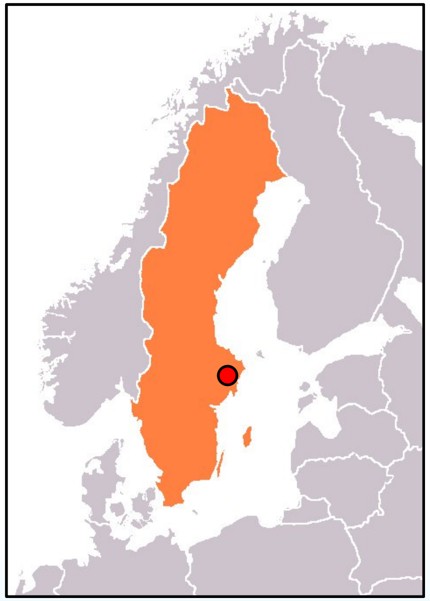
Rearing more wild-like fish for stocking – does it work?

LOCAL AND GLOBAL INITIATIVES:

HOW SCIENCE SUPPORTS MANAGEMENT ACTIONS ON DIADROMOUS FISH

Rearing more wild-like fish for stocking – does it work?

Joacim Näslund, Researcher
Swedish University of Agricultural Sciences



REVE Shad'EAUNA Interreg Atlantic Area DiadES

The Problem:

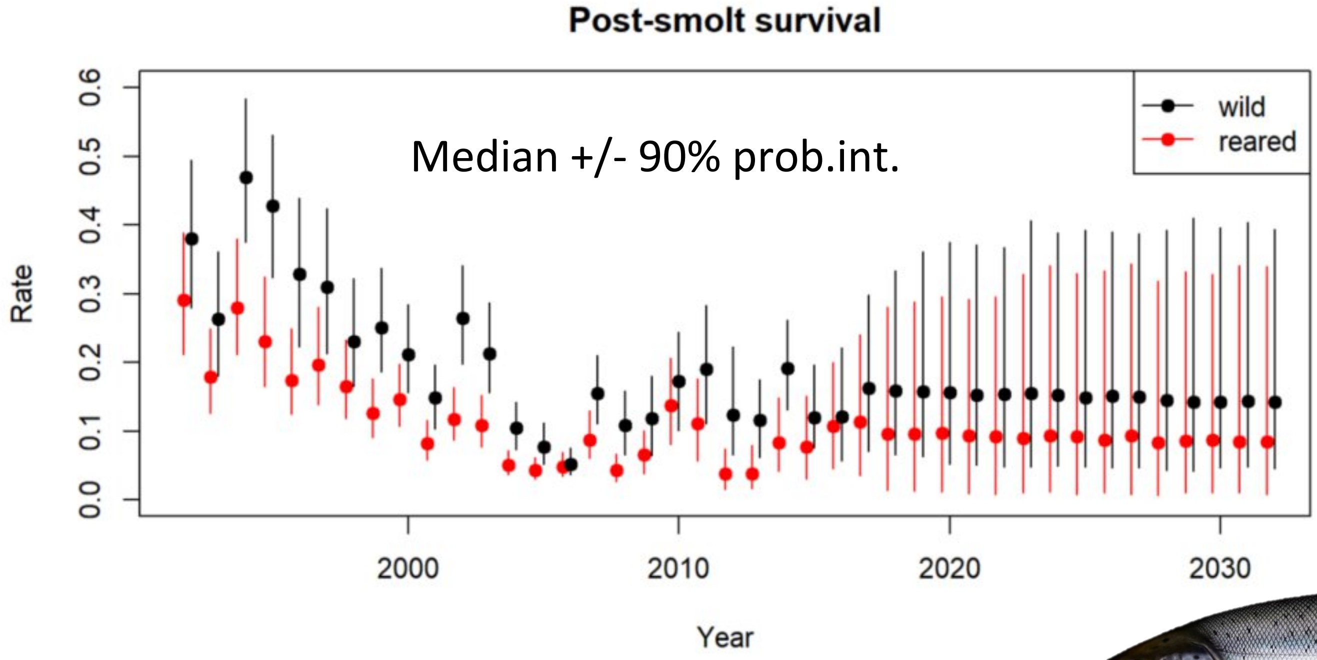
Stocked hatchery fish perform worse than wild conspecifics and often have unnatural behaviour

We assume that something in the rearing environment makes the fish less wild-like

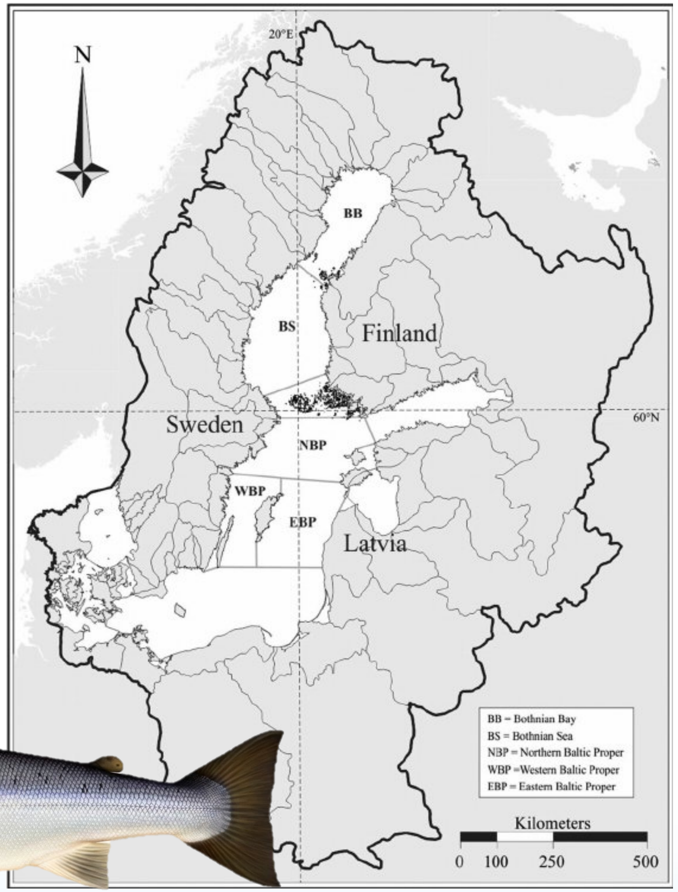
Example: Baltic salmon (*Salmo salar*)

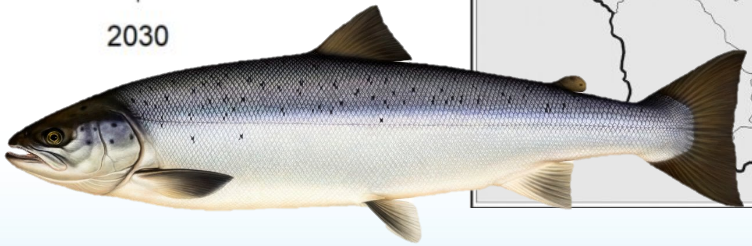
Wild smolts (2019): 2.8M

Hatchery smolts (2019): 4.7M



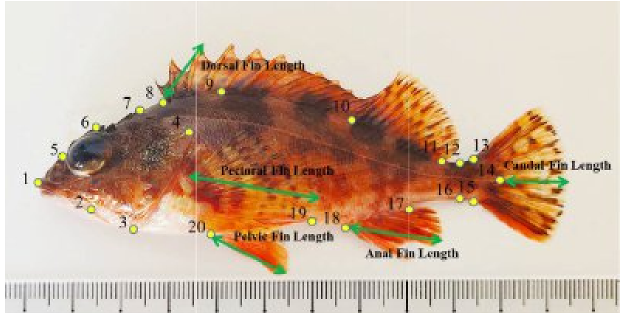
ICES Scientific Reports 2(22) 2020 (WGBAST)

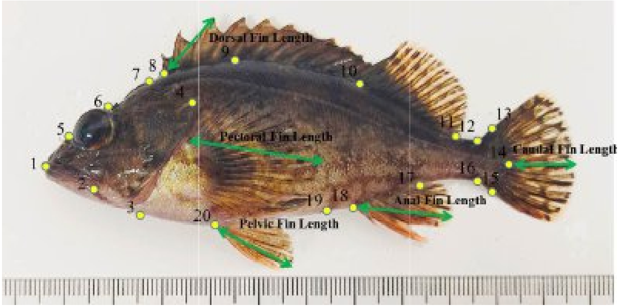




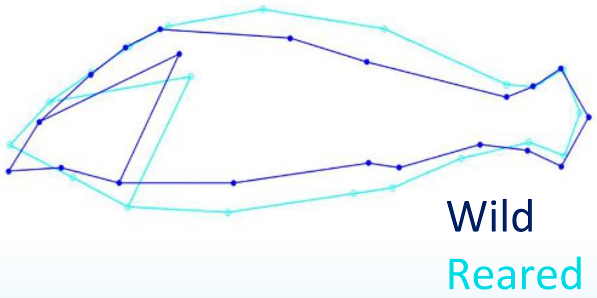
Differences between wild and reared fish

Guo et al. 2022, Front. Mar. Sci.

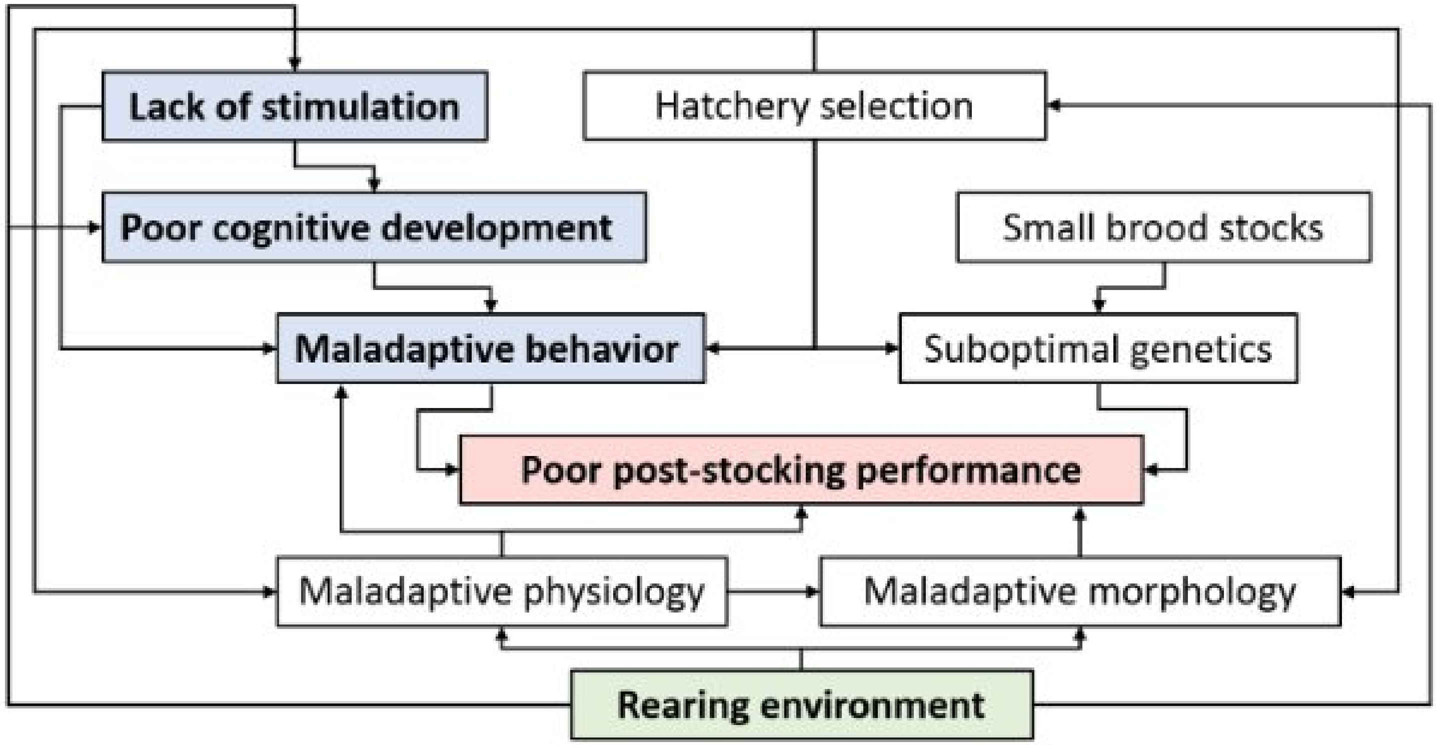




- **Morphology/Anatomy:** head/body proportions, jaw morphology, fin size, brain size, % fat, colour, etc.
- **Behaviour:** Boldness, foraging ability, anti-predation, social interactions, migration ability etc.
- **Cognition**: Memory, learning rate, etc.



Hypothetical causation of maladaptive traits



Näslund 2021, Bull. Mar. Sci.

The problem has been recognized for over a century!

The problem of poor performance of stocked fish is well known, since at least the early 1900’s:

•*‘These fish [Atlantic salmon] have become so tame that they are unsuitable to persist in the struggle for survival as it is manifested in nature, […] their innate natural caution is completely vanished.’*

– Sörensen 1919 (Skr. S. Sv. Fiskerifören.)

•*‘In strength and capability the difference was as between day and night; the wild natural fry hugged the shore singly or in very small schools, and when pursued made for a hiding place with frenzied erratic dashes. Hatchery fry when liberated swam aimlessly about, and only after repeated onslaughts of trout and ducks, during which they lost heavily, were they herded into shallow water’*

– Robertson 1919 (Tr. Am. Fish. Soc.)

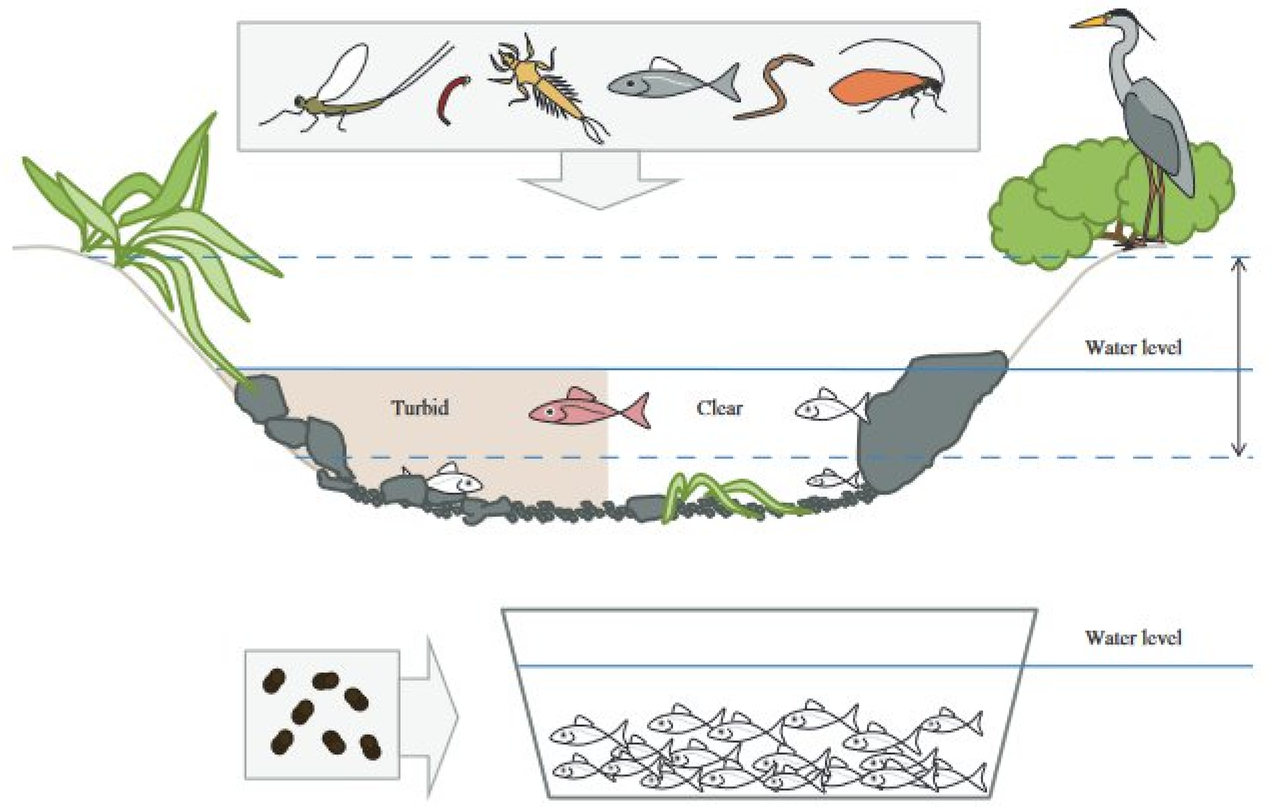
Howard Schuck 1948 (Progr. Fish-Cult.):

1. Too much fats and carbohydrates in diet
2. Overfeeding: detrimentally high growth rates
3. Lack of exercise
4. Artificial conditions, little foraging for food is necessary
5. Relative freedom from predators
6. Stable water temperatures
7. Domestication of hatchery breeders
8. Intentional/unintentional selection for good hatchery performance, i.e. high growth and egg production
9. Absence of live natural food
10. Suboptimal transport and release procedures

Expansion of hypotheses over time

Schuck's list extended
(Johnsson et al. 2014, J. Fish. Biol.)

11. Absence of sensory stimulation
    (e.g. Blaxter 1970)
12. Absence of physical structure and environmental variation
    (e.g. Salvanes et al. 2013)
13. Unnaturally high densities
    (e.g. Brockmark et al. 2010)



Factors related to learning and cognition

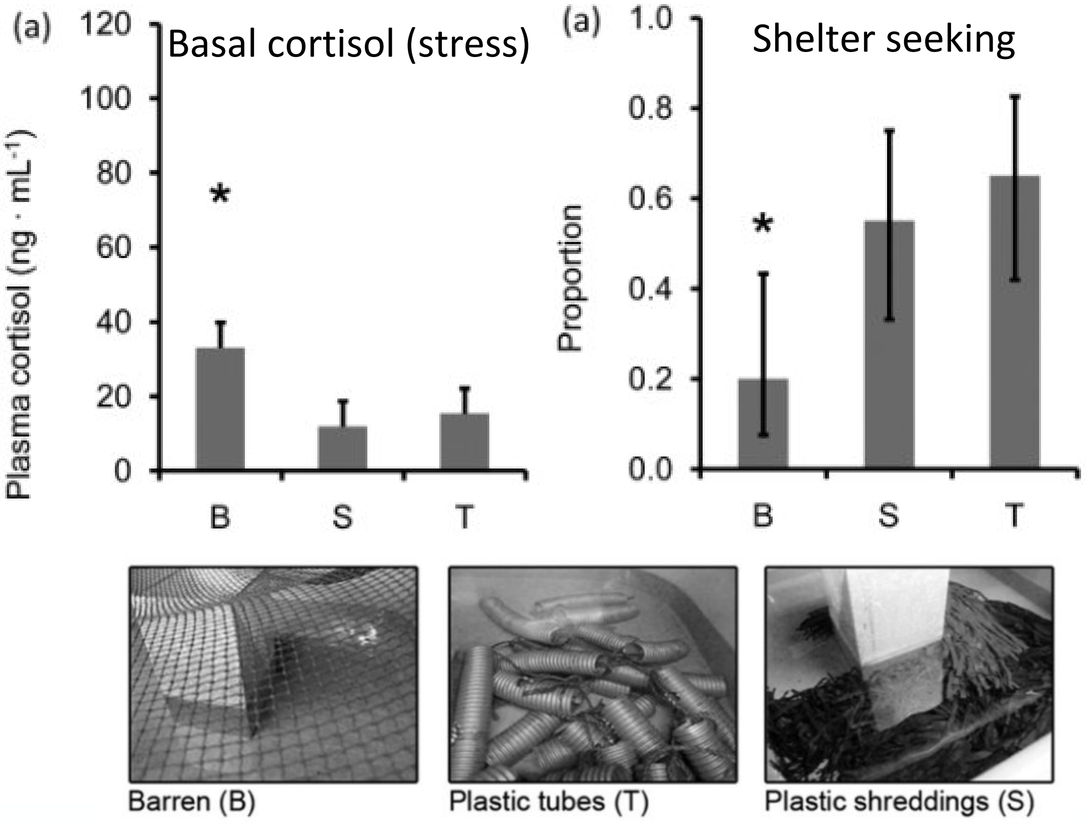
4. Artificial conditions, little foraging for food is necessary	Don’t learn to search for food
5. Relative freedom from predators	Don’t learn to avoid predators
9. Absence of live natural food	Don’t learn to handle prey
11. Absence of sensory stimulation	No brain stimulation
12. Absence of physical structure and environmental variation	Don’t learn to navigate complex environments
13. Unnaturally high densities	Don’t learn appropriate social behaviour

Proposed solutions

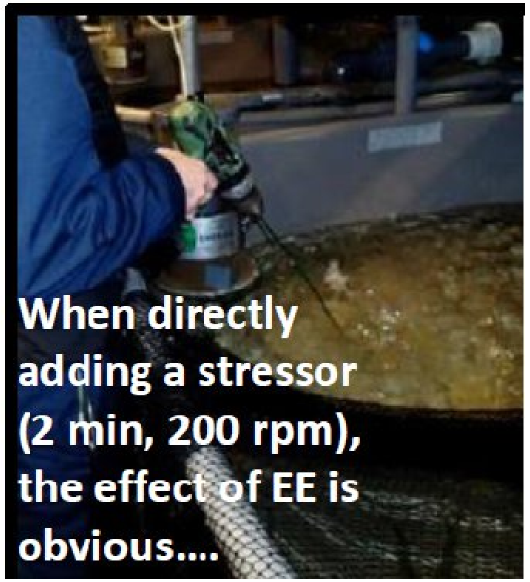
- Live food and foraging training
- Predator exposure
- Environmental enrichment (complexity and variation)
- Reduced densities

Some examples

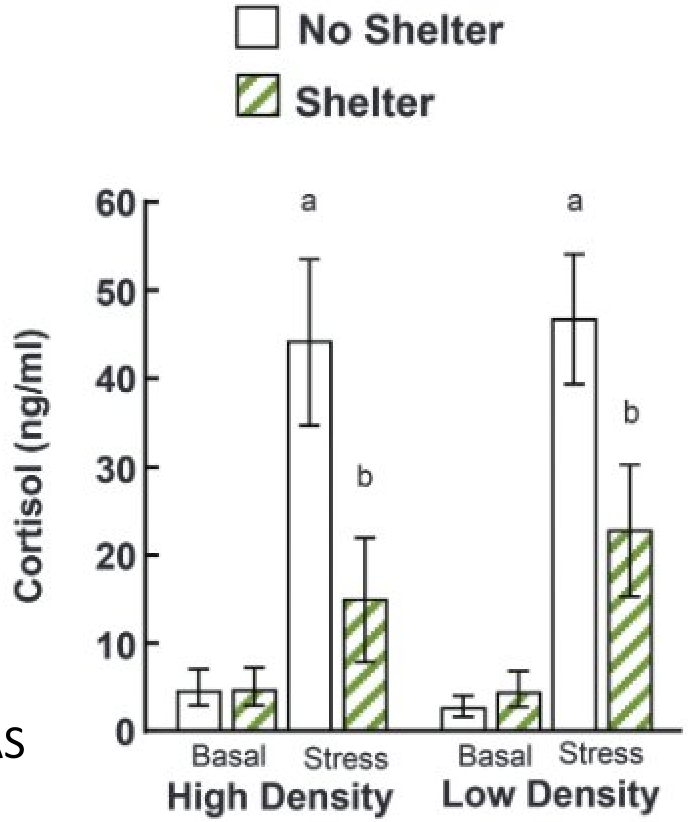
Environmental complexity – stress and behaviour



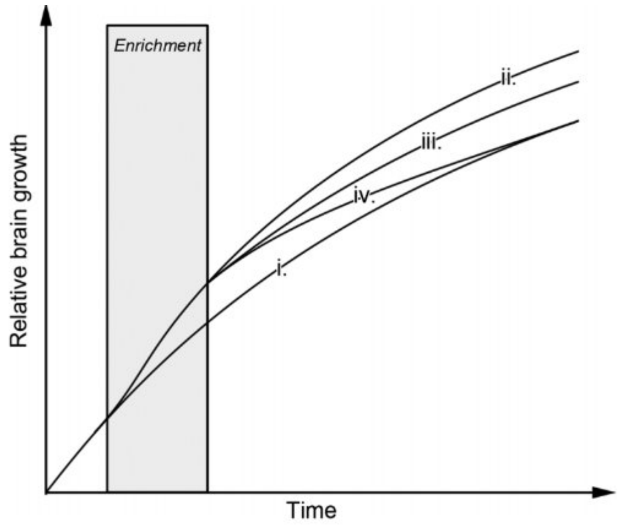
Näslund et al. 2013, CJFAS



Rosengren et al. 2016, CJFAS



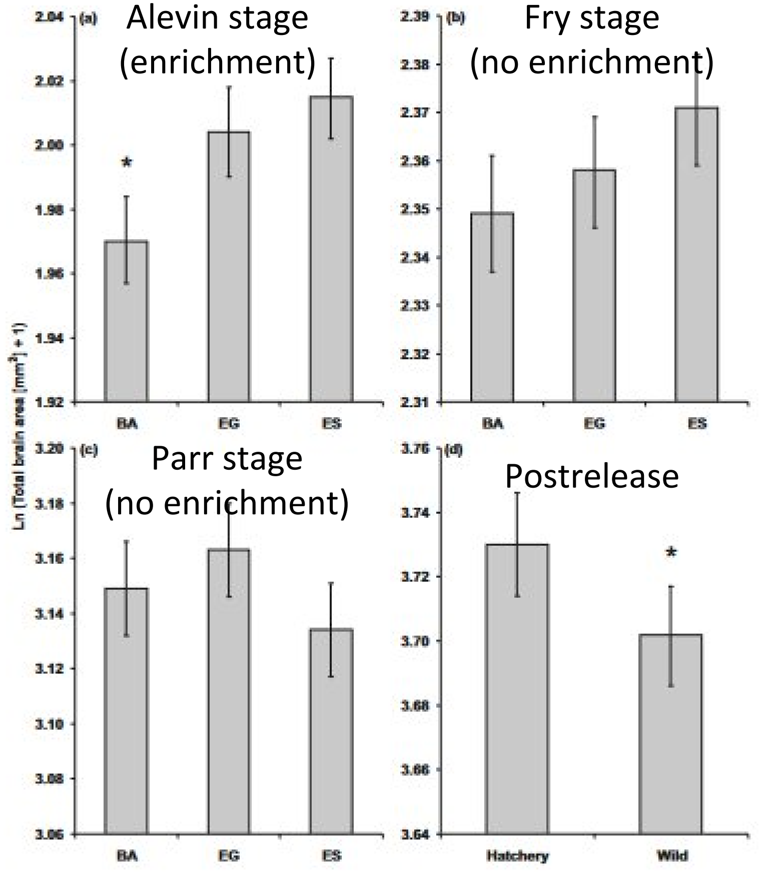
Environmental complexity – brains



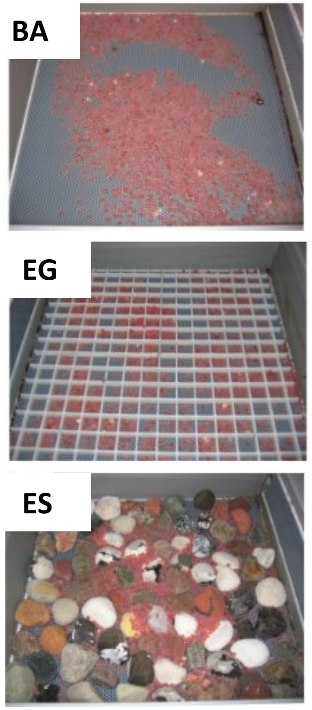
Kihslinger & Nevitt 2006, J. Exp. Biol.
Enrichment → larger brains.

Can we modify the brain growth trajectory, by early life enrichment?

No, we can't.

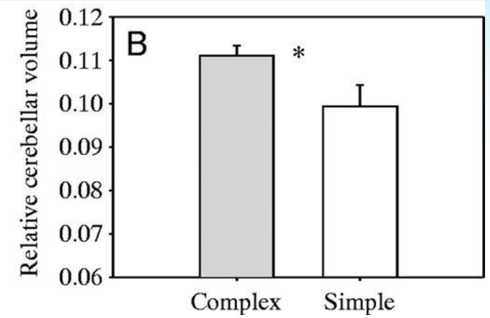


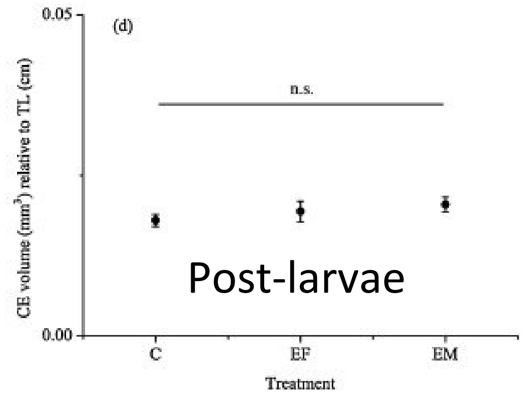
Näslund et al. 2012, CJFAS

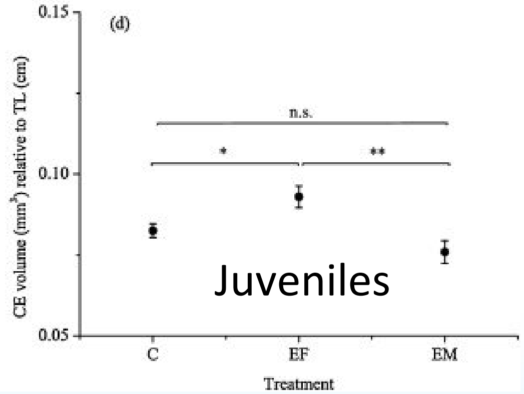


Environmental complexity – brains
- it's complex….

- Kihslinger & Nevitt 2006 found positive enrichment effects on the hindbrain (cerebellum) in steelhead trout
- Zhang et al. 2019 (Appl. Anim. Behav. Sci.) find variable enrichment effects on the various brain regions in rockfish (depending on life-stage)
- In one of our studies we find no effects on the hindbrain from enrichment, but positive effects of higher density (Näslund et al. 2019, Environm. Biol. Fish.).
- Effects may be species-specific, life-stage-specific, or even dependent on confounding factors (higher densities in complex environments?)
- Furthermore, we just assume that brain size is a positive trait for post-release performance – field studies needed, but difficult…







Environmental complexity – brains
- it's complex….

BEHAVIOUR/ COGN.

+

Atl. salmon Näslund et al. '13
Atl. salmon Roberts et al. '11
Atl. salmon Salvanes et al. '13
Atl. cod Salvanes & Braithwaite '05
Atl. Cod Moberg et al. '11
White seabream D'Anna et al. '12
Pike Einfalt et al. '13
Black rockfish Zhang et al. '19
Rainbow Bergendal et al. '15; '16
+ many others

0/-

Cichlids Misc. authors
Rainbow unpubl.
Eur. perch Mikheev et al. '05
Black seabass Gwak et al. '03
Gopher rockfish Hoelzer '87

Mainly about aggression!
(Defendable resources)

STRESS/METAB.

+

Atl. salmon Näslund et al. '13
Chinook Cogliati et al. '19
Burbot Fisher '00
Black rockfish Zhang et al. '19
Rainbow Pounder et al. '16
White sturgeon Bates et al. '14

0/-

Stone loach Fischer '00
Zebrafish von Krogh et al. '10
Zebrafish Wilkes et al. '12

POST-STOCKING PERFORMANCE

+

White seabream D'Anna et al. '12
Atl. salmon Rodewald et al. '11
Atl. salmon Hyvärinen & Rodewald '13
Atl. salmon Roberts '14
Atl. salmon Mes et al. '19
Rainbow Berejikian et al. '00; '01
Rainbow Tatara et al. '08
Brown trout Watz et al. '18

0/-

Atl. salmon Rosengren et al. '17
Atl. salmon Brockmark et al. '07
Atl. salmon Solås et al. '19
Rainbow Tatara et al. '08; '09
Rainbow Berejikian et al. '99
Chinook Fast et al. '08

BRAINS

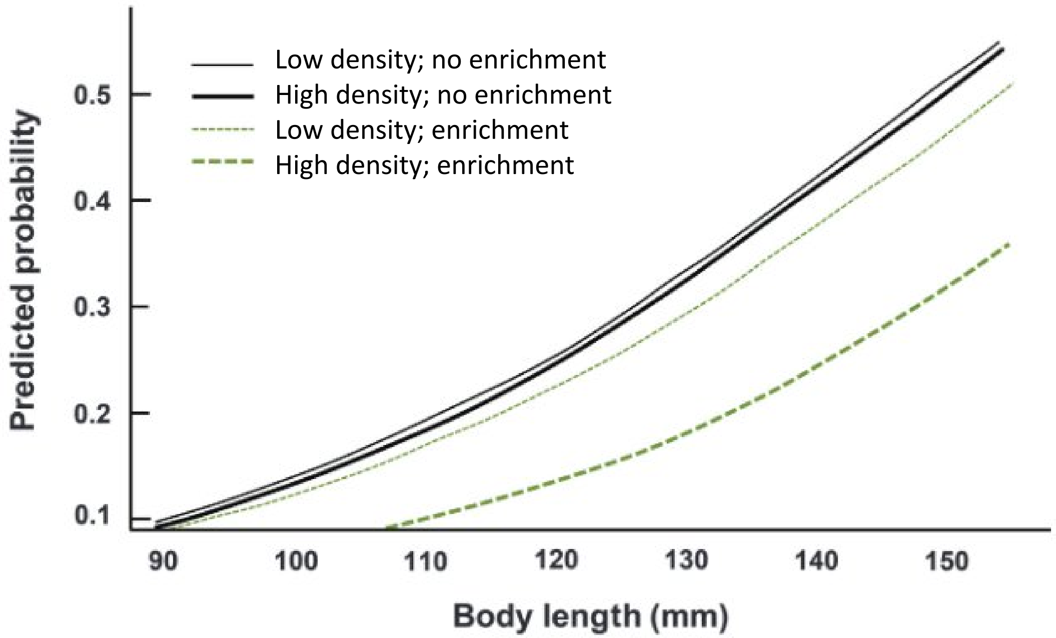
+

Atl. salmon Näslund et al. '12
Atl. Salmon Salvanes et al. '13
Zebrafish von Krogh et al. '10
Rainbow Kihslinger & Nevitt '06
Black rockfish Zhang et al. '19
Zebrafish DePasquale et al. '16
Goldfish Abreau et al. '19

0/-

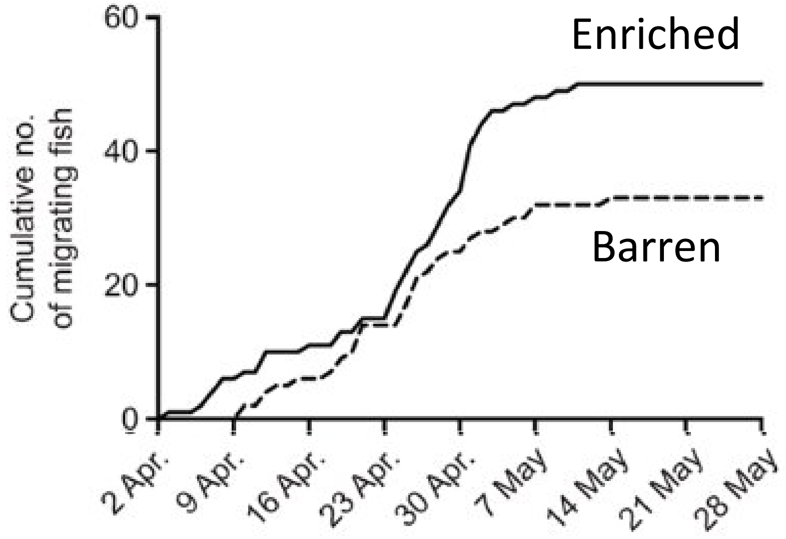
Atl. salmon Näslund et al. '19
Coho Lema et al. '05
Chinook Kihslinger et al. '06
Guppy Burns et al. '09
Coho Kotrschal et al. '12
Bull trout Brignon et al. '18
3-sp. stickleback Toli et al. '17
Mosquitofish Turschwell & White '16

Environmental complexity – post-stocking performance



No positive effects of enrichment on smolt migration, effect depending on density (high: 150 ind/m^2; low: 50 ind/m^2). (Rosengren et al. 2017)

River Imsa, Norway



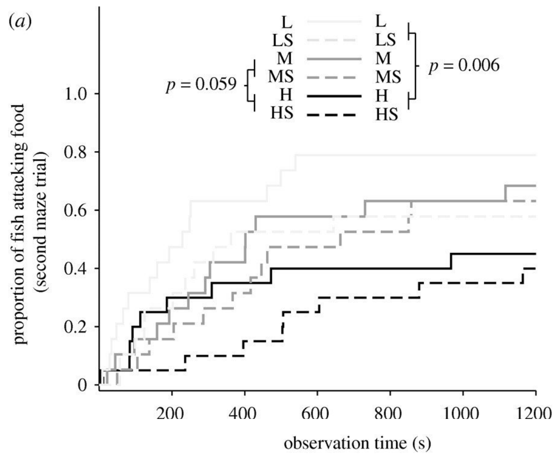
A later study on the same population, by a different research group, found positive effects of enrichment (65 ind/m^2; fish released earlier into the river). (Mes et al. 2019, J. Exp. Biol.)

Density reduction – behaviour/cognition

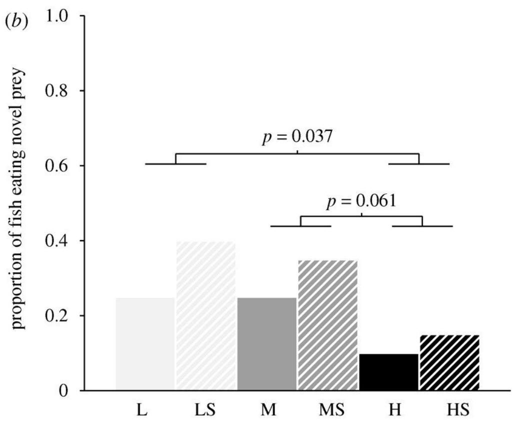
Brockmark et al. (2010, Proc. R. Soc. B) found that brown trout reared at lower densities performed better in cognitive trials (finding food in a maze, eating novel food, and using refuges after predator attack). Enrichment had no significant effects.

HYPOTHESIS:
Lower densities are more similar to natural environments, which stimulates the cognitive ability through e.g. resource defence, individual recognition, individual decision-making, etc.

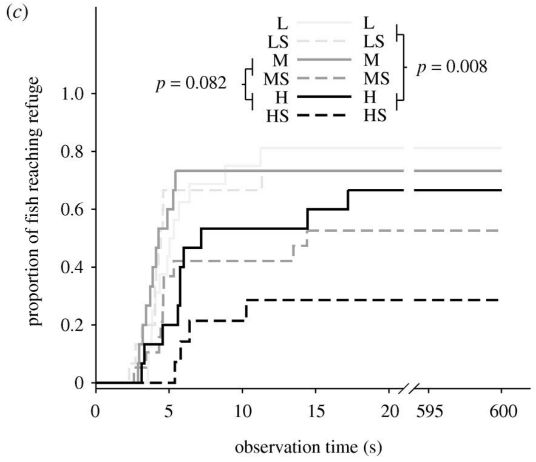
Finding food in a maze

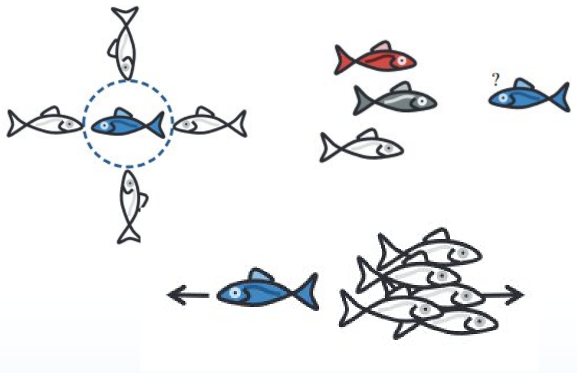


Eating novel food



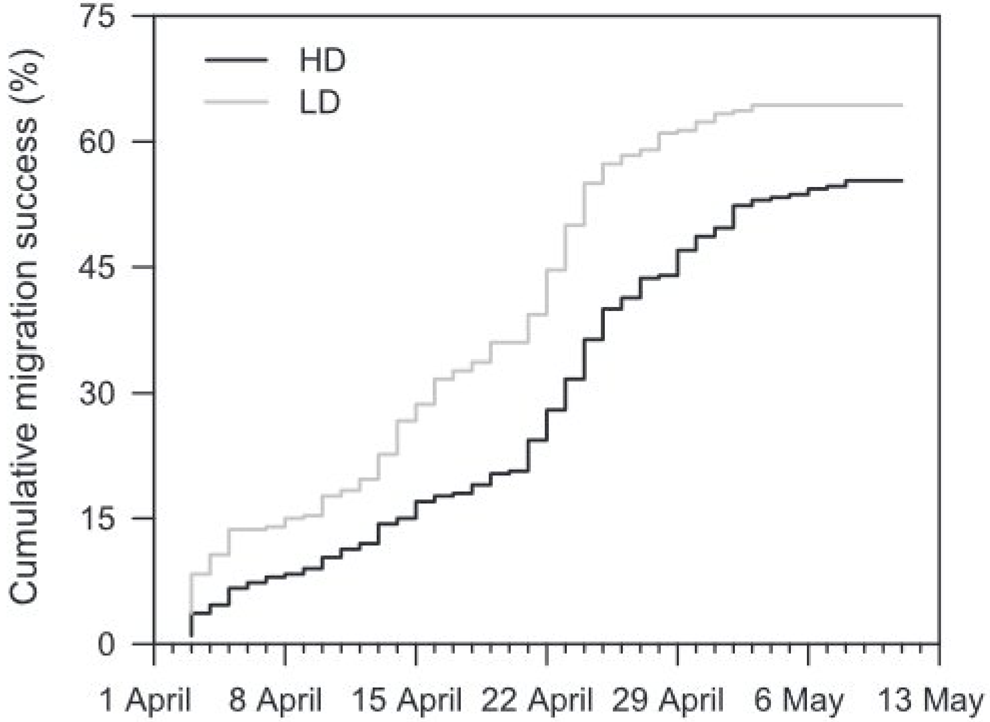
Refuge-use after attack



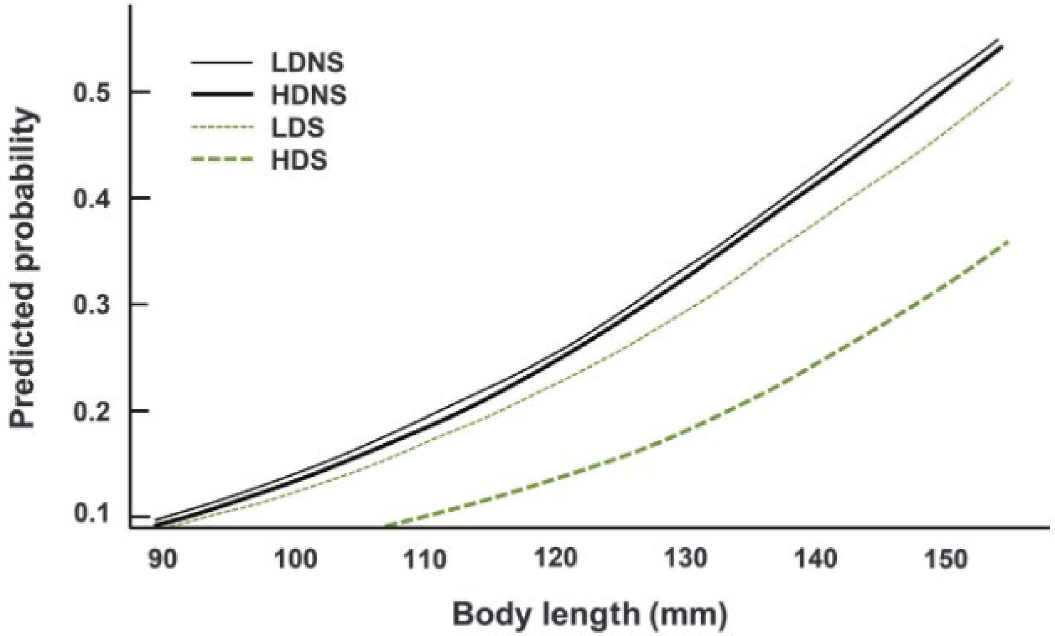


L: Low density (150 ind/m^2)
M: Medium desnity: (600 ind/m^2)
H: High density: (2500 ind/m^2)
S: Structural enrichment

Density reduction – post-stocking performance



Salmon reared in low density (500 ind/m^2) survive better than salmon reared at higher density (1500 ind/m^2) during smolt migration (Larsen et al. 2016)



Results can vary! In our Norwegian study, we find that smolt migration is poorer in high-density fish, but only when combined with environmental enrichment. (Rosengren et al. 2017)

Density reduction – post-stocking performance

Large scale post-stocking experiment in River Imsa, Norway

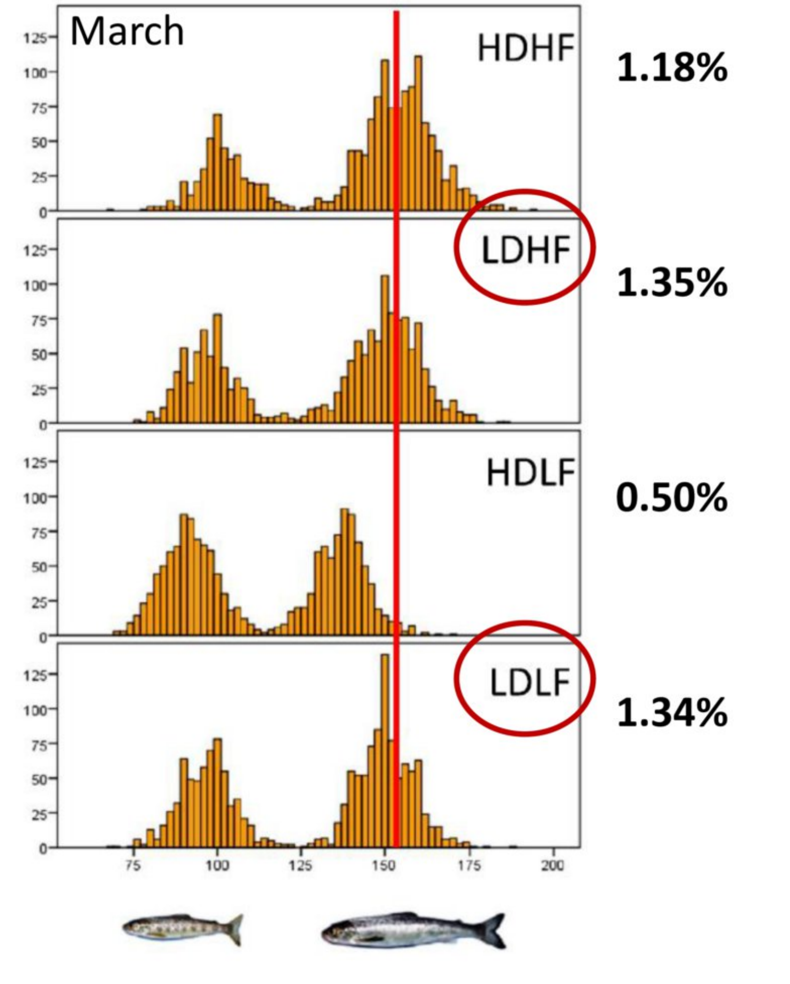
Experimental treatments:

- Food fat content (HF: high or LF: low)
- Density: (HD: high or LD: low)

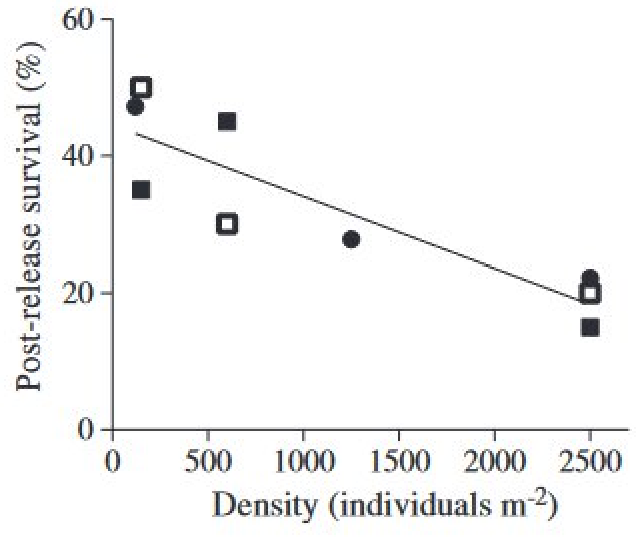
Monitoring returns to the river (1 SW)

Results:
Low fat content in high density = not good at all
Low density treatments = best

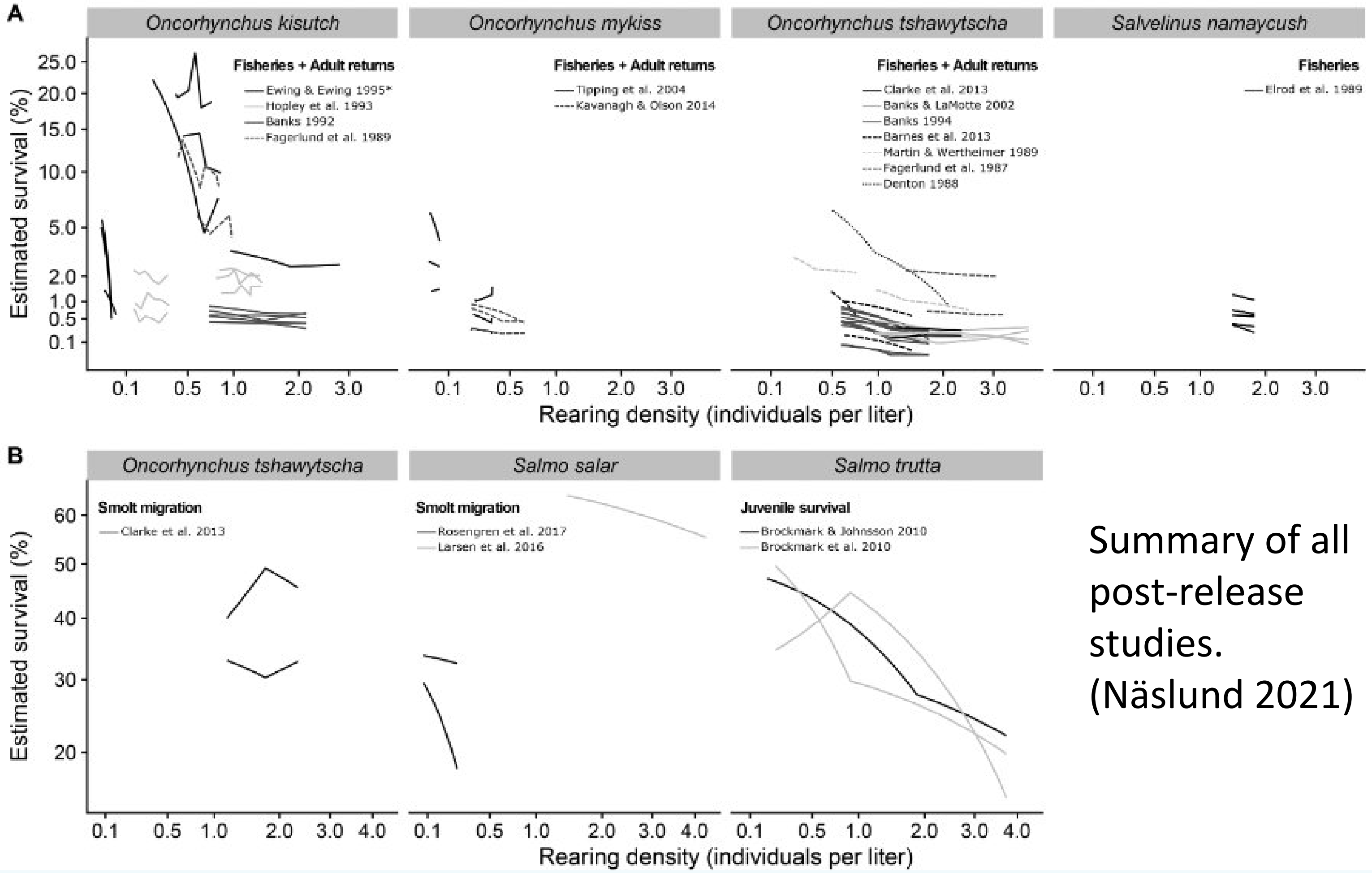
(Unpublished)



Density reduction – post-stocking performance

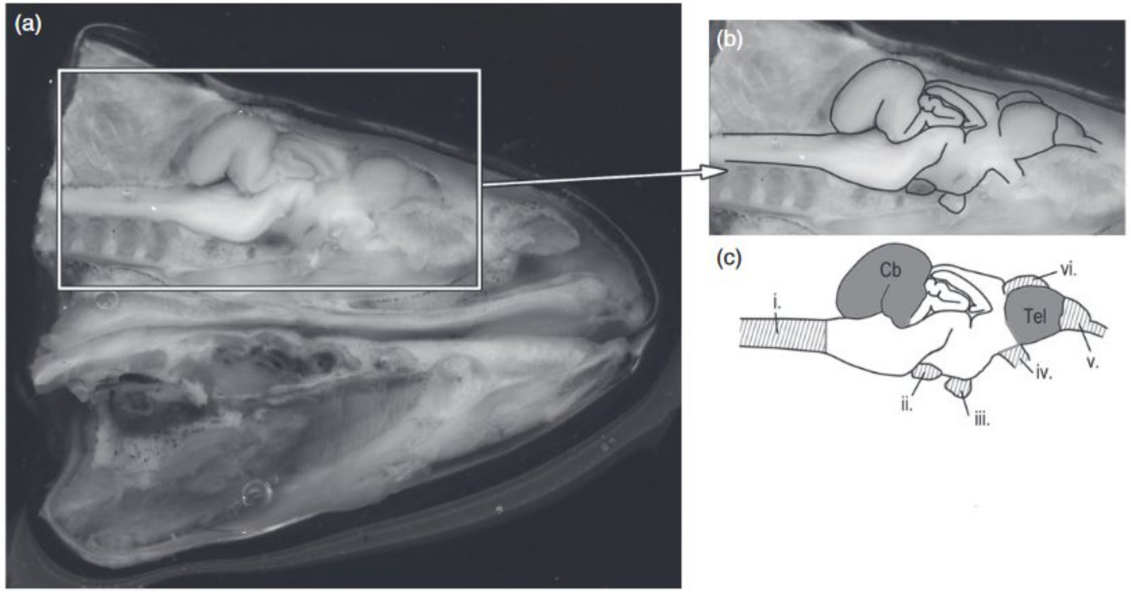


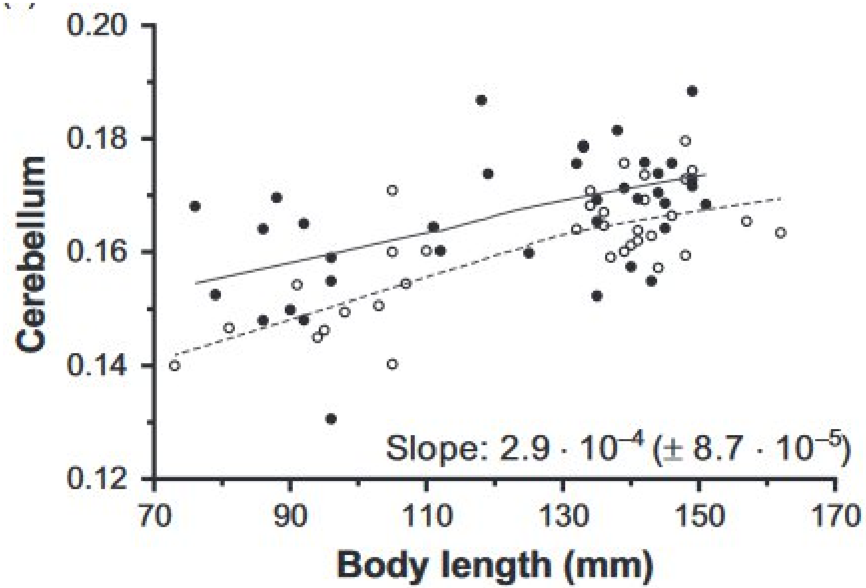
Post-stocking survival of brown trout in streams is better when reared at lower densities (studies by Brockmark et al, summarized in Johnsson et al. 2014)



Summary of all post-release studies. (Näslund 2021)

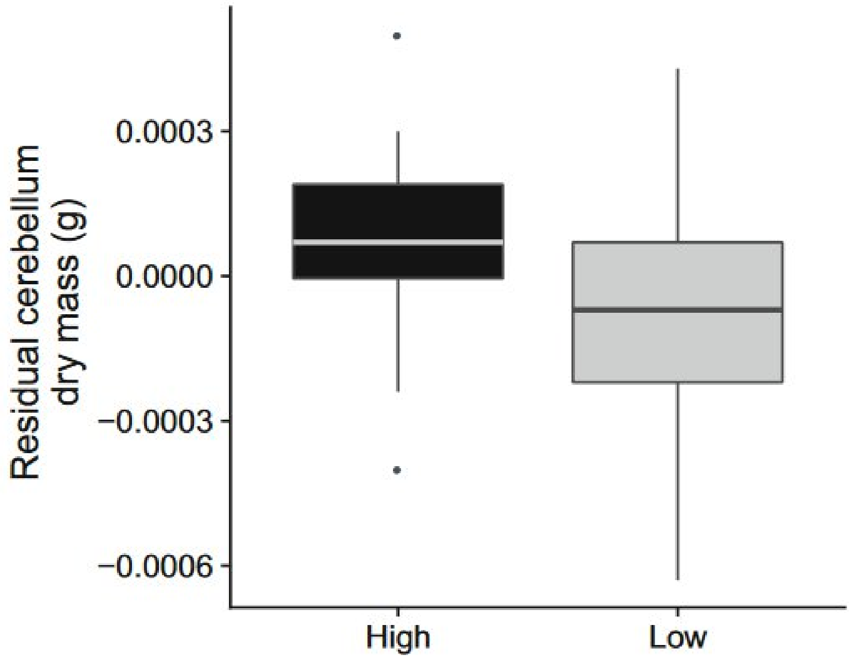
Density reduction – brains



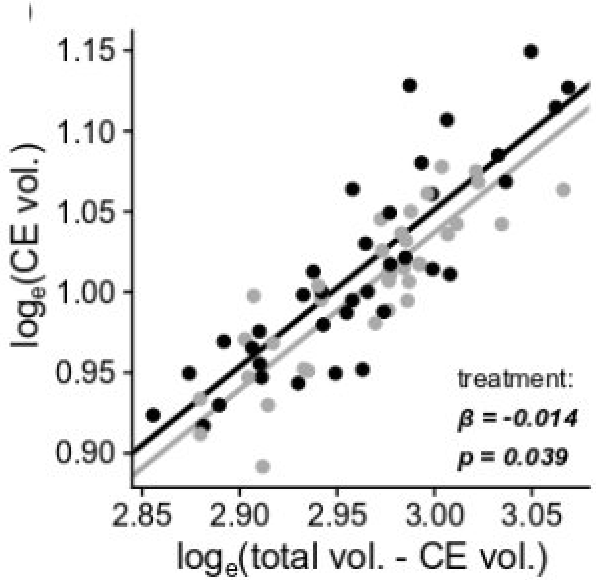


Fish rered in higher density (1500 fish/m^2) had **larger hind brain** than fish reared in lower density (500 fish/m^2). Nevertheless, the lower density fish performed better after release
(Näslund et al. 2017, J. Zool.; same experiment as Larsen et al. 2016)

Density reduction – brains



Hind brain was also larger in higher density in Norwegian salmon – but no effect of environmental enrichment! (Näslund et al. 2019, Environ. Biol. Fish.; same experiment as Rosengren et al. 2017)



Similarly, hind brain is bigger in salmon reared in groups as compared with isolation-reared salmon. (Guo et al. 2022, J. Fish Biol.)

Training – live food handling and foraging

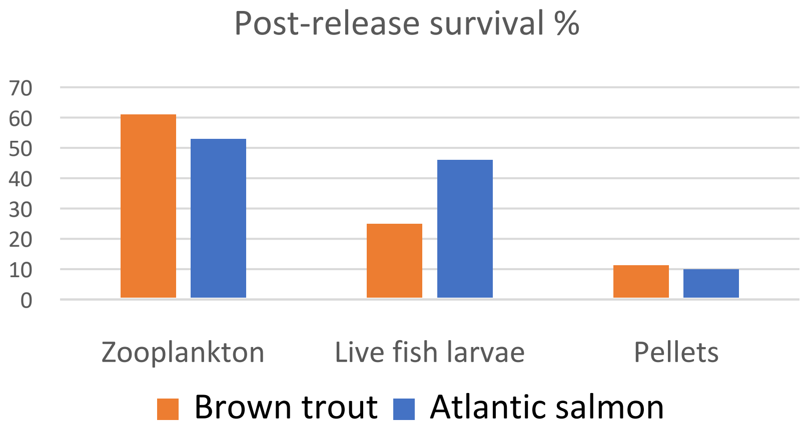
Summary from review paper: Näslund 2021, Bull. Mar Sci

Hypothesis: Inexperience with live food leads to inefficient foraging, which can be mitigated by providing live food or foraging training in the hatchery.

Most studies show positive effects.
Effects are <u>often very rapid</u> (few trials necessary to improve skills)

Few fish will starve to death immediately after release, and learning opportunities will be present in nature. *Does it matter if we train the fish?*

Perhaps. Novel environment, stress, predators, etc. may reduce the learning opportunities after release. Few post-release studies, but often positive results. Lab-evidence is, however, not enough.



(Czerniawski et al. 2011, J. Appl. Ichthyol.)

Training – predation avoidance

Summary from review paper: Näslund 2021, Bull. Mar Sci

Hypothesis: Inexperience with predators leads to predation vulnerability, which can be mitigated by providing experience of predators or predator cues hatchery.

Some, but not all, species have innate predator recognition skills.

Effect of live predator experience is generally strong (often one exposure can enough – but may not be legal in some countries.

Effect of predator cues (chemical or visual – but no direct contact) – seems to work when coupled with intraspecific alarm cues – more variable effects when using only predator cues.

In contrast to starvation effects, post-release predation effects are acutely important. One predator encounter may lead to death.

Predator memory retention:

June suckers: <10 days (Archer & Crowl 2014)
Brook charr: >10 days (Mirza & Chivers 2000)
Rainbow trout:

- At least 21 days (Brown & Smith 1998)*
- Less than 9 days (Berejikian et al. 1999)*

** Similar exposure time (8-10 min), but different life-stages!*

Several studies show that responses differ at different life-stages!

Training – more examples

Bull Mar Sci. 97(4):489–538. 2021
https://doi.org/10.5343/bms.2020.0039

FSU–Mote Symposium invited paper

Reared to become wild-like: addressing behavioral and cognitive deficits in cultured aquatic animals destined for stocking into natural environments—a critical review

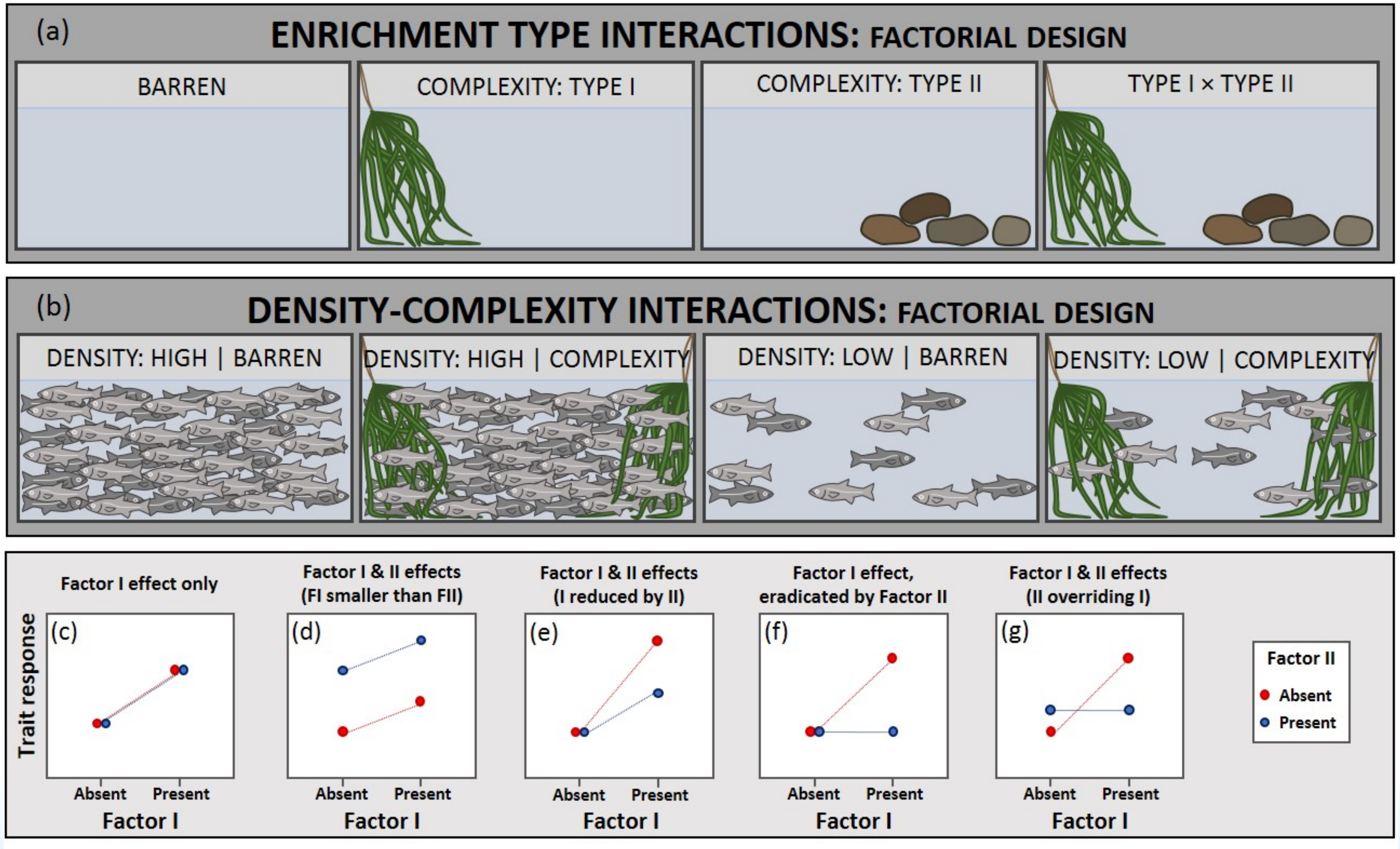
Joacim Näslund

Note! Summaries of all relevant papers are found in the supplement!

Where to go next within this field of research?

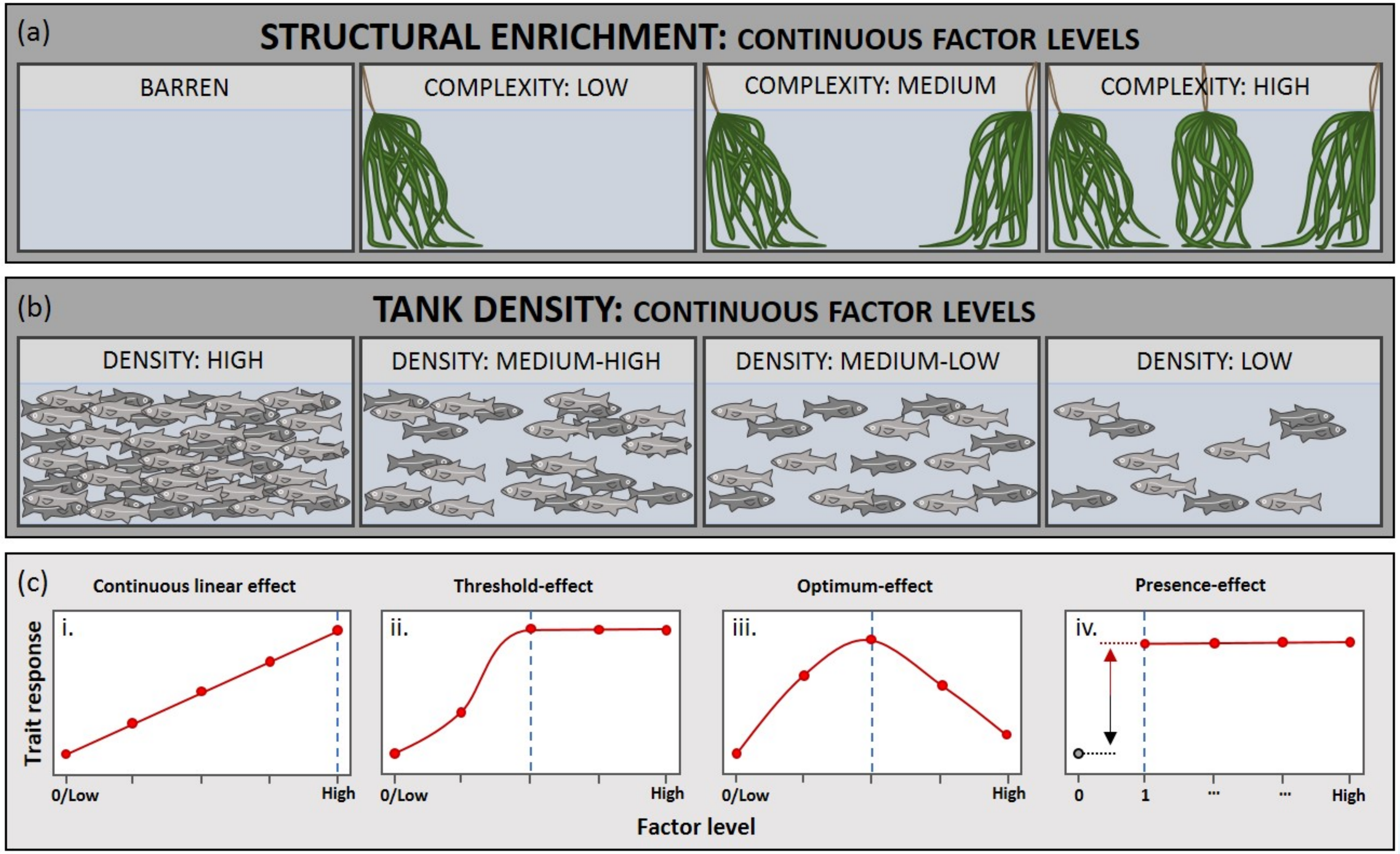
Need to investigate interactive effects, using factorial designs:

(structure types/flow/substrate/tank colour, etc) .

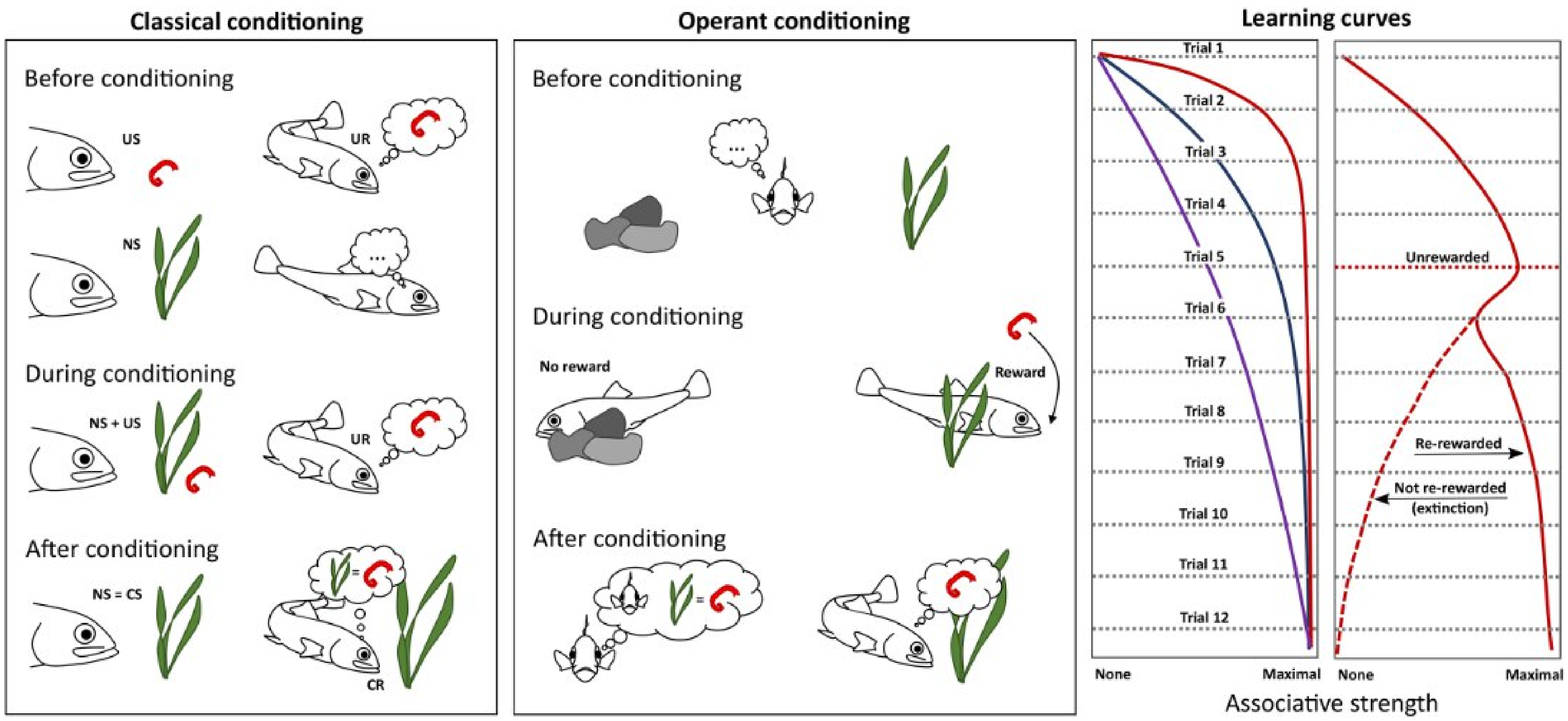


Too many combinations?
Fractional factorial design: carefully chosen subsets of a factorial design – strategically confounding factors, limiting the analyses to e.g. 2-way interactions.

Detecting non-linearity requires multiple levels of the factor



Training programmes for fish



Important to take influence from the field of cognition science!

- ***How many learning trials are needed?*** Learning curves measuring associative strength
- ***How long is the effect retained?*** Extinction effects

Publishing results

- One major danger that may lead to wasted money is **too optimistic interpretation of results** - a focus only on significance omits the **importance of effect size**. The important question to ask is "*How large does an effect have to be to lead to a positive post-stocking effect?*" To answer this question we will need to do **field studies on released fish**.
- Focus on only significance could encourage data torture and p-hacking (testing until significance).
- **Negative results need to be published** – these are as important as the positive results, in particular since the field approaches the stage of meta-analyses. An unthankful task, but not that hard…

Take-home messages

- **There are potentially positive effects from various training protocols, enrichment and density reduction, but effects vary a lot and are likely species- and stage specific.**
- **We need more multi-level experiments to detect possible non-linear responses.**
- **Test interaction effects among different solution treatments**
- **More field studies required!**
- **Publish negative results!**

"We have been too content with turning out a nice looking report of the number of fish hatched, reared, and presumably planted; and not sufficiently concerned with what actually happened to the fish afterward" – WM Keil 1935

Thank you for listening!

REFERENCES AND SUPPLEMENT

- **Archer, Crowl**. 2014. Retention of learned predator recognition in an endangered sucker *Chasmistes liorus liorus*. *Aquat. Biol. 20*:195–202.
- **Berejikian, Smith, Tezak, Schroder, Knudsen.** 1999. Chemical alarm signals and complex hatchery rearing habitats affect antipredator behavior and survival of chinook salmon (*Oncorhynchus tshawytscha*) juveniles. *Can. J. Fish. Aquat. Sci. 56*:830–838.
- **Blaxter**. 1970. Sensory deprivation and sensory input in rearing experiments. *Helgol. wiss. Meeresunters*. *20*:642–654.
- **Brockmark, Adriaenssens, Johnsson.** 2010. Less is more: density influences the development of behavioural life skills in trout. *Proc. R. Soc. B 277:*3035-3043.
- **Brown, Smith.** 1998. Acquired predator recognition in juvenile rainbow trout (*Oncorhynchus mykiss*): conditioning hatchery-reared fish to recognize chemical cues of a predator. *Can. J. Fish. Aquat. Sci*. 55:611–617.
- **Czerniawski, Pilecka-Rapacz, Domagala.** 2011. Stocking experiment with Atlantic salmon and sea trout parr reared on either live prey or a pellet diet. *J. Appl.Ichthyol. 27:*984-989.
- **Guo, Zhang, Näslund, ... , Zhang.** 2022. Differences in external morphology, body composition and swimming performance between hatchery-and wild-origin marbled rockfish (*Sebastiscus marmoratus*). *Front. Mar. Sci. 9:*912129.
- **Johnsson, Brockmark, Näslund.** 2014. Environmental effects on behavioural development consequences for fitness of captive-reared fishes in the wild. *J. Fish Biol. 85*:1946-1971.
- **Kihslinger, Nevitt.** 2006. Early rearing environment impacts cerebellar growth in juvenile salmon. *J. Exp. Biol. 209*:504-509.
- **Larsen, Johnsson, Näslund, Thomassen, Aarestrup.** 2016. Reduced rearing density increases postrelease migration success of Atlantic salmon (*Salmo salar*) smolts. *Can. J. Fish. Aquat. Sci. 73:*804-810.
- **Mes, van Os, Gorissen, … , Vindas. 2019.** Effects of environmental enrichment on forebrain neural plasticity and survival success of stocked Atlantic salmon. *J. Exp. Biol. 222:*jeb212258.
- **Mirza, Chivers**. 2000. Predator-recognition training enhances survival of brook trout: evidence from laboratory and field enclosure studies. *Can. J. Zool. 78*:2198–2208.
- **Näslund. 2021.** Reared to become wild-like: addressing behavioral and cognitive deficits in cultured aquatic animals destined for stocking into natural environments—a critical review. *Bull. Mar. Sci. 97:*489-538.
- **Näslund, Rosengren, Del Villar, ... , Kvingedal.** 2013. Hatchery tank enrichment affects cortisol levels and shelter-seeking in Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci. 70:*585-590.
- **Näslund, Larsen, Thomassen, Aarestrup, Johnsson.** 2017. Environment-dependent plasticity and ontogenetic changes in the brain of hatchery-reared Atlantic salmon. *J. Zool. 301*:75-82.
- **Näslund, Rosengren, Johnsson. 2019.** Fish density, but not environmental enrichment, affects the size of cerebellum in the brain of juvenile hatchery-reared Atlantic salmon. *Environm. Biol. Fish. 102:*705-712.
- **Robertson. 1919.** Hatching fry in gravel. *Trans. Am. Fish. Soc.* 48:146–156.
- **Rosengren, Kvingedal, Näslund, Johnsson, Sundell K. 2017.** Born to be wild: effects of rearing density and environmental enrichment on stress, welfare, and smolt migration in hatchery-reared Atlantic salmon. *Can. J. Fish. Aquat. Sci. 74:*396-405.
- **Salvanes, Moberg, Ebbesson, … , Braithwaite.** 2013. Environmental enrichment promotes neural plasticity and cognitive ability in fish. *Proc. R. Soc. B*. *280*:20131331.
- **Schuck. 1948.** Survival of hatchery trout in streams and possible methods of improving the quality of hatchery trout. *Progr. Fish-Cult*. 10:3–14.
- **Sörensen. 1919.** Om kläckning och utplantering av olika fiskslag. *Skrifter utgivna av Södra Sveriges Fiskeriförening 1919*:68–74.
- **Zhang, Zhang, Li, Zhang.** 2019. Effects of different levels of environmental enrichment on the sheltering behaviors, brain development and cortisol levels of black rockfish *Sebastes schlegelii*. *Appl. Anim. Behav. Sci. 218:*104825.

Comparative (multi-spp.) studies are largely missing, particularly at the species level, but could help in building knowledge about how ecological traits are important for performance under different culture conditions.

- How do different species and populations react to intervention?
- Are some species or populations more or less influenced than others?

Existing studies suggest there are potentially important effects that need further exploration in more species and in postrelease studies.

- How do different ontogenetic stages of a species respond to interventions?
- Does it matter at which life-stage an intervention is introduced?

Broodstock variation could be an important factor to consider, in addition to preparing the animals for a life in nature.

- What is the effect of genetic diversity in the reared animals on different intervention outcomes?
- Is there a genetic component affecting the responsiveness to interventions?

How are different phenotypes [relating to behavior ("personality"), morphology, coloration, stress responsiveness, etc.] affected by interventions?

- Are specific phenotypes promoted over others when an intervention is applied and, if so, how does the surviving part of the stocked population compare with the phenotype distribution of natural populations and standard-reared groups?
- Do different phenotypes require different amounts of training (e.g., different numbers of live-food exposures, depending on level of neophobia)?

Few studies specify end goals for their interventions, apart from a vague aim of improved performance.
Which behavioral and cognitive traits are critical for postrelease performance, and which are not? How much do cultured animals differ from wild ones in those traits?
What are the specific goals when aiming for culturing a wild-like phenotype?

More large-scale studies following up on results from small laboratory experiments are needed; several studies suggest that scale matters.

- How can successful experimental results be applied in large-scale production?

What is the timespan of intervention effects?

- How long is the memory window of the learned skills, and how much does it vary among individuals?
- For how long postrelease do cultured animals from an altered environment differ compared to standard-reared and wild individuals?

Distinguishing whether animals are reinforced or habituated during repeated or prolonged interventions, making optimization of interventions in relation to stocking date possible.

- How does retention of effects depend on the level of exposure (e.g., number of learning trials, length of training trials, or length of exposure to an altered environment)?

Responses to different types of food or predators after conditioning training need to be measured to understand how generalized the trained responses are.

- Can the cultured animals generalize learned responses to situations similar, but not identical, to the training situation?

Get a picture of the generality of responses to a specific intervention, and how to optimize the intervention.

- How do different varieties of the same type of factor (e.g., different prey species, predator cues, enrichment structures, etc.) affect performance?

Design experiments that can detect nonlinear patterns, to optimize interventions.

- How do different levels of the same factor, along continuous scales (e.g., different length of exposure, amounts of enrichment structures, or densities) affect performance?

Find out whether we get additive or non-additive (either more or less than additive) effects of applying several types of interventions.

- How do different types of interventions interact?