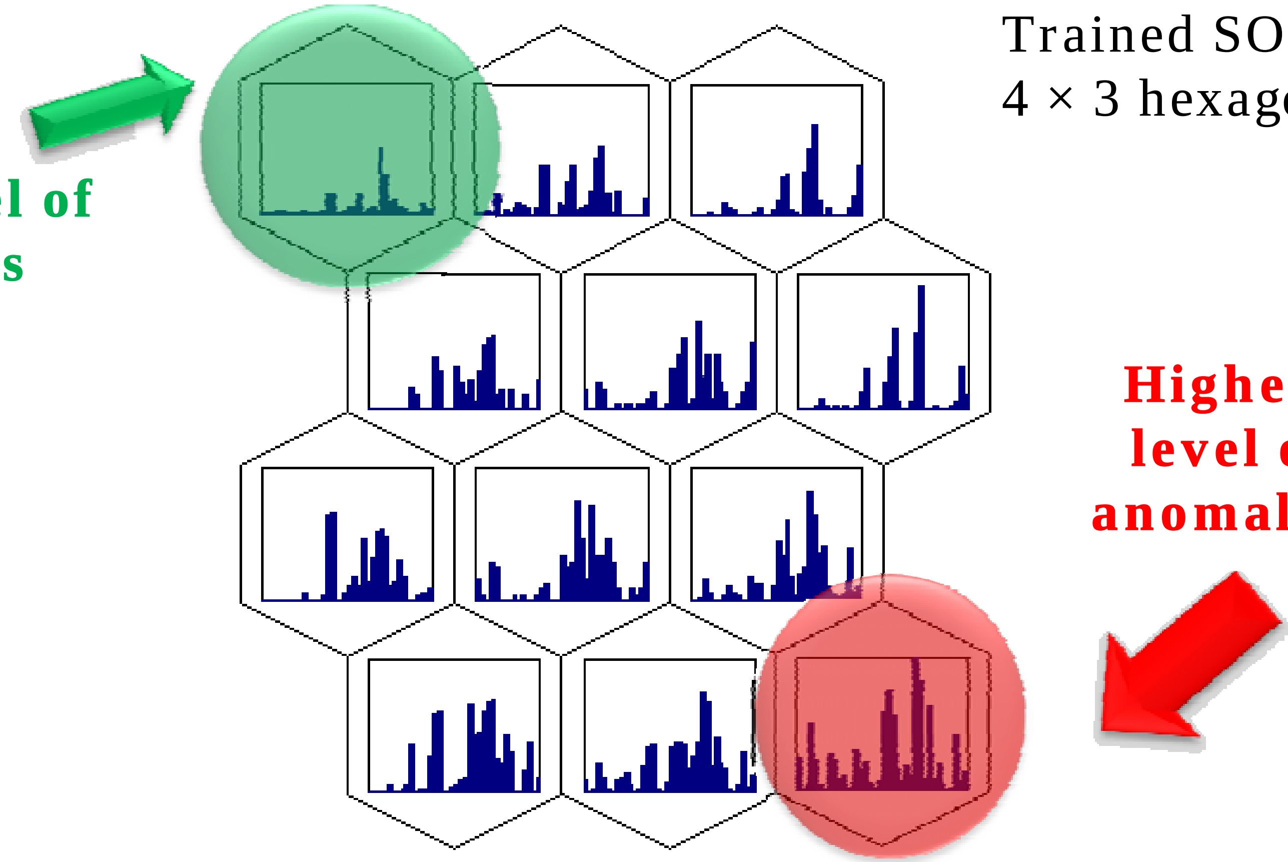




SOMs were applied to a large dataset containing data on skeletal anomalies inherent to 58 lots of both wild and cultured sea bream juveniles (total n. = 3,942). Lots origins: Wild, Intensively and Semi-intensively reared (mesocosms *sensu* Divanach and Kentouri, 2000 - Large Volumes *sensu* Cataudella et al., 2002)

Construction of a model for the incidence of skeletal anomalies

1. The **weights** of each map unit, that is the virtual profiles of frequency for the skeletal anomalies considered, are plotted in an histogram for each unit of the map

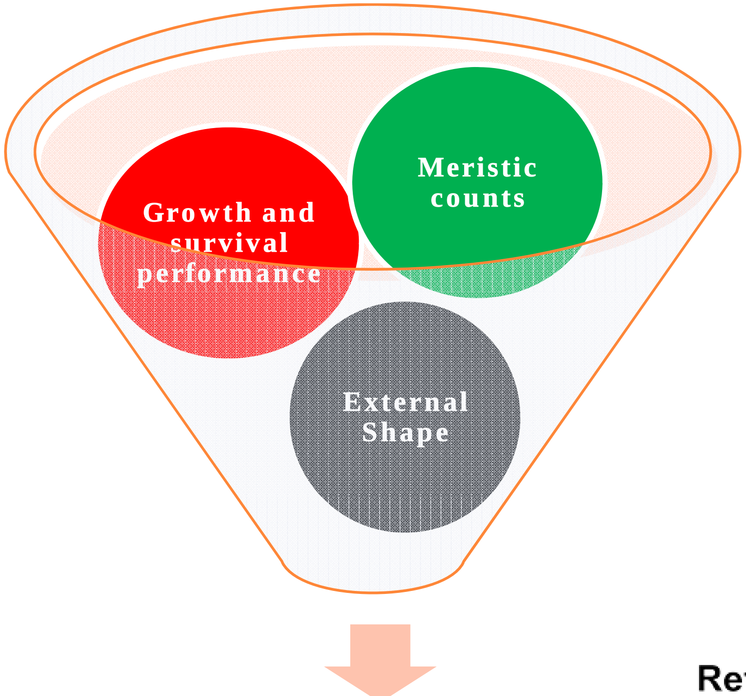


Trained SOM:
4 × 3 hexagons

Lowest level of anomalies

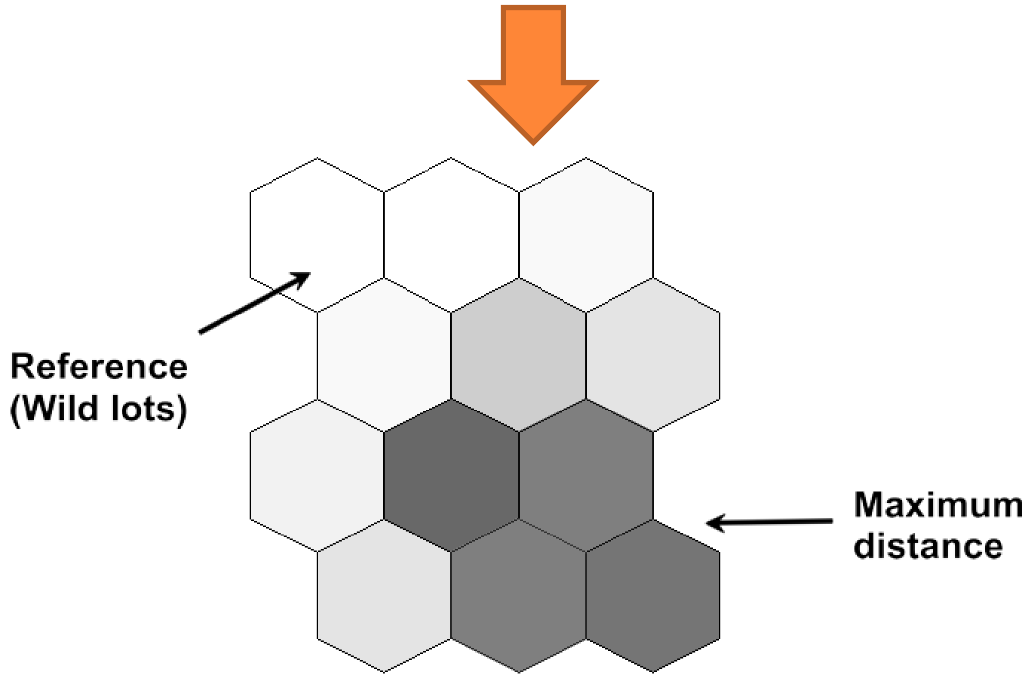
Highest level of anomalies

BEYOND THE MODEL: SUPERIMPOSITION OF DATA FROM OTHER SOURCES



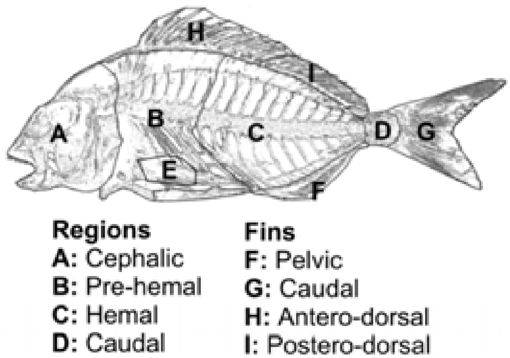
Trained SOM

Example: Hellinger distances (from the wild) for meristic counts

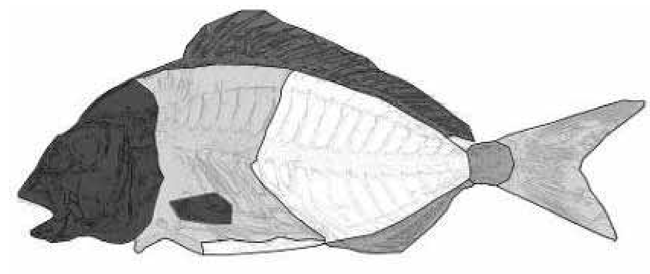


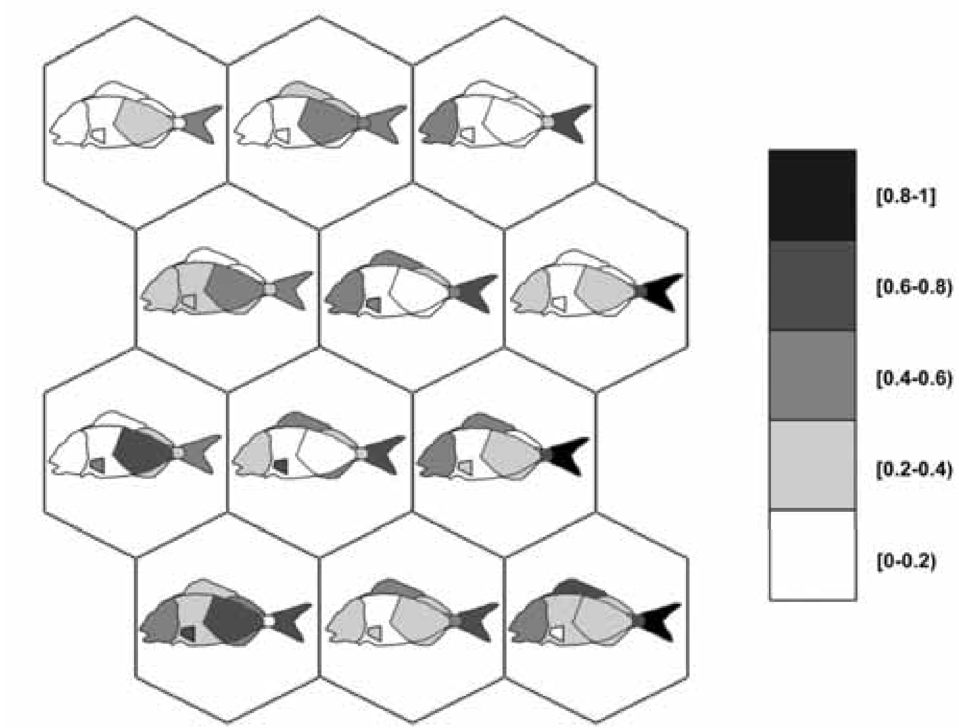
Cumulated Hellinger distance

BEYOND THE MODEL: CONSTRUCTION OF A TOOL FOR THE ASSESSMENT OF QUALITY



The anomalies were named accordingly to the anatomical region in which they occur

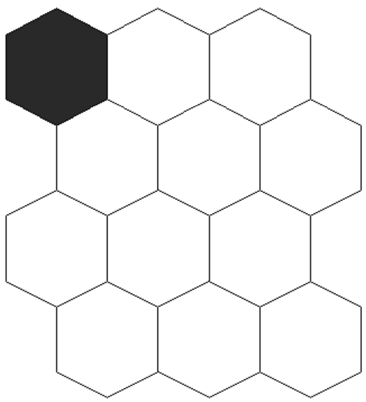


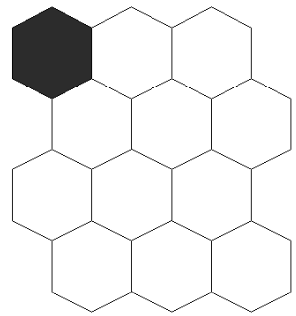


The model can be visually understood by looking at the theoretical distribution of anomalies by region

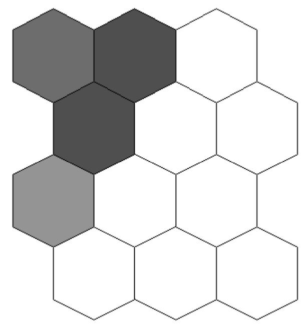
- **Similar rearing methodologies return the same morphological quality of juveniles?**

Wild catched lots

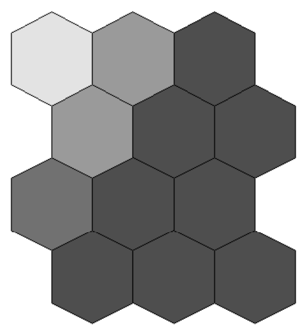




Mesocosms



Large Volumes

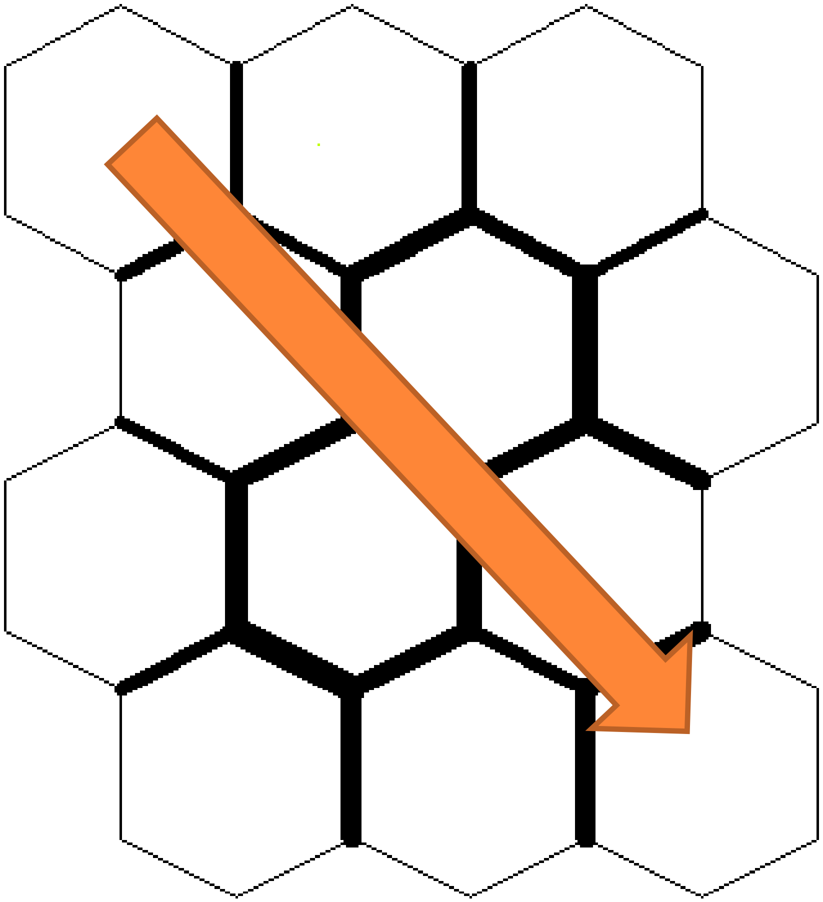


Intensive

The answer is sometimes NO!

Evaluation of quality (use of the model to assess the quality of a new lot)

Using this model is possible to <u>compute the distance of each lot</u> (yet available or coming from future observations) from the "wild-like" morphology represented by the first neuron of the trained SOM



CASE #2: CONSTRUCTION OF A MODEL FOR THE DETECTION OF ORIGIN IN DUSKY GROUPER

Aquaculture 291 (2009) 48–60

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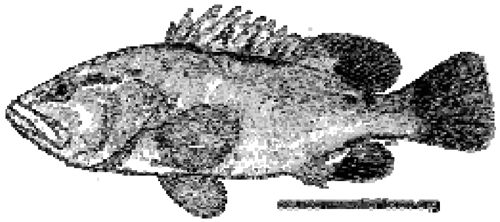
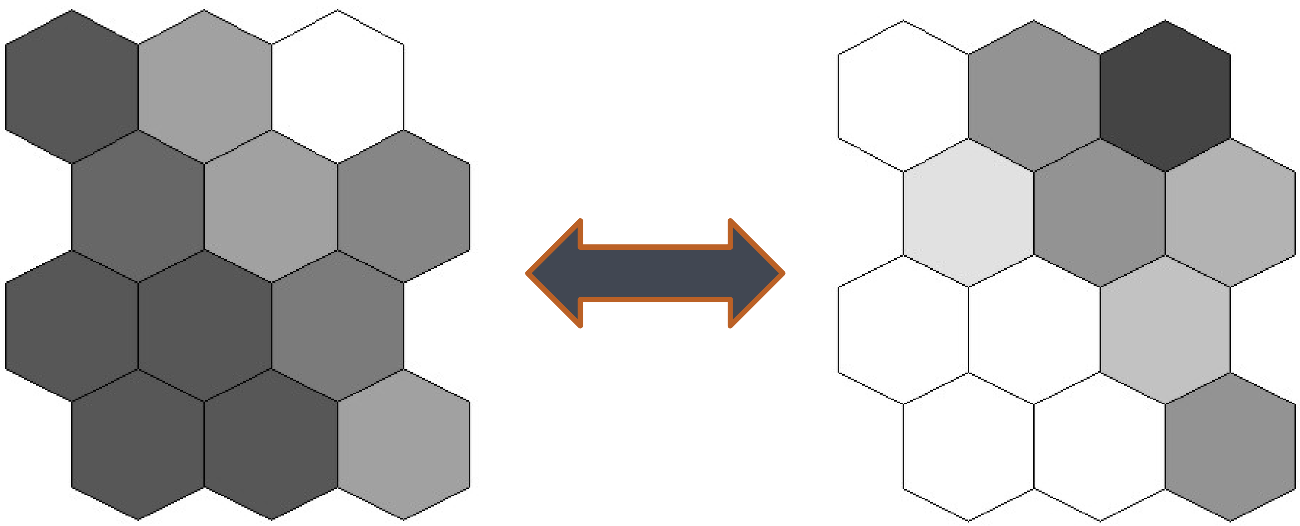


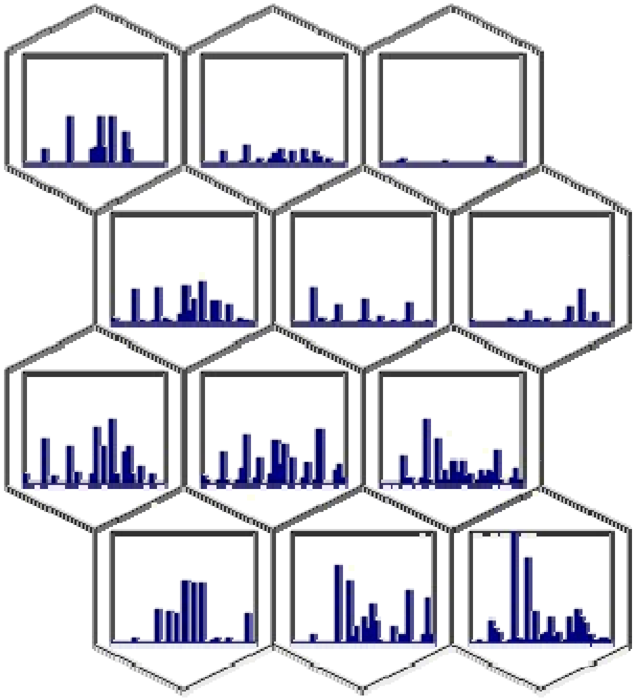
Skeletal anomalies in dusky grouper *Epinephelus marginatus* (Lowe 1834) juveniles reared with different methodologies and larval densities

Clara Boglione [a,*], Giovanna Marino [b], Maurizio Giganti [a], Alessandro Longobardi [b], Paolo De Marzi [a], Stefano Cataudella [a]

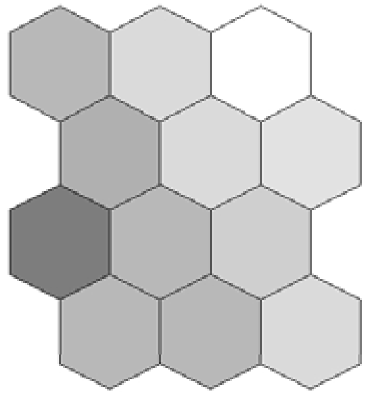
Green water **Large volume**



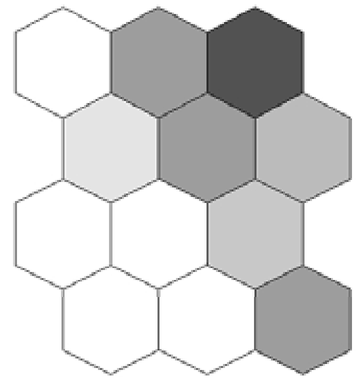
EFFECTS OF LARVAE DENSITIES AND REARING METHODOLOGIES ON SKELETAL ANOMALIES



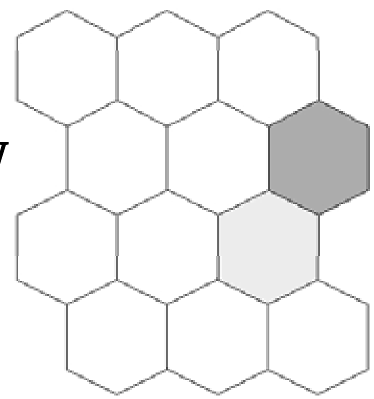
Density (overall)



Low Density LV

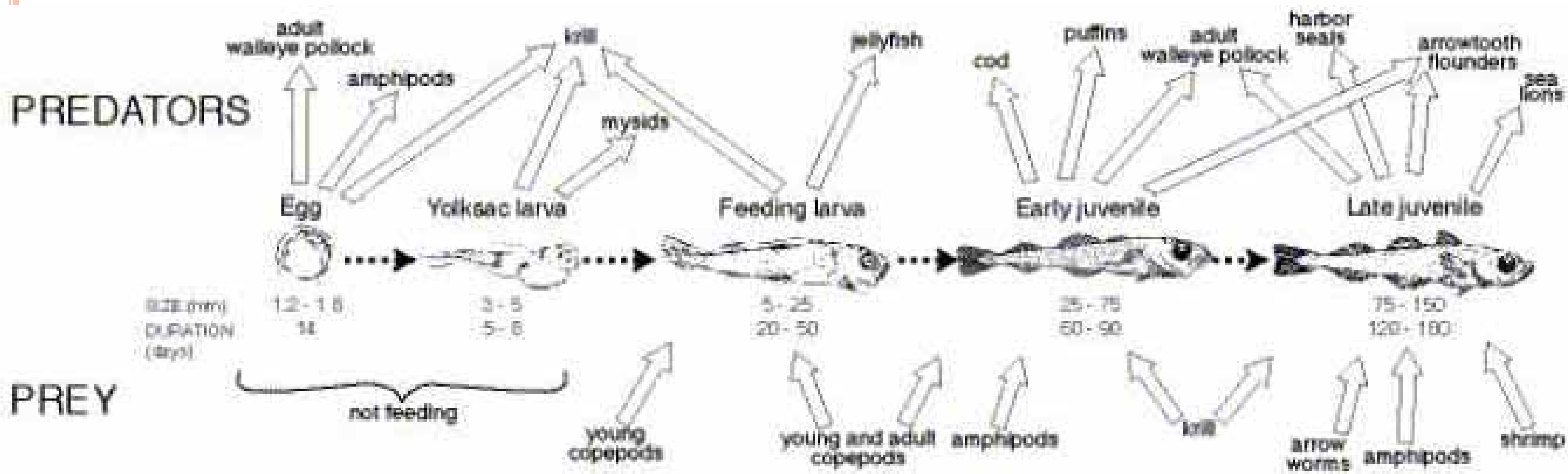


Low Density GW



Our results confirm that:

- ecological interactions, feeding behaviour, requirements change with life stage, species, and environmental conditions
- it is now possible to integrate and to analyse multidisciplinary information with sound tools



We are dealing with complexity and we have not to forget it if our goal is to rear healthy, wild-like fish

ACKNOWLEDGEMENTS

- Publication benefits from participation in LARVANET COST action FA0801'
- This study has been carried out in part with the financial support from the Commission of the European Communities, specific RTD programme “Specific Support to Policies”, SSP-2005-44483 “SEACASE - Sustainable extensive and semi-intensive coastal aquaculture in Southern Europe”, and does not necessarily reflect the European Commission views and in no way anticipates the Commission’s future policy in this area”

THANK YOU!

Materials and Methods

Materials & Methods: **Skeletal anomalies inspection**

Table 1: list of considered anomalies

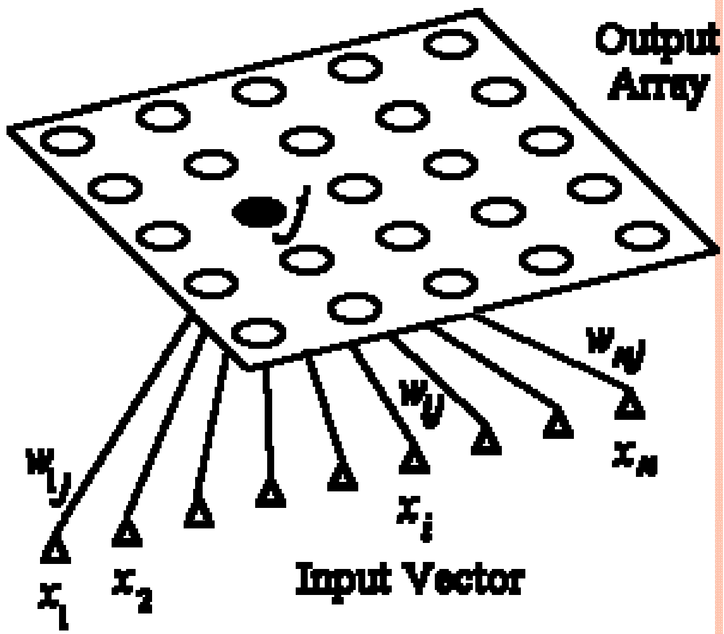
Region	
A	Cephalic vertebrae
B	Pre-hemal vertebrae
C	Hemal vertebrae
D	Caudal vertebrae
E	Pectoral fin
F	Anal fin
G	Caudal fin
H	Dorsal spines
I	Dorsal soft rays

Type	
S	Scoliosis
1	Lordosis
2	Kyphosis
3	Complete and Incomplete vertebral fusion
4	Malformed vertebral body
5	Malformed neural arch and/or spine
6	Malformed hemal arch and/or spine
7	Malformed ray
8	Malformed pterygophore
9	Malformed hypural
10	Malformed epural
12	Swim-bladder anomaly
13	Calculi in the urinary ducts
14	Prognatism of dental
15	Reduced dental
16	Dislocation of glossohyal
17	Deformed or reduced opercle

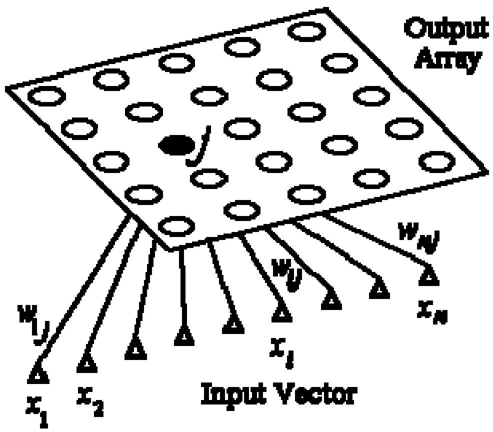
Materials & Methods: Kohonen's Self-Organising maps (SOMs)

SOMs

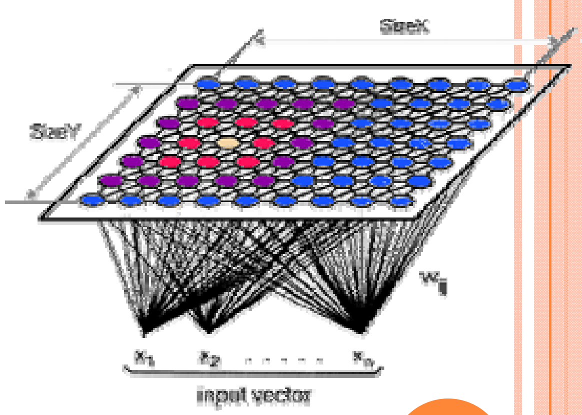
- are a particular type of artificial neural networks
- were used to display the high-dimensional datasets of skeletal anomalies in a two- dimensional space: this implies a not-linear projection onto a lattice of hexagons
- consist of two layers: the **input layer**, connected to each vector of the dataset, and the **output layer**, consisting of a two-dimensional network of neurons (the units of the map).



<u>INPUT VECTORS:</u>
Mean frequencies of 38 skeletal anomalies data for each lot (n individuals = 3,942 grouped in 58 lots)



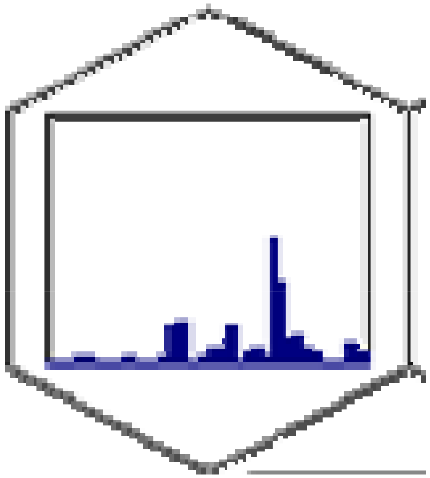
The <u>learning procedure</u> is an iterative sequence of instructions repeated for a fixed number of times.



During SOM learning, only the input layer is used, so that this procedure is defined as “unsupervised”.

MATERIALS & METHODS: SOMs – LEARNING PROCEDURE

virtual shape units (**VU** - the element of output layer) for each hexagon of the map are computed in order to put the **sample units** (**SU** - the shape of each specimen which constitutes the input layer) on the map and preserve the neighbourhood, so that similar shapes map close together on the grid.



1) t=0, when the VUk are initialised with random samples drawn from the input dataset;
2) a sample unit SUj is randomly chosen as an input unit;
3) the distance between SUj and each VUs is computed using some distance measurement;
4) the VUc closest to the input SU is chosen as the best matching unit (BMU);
5) the VUjs are updated
6) t=t+1 and steps from 2 to 6 are repeated until t=tmax .

MATERIALS & METHODS: SOMS – LEARNING PROCEDURE

The neighbourhood function defines the extension of the VU range that was updated in step 5 and, in this study, was chosen to be Gaussian.

Moreover, neighbourhood shrinking and learning rate decay were chosen to be exponential.

The City-Block (Manhattan distance) was chosen as distance measure and several parameters, such as the number of training epochs times and map sizes (number of output units, distributed in rows and columns), were optimized by choosing an optimum based on the minimum values of quantization and topographic errors (Park et al. 2003, 2004).

The number of epochs was set to1,000 in all cases.

Subsequently, the fine-tuning epochs were set to 500.

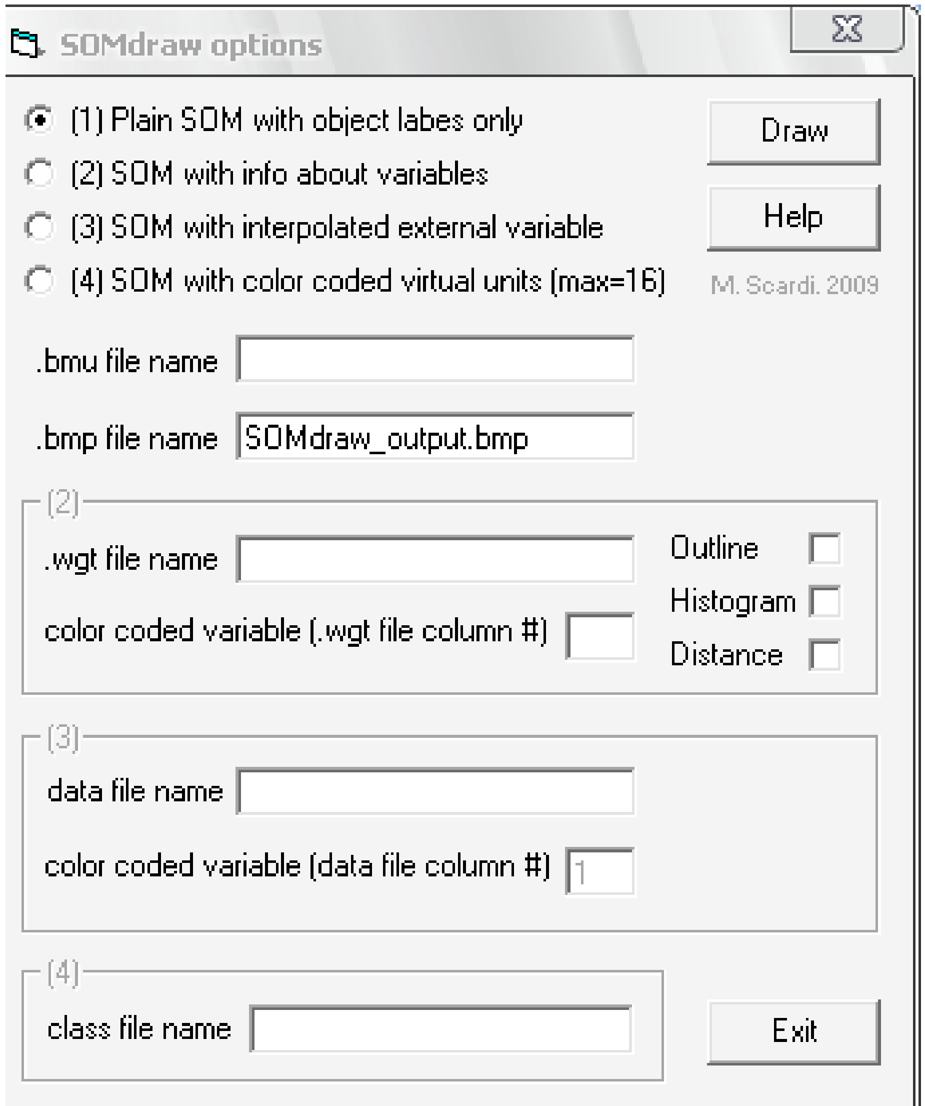
Slide 38

G1 che sono le iterazioni successive, quando si aggiungono altri dati?

No, sono delle iterazioni finali in cui vengono sistemati solo gli esagoni periferici, cioè quelli che stanno al contorno. Volendo, questa frase "tecnica" la puoi pure levà

Grishnackh; 27/04/2009

Materials & Methods – SOMs – 2. Representation of the output of the SOM learning procedure

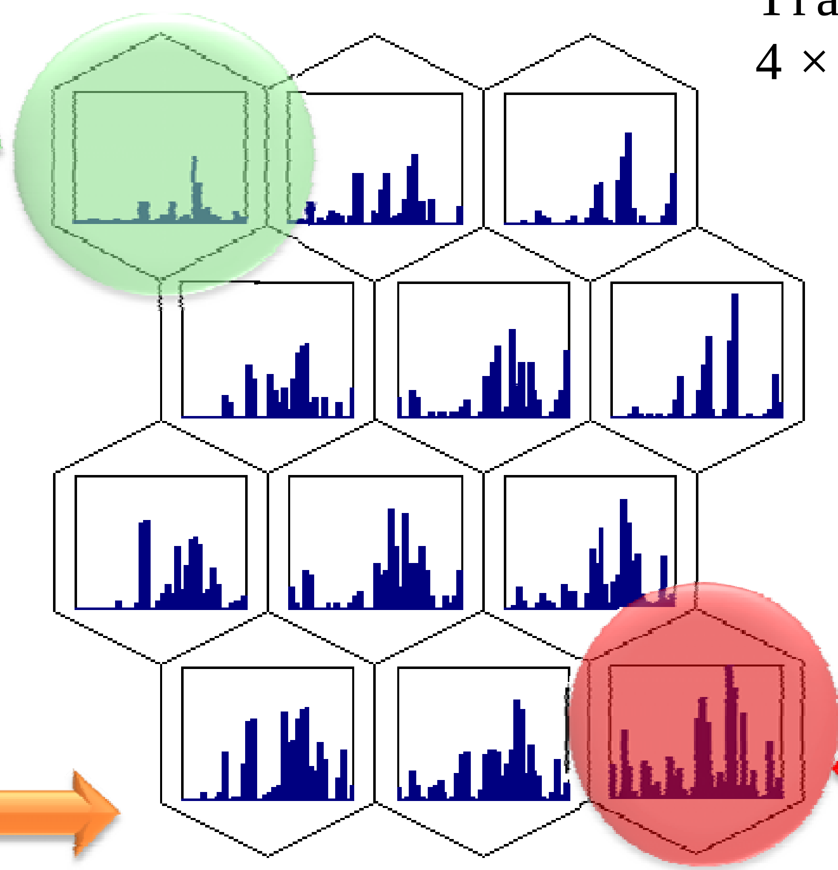


Results: Construction of a model for the incidence of skeletal anomalies

1. The **weights** of each map unit, that is the virtual profiles of frequency for the skeletal anomalies considered, are plotted in an histogram for each unit of the map

Lowest level of anomalies

Trained SOM:
4 × 3 hexagons



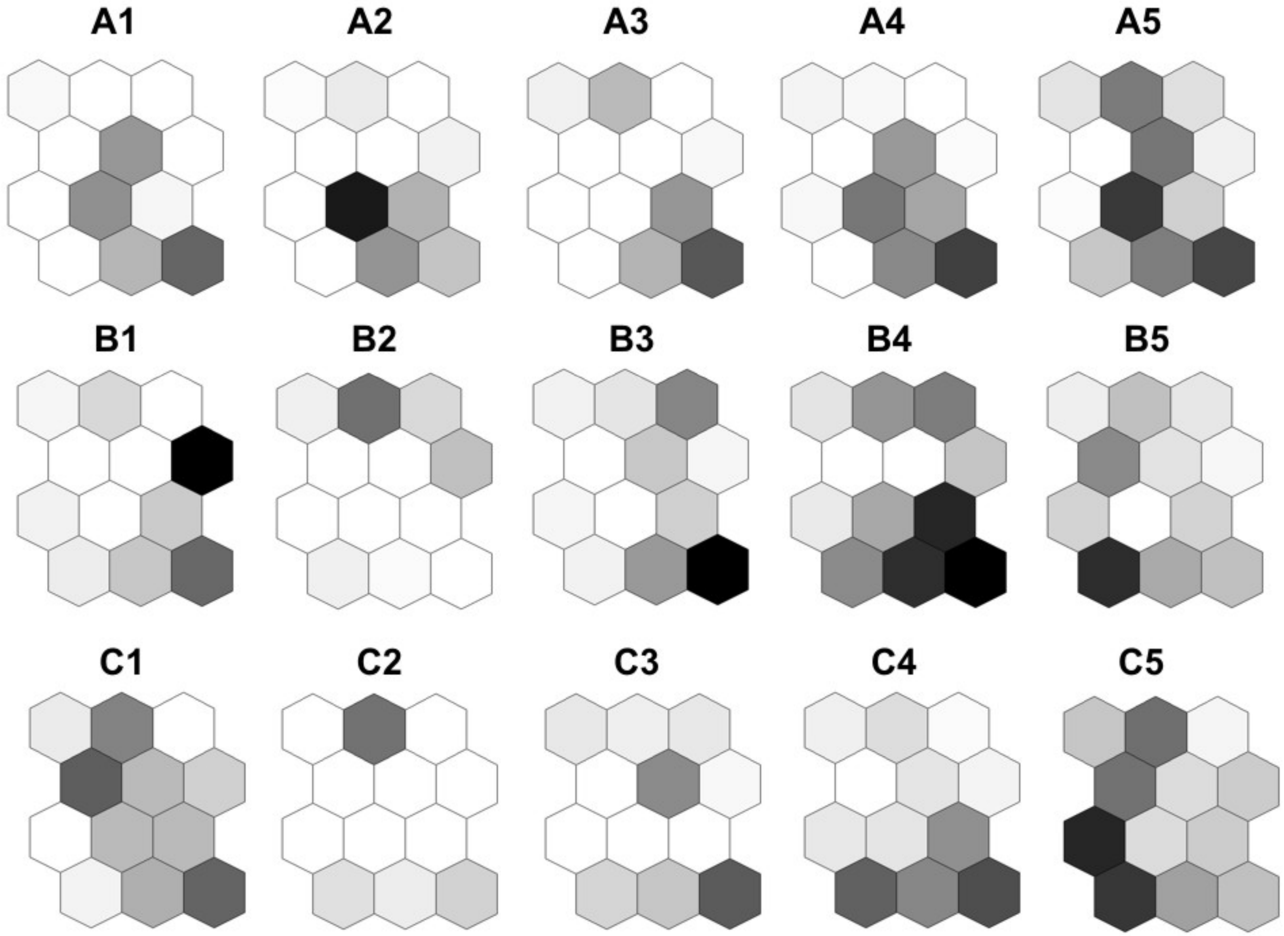
Dataset: 58 lots characterized by 38 skeletal anomalies

Frequency of each anomaly computed on the binary (0/1) matrix of presence

Highest level of anomalies

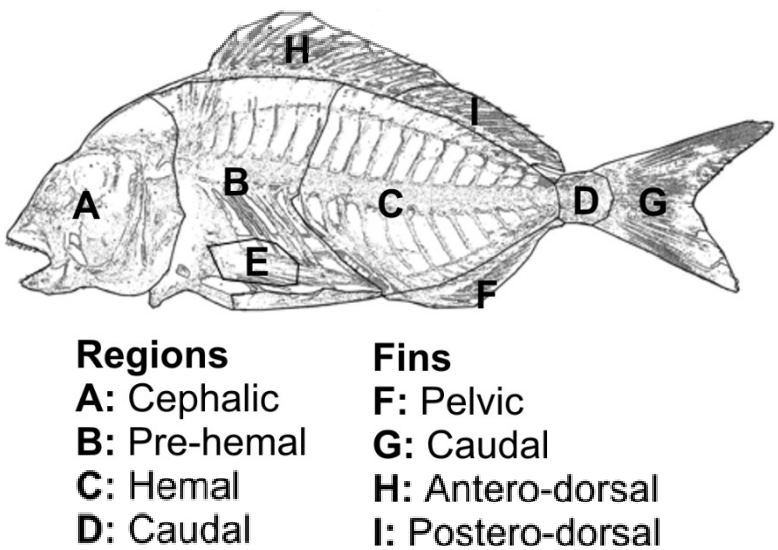
Results: gradients for each type of skeletal anomalies used for SOM training

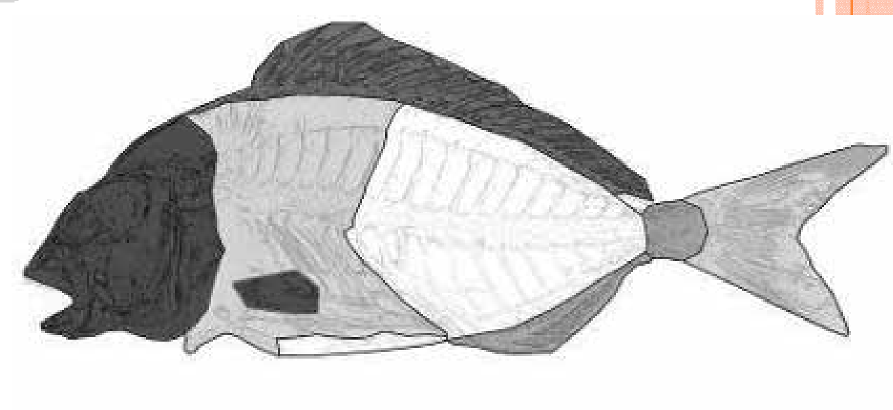
2. To analyze the contribution of each skeletal anomalies to the pattern obtained by SOM, each input variable was visualized in each neuron **in grey scale**



2.To analyze the contribution of each skeletal anomalies to the pattern obtained by SOM, the input variables were grouped in **body regions**

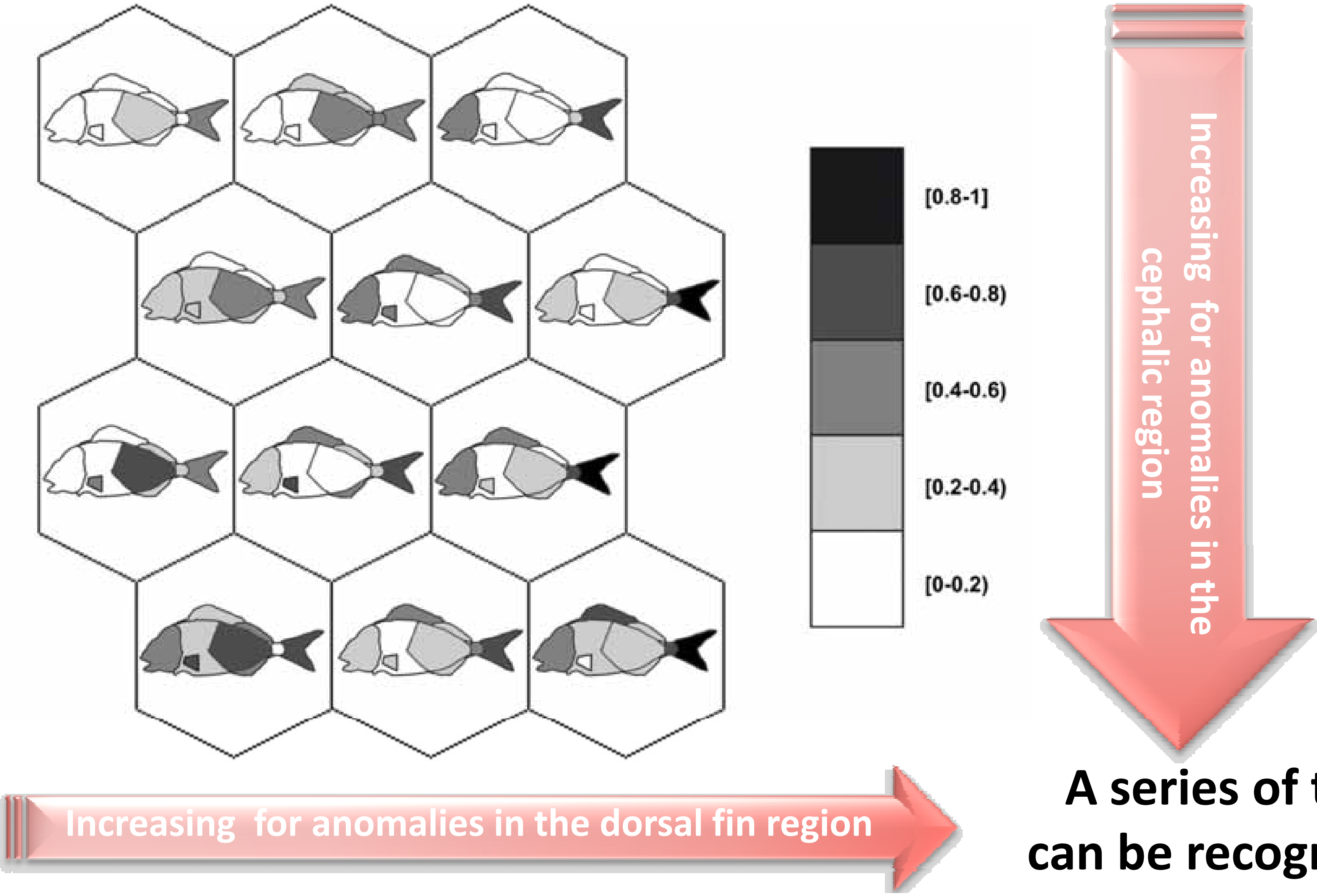
The anomalies were named accordingly to the anathomical region in which they occur





Results: Simplified pattern of occurrence of skeletal anomalies

The model can be visually understood by looking at the theoretical distribution of anomalies by region



A series of trend can be recognized...

Results: Position of the lots into the trained SOM

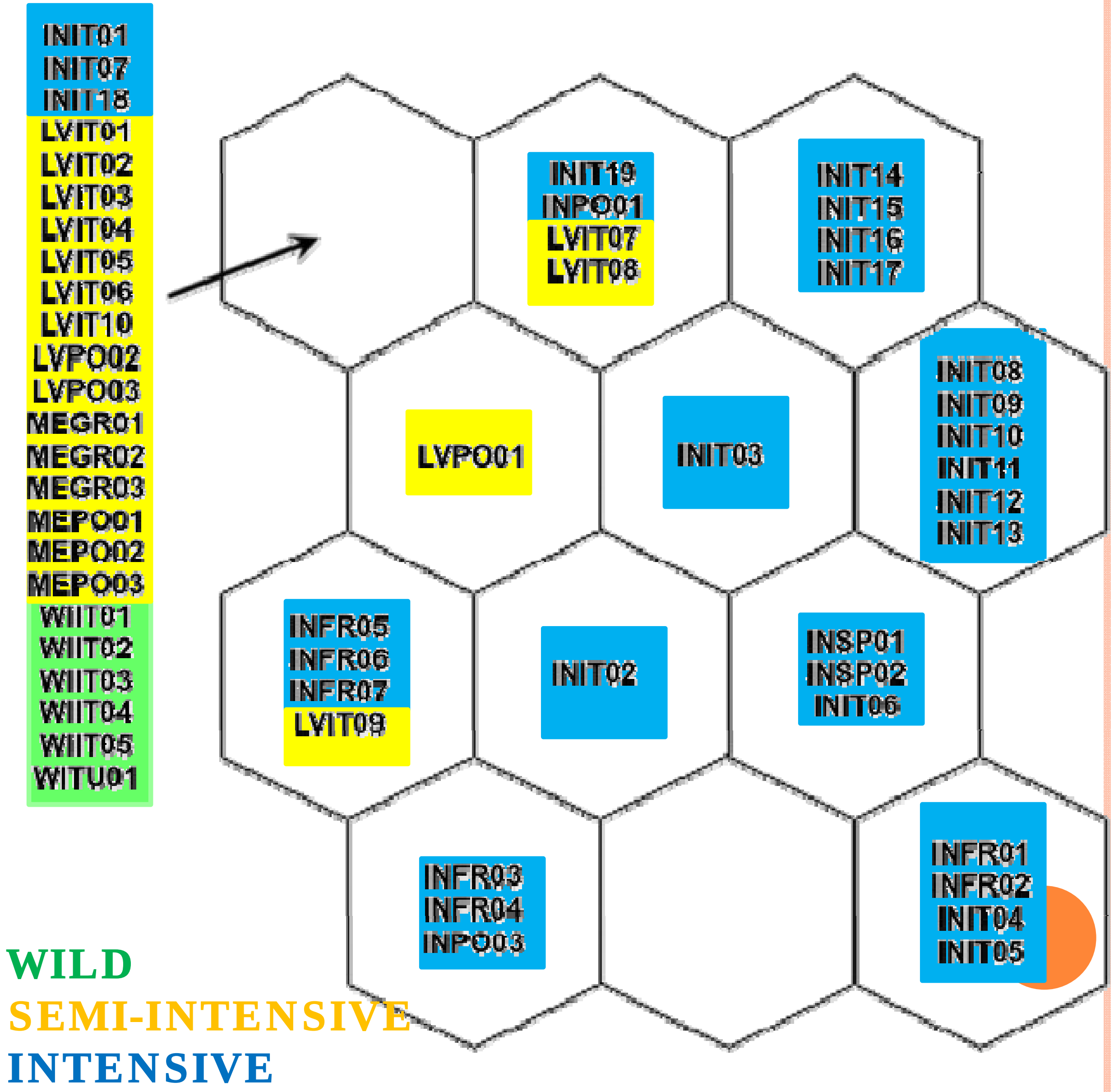
3. **Labels** were used to mark the SOM unit corresponding to each lot

1) **Different number of lots assigned to each virtual units**

   ⬇

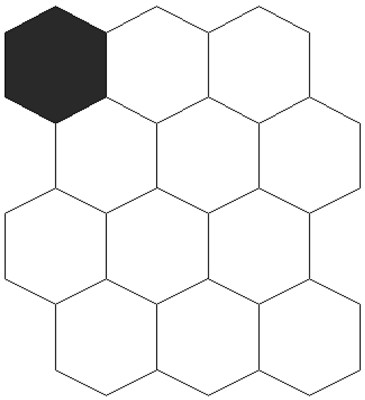
   high heterogeneity

2) **Some theoretical conditions were never observed (empty hexagon)**
3) **Higher heterogeneity in intensive lots**
4) **Mesocosms, Large Volumes and Wild largely coincide**

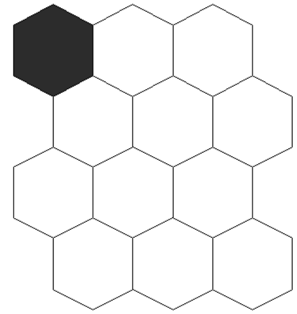


Results: Origin of lots (with respect to the rearing approach)

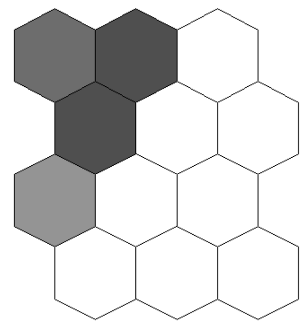
Wild catched lots



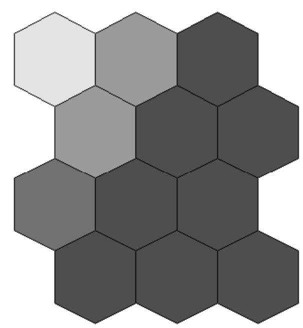
Mesocosms



Large Volumes



Intensive



Grey levels gives the number of lots in each hexagon

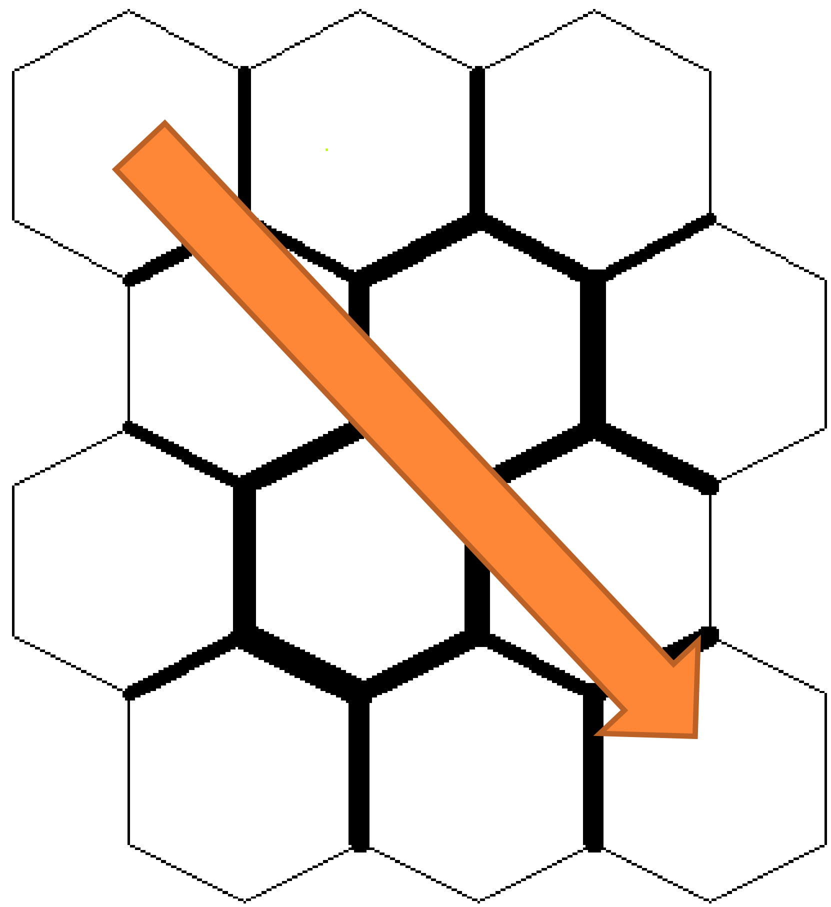
The differences between origin of lots in terms of skeletal anomalies were validated using ANOSIM

***p*=7*10-3**

Results: Distances among different SOM units (that is among lots assigned to different units

1) The Manhattan distance was computed between each pair of neighbour hexagons and then represented by differential thickness of hexagon borders;

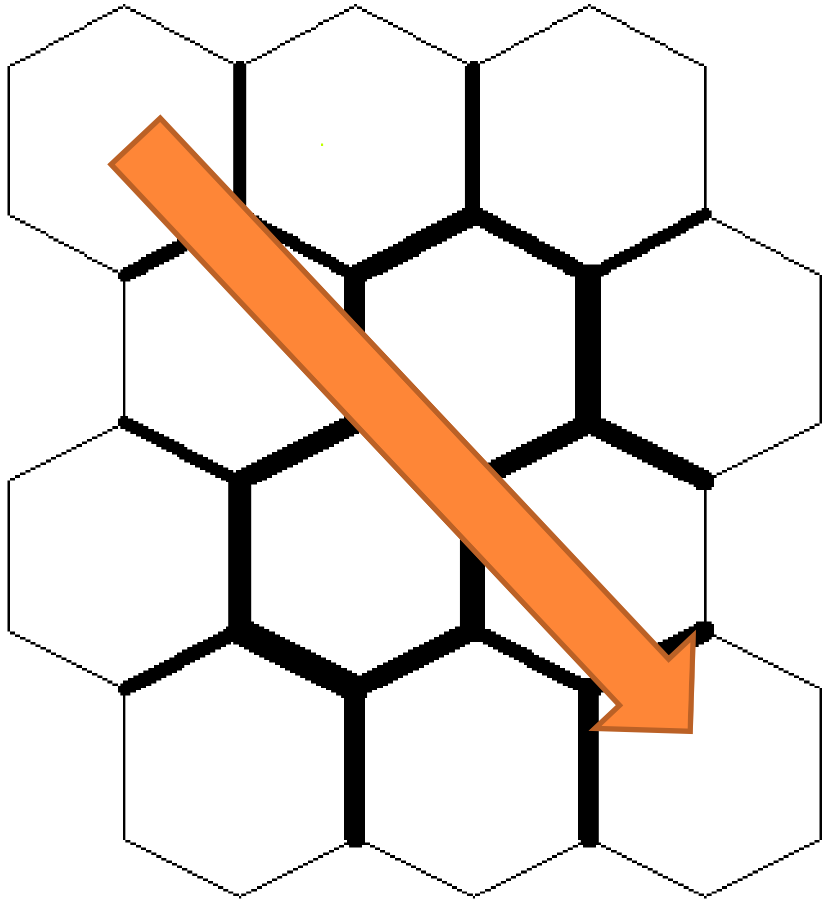
2) A progressive increase of inter-hexagon distances can be observed along the main diagonal



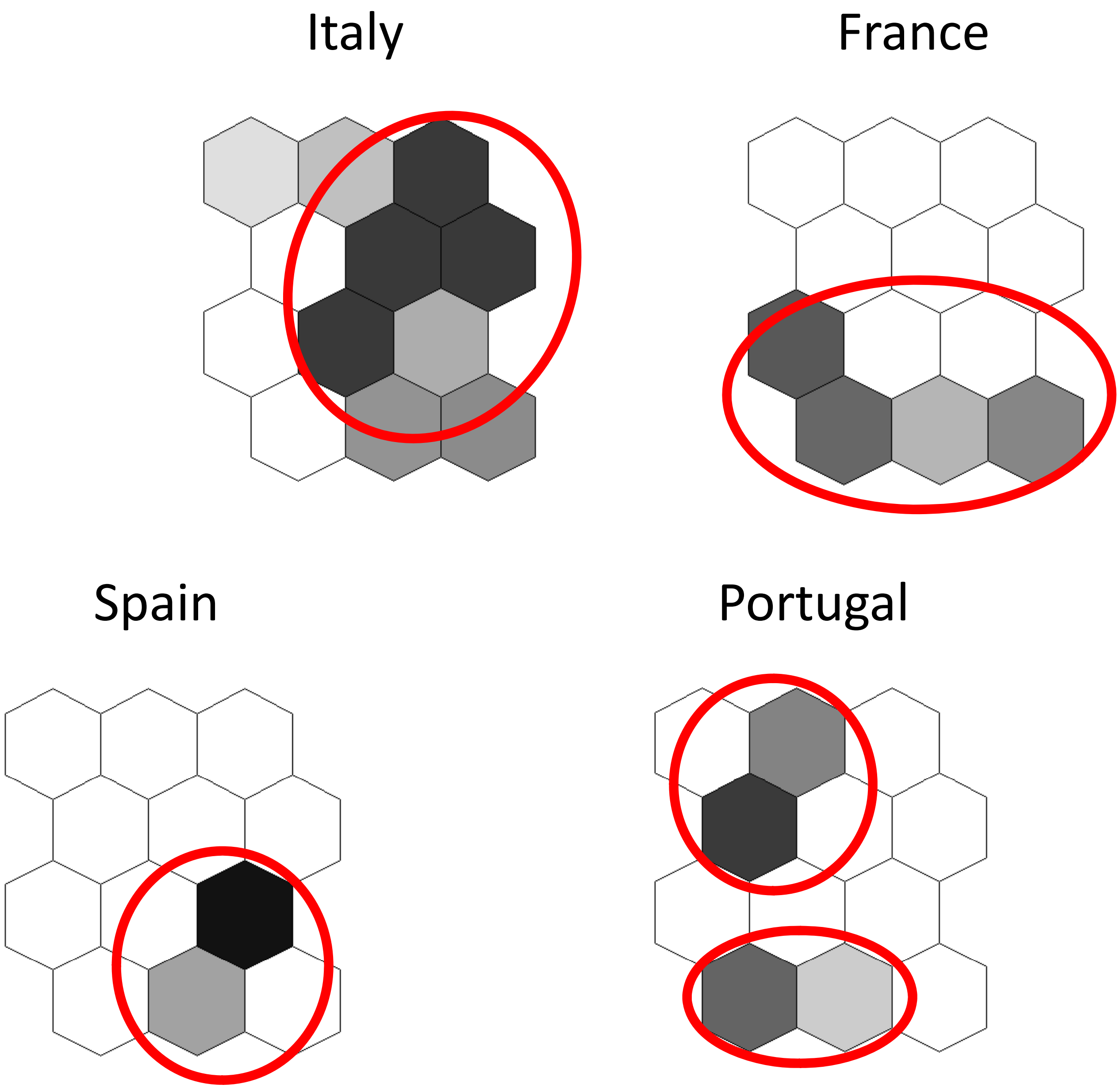
Ticker lines represent larger distances

Results: **Evaluation of quality (use of the model to assess the quality of a new lot)**

Using this model is possible to <u>compute the distance of each lot</u> (yet available or coming from future observations) from the "wild-like" morphology represented by the first neuron of the trained SOM



Results: Geographic origin of lots (within the Intensive group)

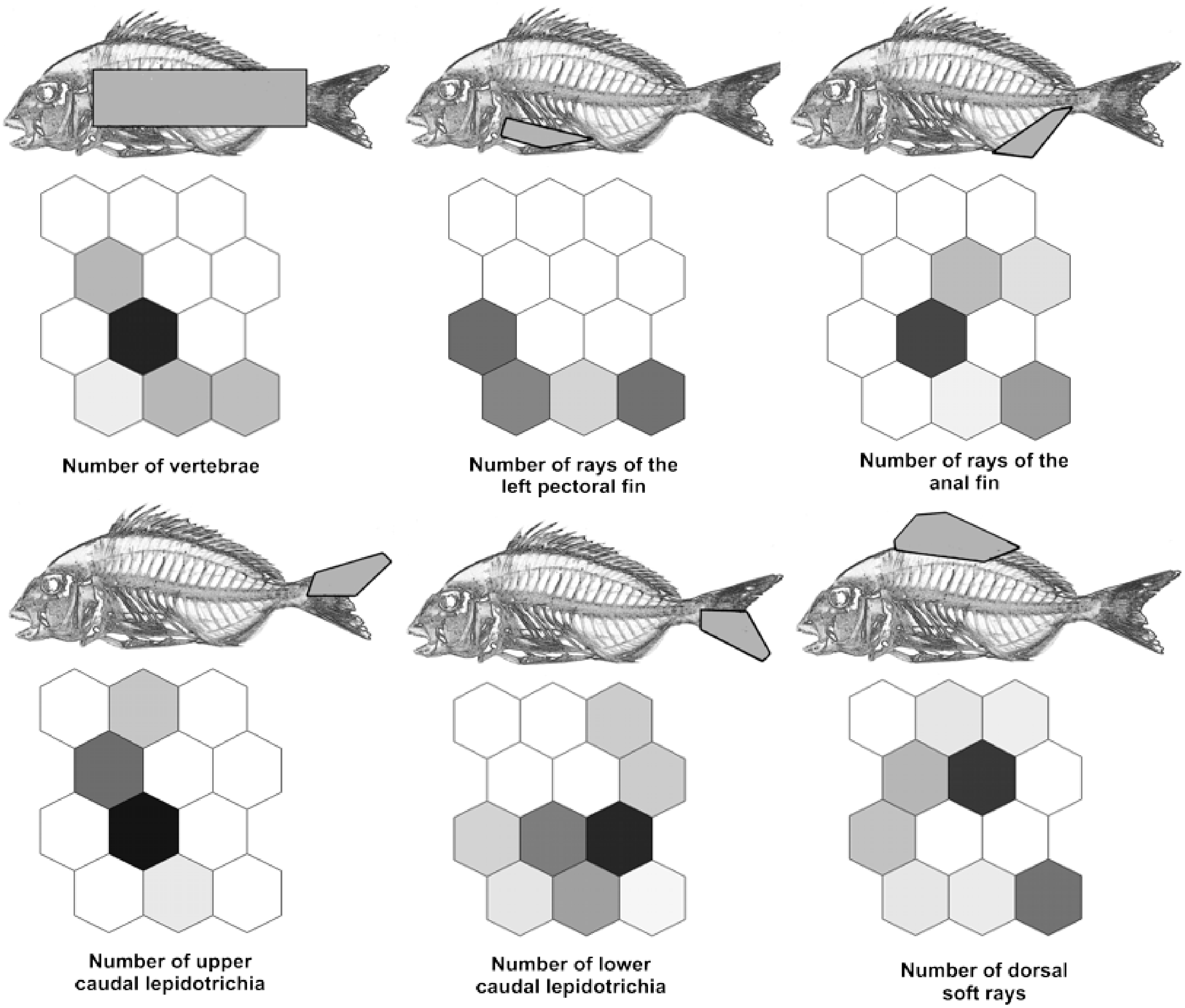


Results: Superimposition of data from meristic counts

1. Range and median values were computed for each meristic character obtaining *m* discrete classes for each meristic character;
2. The value of frequency of individuals was then calculated for each class of each meristic character, for each lot
3. **Hellinger distance** was computed between the wild condition, used as reference, and each lot from captive conditions, for each meristic character

$$H(l_1, l_2) = \left[\sum_{j}^{J} \left(\sqrt{l_1} - \sqrt{l_2} \right)^2 \right]^{\frac{1}{2}}$$

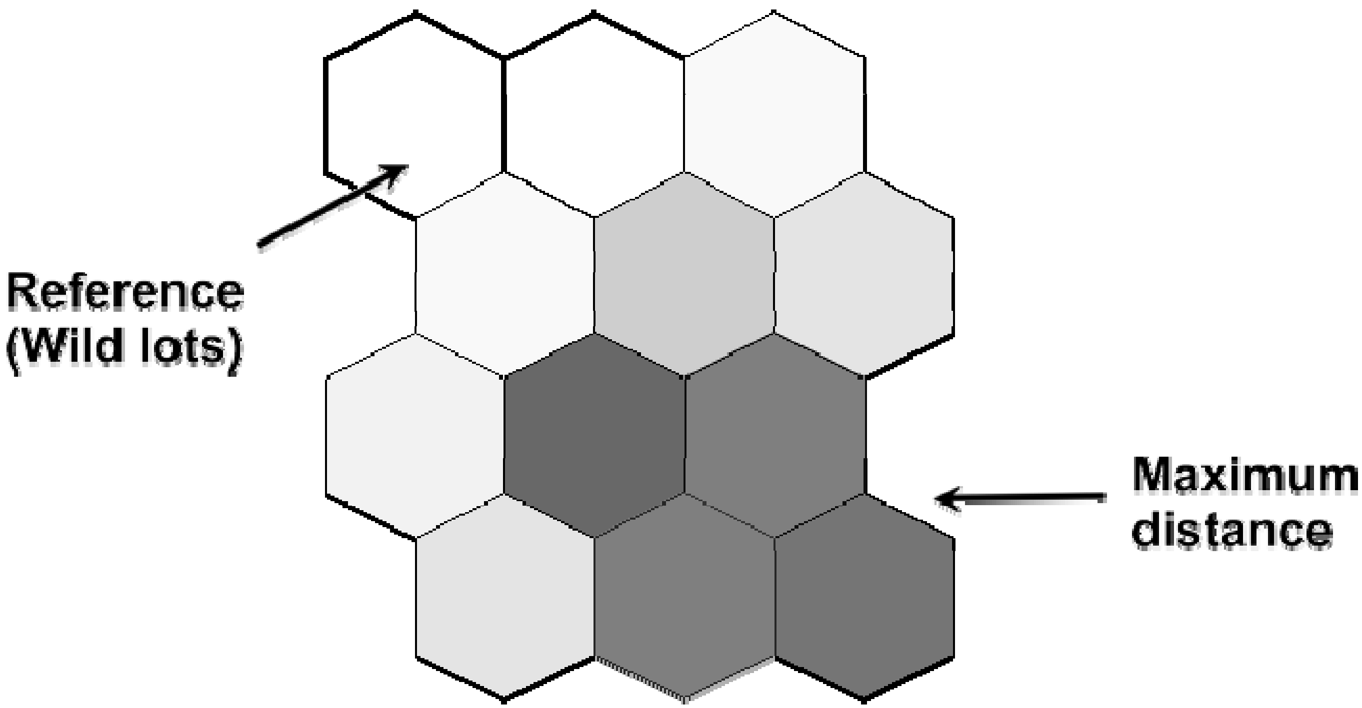
Results: Hellinger distances (from the wild) for meristic counts



A correspondence can be observed between intensive conditions (and then high level of skeletal anomalies) and Hellinger distances from the wild

Results: Hellinger distances (from the wild) for meristic counts

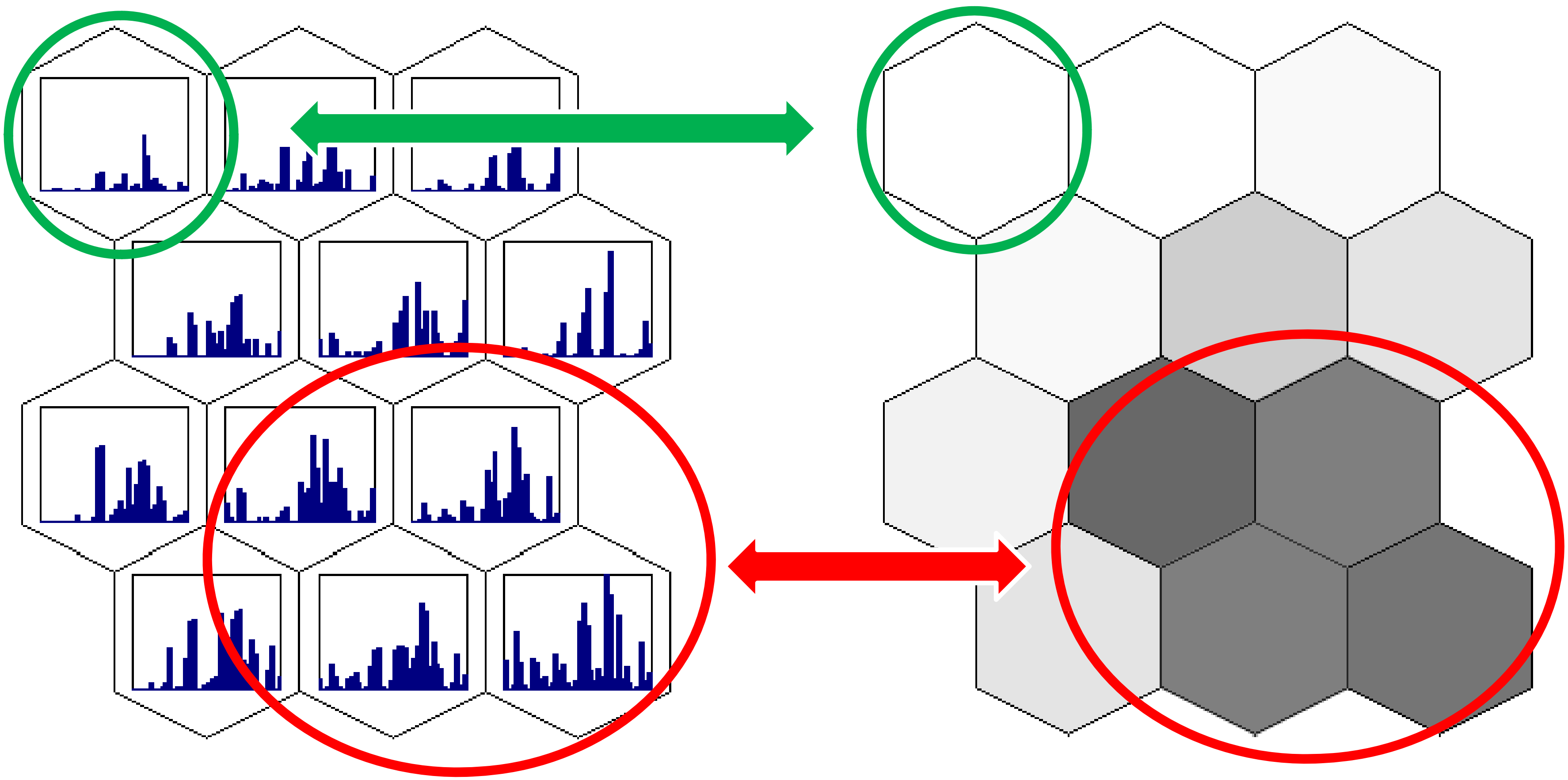
A cumulated Hellinger distance was obtained by summing the single distance ➡ **<u>The global signal is very clear</u>**



Cumulated Hellinger distance

<u>It should be stress that meristic data were NOT used for SOM training</u>

Results: **Correspondence between pattern of occurence of skeletal anomalies and Hellinger distances for meristic counts sovrapporre**



Questionnaire about rearing approach and performance

SECTION 1: TECHNICAL ASPECTS	
1. Exact sizes (length × width × height in meters) of the rearing tanks/ponds/mesocosms/……	
2. Type of air supply system (if any). Please specify position and number of elements. (i.e., air stone in the middle of the tanks)	
3. Shape (i.e., rectangular, circular, etc.) and volume (liters or m3) of the rearing tanks/ponds/mesocosms/……	
4. Days post hatching (DPH) at which larvae were transferred from eggs tanks to larval rearing tanks/mesocosm/pond/….. (*please, specify*) *Please, indicate a range when appropriate.*	
5. Initial density of fish larvae (individual×m-3 or grams×m-3)	
6. DPH, mean TL (*if available*), mean Weight (*if available*), at which weaning started	
7. Final density at the end of larval rearing phase (individual×m-3 or grams×m-3)	
8. Days post hatching at which postlarvae were transferred from larval rearing tanks to pre-fattening tanks/pond/….	
9. Temperature throughout larval rearing (mean and standard deviation in C°)	
10. Type of food supplied throughout the larval rearing (i.e., cultured live preys, pellets, wild collected live preys)	
SECTION 2: PRODUCTIVE ASPECTS	
1. Hatching rate	
2. DPH, TL (*if available, mean and standard deviation in mm*), Weight (*mean and standard deviation in grams*), at which larval rearing finished	
3. Survival rate at the end of larval rearing (%) (*before and after weaning phase, if considered*)	
4. Estimated growth performance during larval rearing (i.e., mean grams×day-1 and/or K, and/or TL ×day-1)	
5. Estimated feeding conversion rate during larval rearing (before and after weaning)	
6. Estimated growth performance (i.e., mean grams×day-1, K, TL ×day-1) during the pre-fattening (if considered) phase	
7. Estimated feeding conversion rate during the pre-fattening (if considered) phase	
8. Estimated growth performance (i.e., mean grams×day-1, K, TL ×day-1) during the fattening phase	
9. Estimated feeding conversion rate during the during the fattening rearing phase	
10. Survival rate at the end of fattening phase (%)	
11. Final price on market (€ × kilo)	

Other descriptors will be added to the model in order to connect skeletal quality with rearing condition (e.g. density, type of food, survival performance, etc.)