



## Session 8: Vulnerability to Angling and Fisheries-Induced Evolution

L1

### Harvesting-Induced Evolution of Behavior and the Potential for Reproductive Isolation of Evolved Populations: An Experimental Approach in Size-Selectively Exploited Zebrafish (*Danio rerio*)

VALERIO SBRAGAGLIA\*<sup>1</sup>, CATALINA GLIESE<sup>1</sup>, CHRISTOPHER T. MONK<sup>1</sup>, KIM FROMM<sup>1</sup>, DAVID BIERBACH<sup>1</sup>, SILVA UUSI-HEIKKILÄ<sup>3</sup>, CARLOS DIAZ-GIL<sup>2</sup>, ROBERT ARLINGHAUS<sup>1,4</sup>

<sup>1</sup>Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany; <sup>2</sup>Instituto Mediterráneo de Estudios Avanzados, IMEDEA (CSIC–UIB), c/ Miquel Marqués 21, 07190, Esporles, Illes Balears, Spain; <sup>3</sup>Division of Genetics and Physiology, Department of Biology, University of Turku, Turku, Finland; <sup>4</sup>Division of Integrative Fisheries Management, Department of Crop and Animal Sciences, Faculty of Life Science, Humboldt-Universität zu Berlin, Berlin, Germany

\*Email: [sbragaglia@iqb-berlin.de](mailto:sbragaglia@iqb-berlin.de)

Harvesting-induced evolution can happen over short time scales (i.e. few generations) and affect size structure, population dynamics, recovery potential, catchability and yield. Most studies have focused on life-history traits, with little research available on the possibility of harvesting altering the behavioral repertoire of exploited stocks. Size and behavior are often correlated so that strict selection on size-based traits can indirectly alter behavior, which in turn could promote reproductive isolation through sexually selective pressures associated with changing sizes and behaviors. We present data of an ongoing project where we use zebrafish (*Danio rerio*) harvest-selection lines that have experienced five generations of size-selective mortality: large-harvested (large individuals harvested; typical in fisheries with minimum-length limits), small-harvested (small individuals harvested; typical in fisheries with a maximum-size limit), and random-harvested (individuals randomly harvested as control). We found that large-harvested females were more social than random- and small-selected ones. Juvenile large- and random-harvested individuals were shyer than small-harvested fish, while the opposite was found in adult females. Relatedly, in a spawning context large- and small-harvested females were on average more aggressive than the control line. However, females of both size-selectively harvested lines preferred to release eggs to random-harvested males, rejecting the idea of reproductive isolation. Collectively, our data suggest that size-selection common in recreational fisheries will lead to life-stage specific behavioral changes, but that reproductive isolation of the evolved populations is unlikely. This suggests that, if there is potential for gene flow, the evolved traits could recover their original state after fishing is ceased.



L2

## Angling Selects Against Stress-Resilient and Active Phenotypes

BARBARA KOECK\*<sup>1</sup>, LIBOR ZÁVORKA<sup>2</sup>, DAVID ALDVÉN<sup>1</sup>, JOACIM NÄSLUND<sup>1</sup>, ROBERT ARLINGHAUS<sup>3,4</sup>, PER-OVE THÖRNQVIST<sup>5</sup>, SVANTE WINBERG<sup>5</sup>, BJÖRN THRANDUR BJÖRNSSON<sup>1</sup>, JÖRGEN I. JOHANSSON<sup>1</sup>

<sup>1</sup>Department of Biological and Environmental Sciences, University of Gothenburg, Sweden; <sup>2</sup>Laboratoire Évolution & Diversité Biologique (EDB UMR 5174), CNRS, Université de Toulouse, Toulouse, France; <sup>3</sup>Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany; <sup>4</sup>Laboratory for Integrative Fisheries Management, Faculty of Life Sciences, Humboldt Universität zu Berlin, Germany; <sup>5</sup>Department of Neuroscience, Physiology Unit, Biomedical Center BMC, Uppsala University, Sweden

\*Email: [barbara.kock@bioenv.gu.se](mailto:barbara.kock@bioenv.gu.se)

Invasion risks of non-native hatchery reared fish are potentially increased by selection for rapid growth through domestication, resulting in selection towards bold and invasive phenotypes. However, bold behavioural types may also be exposed to higher predation mortality which could counteract the advantage of invasive phenotypes. It can thus be hypothesized that angling, a special form of predation, selects against invasive phenotypes. Angling experiments were conducted in replicated ponds using two different angling techniques to compare the catchability between domesticized rainbow trout and native European brown trout. We investigated the behavioural and neuroendocrine response of those two species to improve our understanding of the mechanism shaping angling selection and individual vulnerability to angling. We found that rainbow trout was more vulnerable to angling than brown trout, but a technique-specific effect was also evident, with rainbow trout being more vulnerable to natural bait compared to lures. We also discovered a phenotypic syndrome in rainbow trout, where lower serotonergic and dopaminergic brain activity and cortisol responses were associated with higher activity forming a bold/proactive phenotype showing increased vulnerability to angling. These findings show that angling targets the most stress-resilient and active phenotypes. More generally, they contribute to our understanding of the mechanisms of fishing induced selection and of the integration of behavioural and neuroendocrine phenotypic traits.



L3

## Emerging Hyperdepletion and Hyperstability Patterns as a Function of Individual Heterogeneity in Encounter-Based Spatial Behaviors of Fish and Anglers

JOSEP ALÓS\*<sup>1</sup>, ROBERT ARLINGHAUS<sup>2,3</sup>

<sup>1</sup>Instituto Mediterráneo de Estudios Avanzados, IMEDEA (CSIC-UIB). C/ Miquel Marqués 21, 07190, Esporles, Illes Balears, Spain; <sup>2</sup>Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany; <sup>3</sup>Division of Integrative Fisheries Management, Faculty of Life Sciences and Integrative Research Institute for the Transformation of Human-Environmental Systems, Humboldt-Universität zu Berlin, Invalidenstrasse 42, 10155 Berlin, Germany

\*E-mail: [alos@imedea.uib-csic.es](mailto:alos@imedea.uib-csic.es) Twitter: @josep\_alos Tel.: +34 971 61 17 16 Fax: +34 971 61 17 61.

In recreational fisheries, behavioral diversity exist both within angler and fish populations. Ecologically, behavioral diversity and plasticity facilitates persistence of fish populations. Socially, however, variation in behaviors of different angler types could be contributing to collapse through patterns of hyperstable catch rates and effort sorting. To examine the potential of behavioural variability at both fish and angler levels, we developed a coupled, spatially-explicit individual based model (IBM) where fish and anglers behave according to empirical data. Four scenarios with i) no, ii) ecological, iii) social and, iv) ecological + social behavioral diversity were simulated, and the emerging properties for the relationship between catch rate and true fish abundance were assessed. Variability of fish behavior can emerge through the presence of spatial behavioral types. Variability in angler behavior can occur when anglers are either strongly or not so strongly motivated to choose sites according to expected catch rates, and different movement strategies searching for fish. We systematically varied our model along these axes of behavioral variability. We found different patterns ranging from hyperdepletion (where catch rate more strongly decline as abundance) to hyperstable (where catch rates stay high even when abundance drops strongly) depending on the particular features of ecological and social behavioral diversity. The model predictions were then confronted with empirical data about fish-angler interactions in a coastal fishery. Our findings have implications for management.



L4

## Are Individual Differences in Fish Movement Related to Angling Vulnerability? A Whole-Lake Reality Mining Experiment in the Wild Using Four Species

CHRISTOPHER T. MONK<sup>1</sup>, THOMAS KLEFOTH<sup>2</sup>, ROBERT ARLINGHAUS<sup>1,3</sup>

<sup>1</sup>Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, 12587 Berlin, Germany; <sup>2</sup>Angler Association of Lower Saxony, Bürgermeister-Stümpel-Weg 1, 30457 Hannover, Germany; <sup>3</sup>Division of Integrative Fisheries Management, Department of Crop and Animal Sciences, Faculty of Life Sciences, Humboldt-Universität zu Berlin, Invalidenstrasse 42, 10115 Berlin, Germany

\*Email: [monk@igb-berlin.de](mailto:monk@igb-berlin.de)

Passive fishing gears, such as hook-and-line angling, are expected to selectively capture fish of certain behavioural types because by definition passive gears exploit fish behaviour. Behaviours increasing angler encounters (e.g., activity or activity space size) and behaviours promoting bites (e.g., boldness or aggression) are good candidates for angling induced behavioural selection, but the importance of specific behaviours is likely a function of a given species' foraging mode in light of the lures and baits by which it is targeted. Further, fishing induced behavioural selection is expected to be modified by the searching strategies and techniques of fishers. Our aim was to comprehensively tease apart the role of fish and fisher behaviour as it relates to fish vulnerability in the wild by analyzing long-term acoustic tracking data at a whole lake-scale collected from both piscivorous and omnivorous fishes, viz.: perch (*Perca fluviatilis*), carp (*Cyprinus carpio*), tench (*Tinca tinca*) and pike (*Esox lucius*). All species were experimentally angled. Direct encounters with anglers and related behaviours including activity, activity space size, or distance to the shore were unrelated to angling vulnerability in carp, tench and perch. Perch preferring a certain habitat (north lake shore) were, however, preferentially captured independent of angler encounters. By contrast, activity and activity space size were significant drivers of vulnerability in pike, supporting the idea that the relationship between fish behaviour and vulnerability is species specific. All behaviours we assessed were repeatable in the wild, such that ultimately our data suggest angling-induced selection targets different behaviours in different species.



L5

## Size-Selective Regulation of Sport Fishing and Shifts in Foodweb Dynamics Lead to Hg Accumulation in Lake Trout

ASIT MAZUMDER<sup>1</sup>, DAVID EVANS<sup>2</sup>

<sup>1</sup>Water and Aquatic Sciences Research Program, University of Victoria, Victoria, BC, Canada, V8W 3N5; <sup>2</sup>Ontario Ministry of Natural Resources and Forestry, Trent University, Peterborough, Ontario K9J 7B8 Canada

\*Email: [mazumder@uvic.ca](mailto:mazumder@uvic.ca)

Shifts in foodweb and trophic interactions can occur due to introduction, stocking, and harvesting of top predators. These shifts can not only cause major changes in trophic interactions within and among species, but also cause major shifts in the accumulation of contaminants at higher trophic levels. Using whole-lake experiments, we tested whether size-selective retention of lake trout by sport fishers could produce significant shifts in size and age distribution, trophic dynamics and accumulation of Hg in these highly sought-after sport fish. We used 10 years of data from two lakes of similar size and productivity in the Haliburton Highlands of Ontario, Canada that were subjected to contrasting size-based harvest regulations. We recorded length and weight of lake trout caught by sport fishers, and collected otoliths and muscle tissue. We present 2 years of pre-regulation, and 8 years of post-regulation data to show how shifts in size-selective sport fishing may have shifted size-distribution, trophic dynamics and accumulation of Hg in trout. We also discuss some of the major ecological processes linked to these shifts in accumulation of Hg.



L6

## Threat Perception and Avoidance Learning Under Catch and Release

JÖRGEN I. JOHNSON<sup>\*1</sup>, BARBARA KOECK<sup>1</sup>, MAGNUS LOVÉN WALLERIUS<sup>1</sup>, DAVID BERGER<sup>1</sup>, ROBERT ARLINGHAUS<sup>2,3</sup>

<sup>1</sup>Department of Biological and Environmental Sciences, University of Gothenburg, Sweden;

<sup>2</sup>Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany; <sup>3</sup>Laboratory for Integrative Fisheries Management, Faculty of Life Sciences, Humboldt Universität zu Berlin, Germany

\*Email: [jorgen.johnsson@bioenv.gu.se](mailto:jorgen.johnsson@bioenv.gu.se)

The success of passive fishing methods such as angling depends on the ultimate decision of a fish to approach and ingest the bait, which is influenced by previous experience and perception of the threat. Although individuals surviving capture are generally more cautious towards lures and hooks, it is unknown to what extent threat perception and social learning (i.e. the experience of watching conspecifics being caught) affect the avoidance response of individual fish and overall catch rates, particularly under catch and release conditions. We therefore investigated the mechanisms of threat perception and avoidance learning in rainbow trout in two angling experiments conducted in replicated semi-controlled ponds where we compared the catch rates over time under different angling scenarios. Firstly, short term fishing closures were simulated by exposing fish to angling at different time intervals and recording catch rates to evaluate the effects of threat perception. We found that short term fishing closures increased catch rates, likely by reducing threat perception and avoidance behaviour of fish towards fishing gear. Secondly, we compared catchability of fish with either prior personal experience of hooking, or prior social experience of hooking of conspecifics (i.e. social learning) to catchability of naïve fish (i.e. no prior experience of hooking). Our results show that not only personal experience, but also social learning shape individual catchability and contribute to the decrease of catch rates. These findings are of particular relevance for managing catch and release fisheries.



L7

## Spearfishing Promotes a Timidity Syndrome and Increases the Safe Operating Distance of Exploited Fishes

VALERIO SBRAGAGLIA<sup>\*1</sup>, LORENZO MORRONI<sup>2</sup>, LORENZO BRAMANTI<sup>3</sup>, BORIS WEITZMANN<sup>4</sup>, ROBERT ARLINGHAUS<sup>1,5</sup>, ERNESTO AZZURRO<sup>2</sup>

<sup>1</sup>Department of Biology and Ecology of Fishes, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany; <sup>2</sup>Institute for Environmental Protection and Research (ISPRA), Livorno, Italy; <sup>3</sup>Sorbonne Universités, UPMC Univ Paris 06, CNRS, Laboratoire d'Ecogéochimie des Environnements Benthiques (LECOB), Observatoire Océanologique, F-66650, Banyuls/Mer, France; <sup>4</sup>Parc Natural del Montgrí, les Illes Medes i el Baix Ter, L'Estartit, Catalunya, Spain; <sup>5</sup>Division of Integrative Fisheries Management, Department of Crop and Animal Sciences, Faculty of Life Science, Humboldt-Universität zu Berlin, Berlin, Germany

\*Email: [sbragaglia@iqb-berlin.de](mailto:sbragaglia@iqb-berlin.de)

Some fishing gears such as spearguns, gill nets or hook-and-line are suggested to preferentially target bold, aggressive and explorative individuals. Moreover, fishes plasticity respond to the threat by human predators. Heavily exploited fishes might thus show patterns of a timidity syndrome in which the average survivor becomes shy and less explorative. Spearfishing is a popular recreational activity in the Mediterranean Sea. Spearfishing is an active fishing gear, but depending on the species and its life-style either bold, explorative individuals are preferentially captured or those being shy and seeking refuge, as long as the refuge can be accessed by the spearfisher. It is not clear how exploited populations respond to intensive spearfishing. We inferred timidity levels by measuring the flight initiation distance (FID) at which five coastal fish species (targeted and not targeted) flew from divers with a speargun and without as a control. Results indicated that FID is overall higher in spearfishing-targeted species than in not targeted ones. The FID was also positively correlated with size of fishes (with large fishes showing greater FID) and with the underwater visibility (with fishes showed longer FID in clear water). Our study demonstrated that exploited fish species can recognize spearfishers as a threat likely by visual cues (e.g. spearguns). We cannot distinguish whether the difference observed are a plastic response of fishes (learning) or based on a genotypic difference (spearfishing-induced evolution), but we have clear evidence of a timidity syndrome caused by spearfishing that promotes an increased safe operating zone in exploited areas.



L8

## Do Anglers Catch the Same Fish as Predators? Vulnerability to Angling and Predation with Respect to Behavior in Eurasian Perch

REETTA VÄÄTÄINEN<sup>\*1</sup>, JOSEP ALÓS<sup>2</sup>, PEKKA HYVÄRINEN<sup>3</sup>, ROBERT ARLINGHAUS<sup>4</sup>, ANSSI VAINIKKA<sup>1</sup>

<sup>1</sup>University of Eastern Finland; <sup>2</sup>Instituto Mediterráneo de Estudios Avanzados; <sup>3</sup>Natural Resource Institute Finland; <sup>4</sup>Leibniz Institute of Freshwater Ecology and Inland Fisheries, Humboldt University of Berlin

\*Email: [reetta.vaatainen@uef.fi](mailto:reetta.vaatainen@uef.fi)

Consistent individual differences in behavior have been widely described in fishes, yet their fitness consequences in exploited systems remain inadequately studied. Research suggest that certain personality traits as well as vulnerability to fishing may have genetic components. Fishing can thus, by selecting individuals with certain behavioral types, affect the within-population distribution of not only the directly selected behavioral types, but also of all correlated traits — such as standard metabolic rate, growth rate or reproductive output. With Eurasian perch (*Perca fluviatilis*) as model species, we studied whether i) individual vulnerability to angling predicts individual activity in shoal and ii) vulnerability to angling or activity predict survival during predatory exposure. First, we angled predator- and angling-naïve perch from semi natural ponds to determine individual vulnerability to angling and tagged the perch with passive integrated transponder (PIT) tags. Secondly, individual behavior (swimming activity in shoal) was quantified in gravel-lined circular streams using automated PIT tracking. Lastly, boldness and survival of perch in the presence of a natural predator, the northern pike (*Esox lucius*), were determined in stream pools where perch only could swim unrestrictedly. Preliminary analyses suggested that i) perch activity in shoal was positively correlated with activity in presence of pike, ii) high activity was associated with low vulnerability to predation by pike and iii) vulnerability to angling did not predict vulnerability to predation by pike. Our study provides new insight into the alignment of predatory and fishing-induced selection, which will allow us to evaluate the fitness costs and benefits of certain behavioral types in harvested freshwater fish populations.