Investigating downstream migration patterns of European eel (*Anguilla anguilla* L.)

Florian M Stein[1,2], Eric Hübner[2,3], N Loes MB van Schaik[1,2], Olle Calles[3] and Boris Schröder[1]

[1]Department of Ecology and Ecosystem Management,Technische Universität München, München / Germany, [2]Institute of Earth and Environmental Science, Universität Potsdam, Potsdam / Germany, [3]Department of Biology, Karlstads Universitet, Karlstad / Sweden

1. INTRODUCTION

The European eel (*Anguilla anguilla* L.) is one of 15 catadromous anguillid species which are widely distributed around the globe (Fig. 1). The complex life cycle includes several marine and freshwater stages (Fig. 2). While developing into migrating silver eels, they leave the freshwater habitat and head towards their spawning grounds in the Sargasso Sea (Tesch 2003).

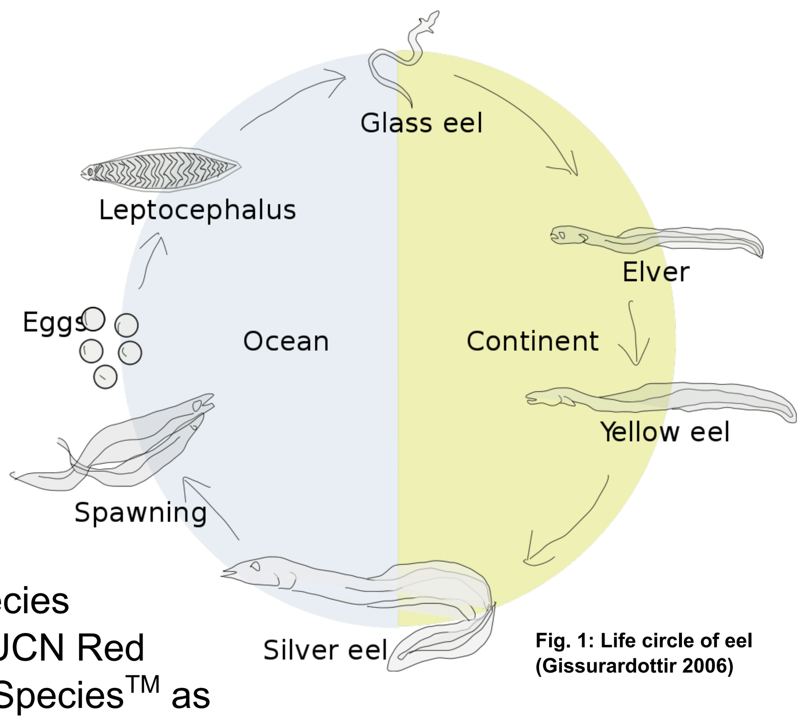


Fig. 1: Life circle of eel (Gissurardottir 2006)

Fig. 2: European eel (Tesch 2003, edited)

European eel stocks are in steep decline and the species was added to the IUCN Red List of Threatened Species™ as critically endangered (IUCN 2012). Along with natural impacts several anthropogenic factors such as mortality by turbines of hydroelectric power plants are proposed as possible explanations. Improved knowledge of environmental conditions triggering downstream migration is essential to adapt turbine operation to migration peaks.

2. METHODS

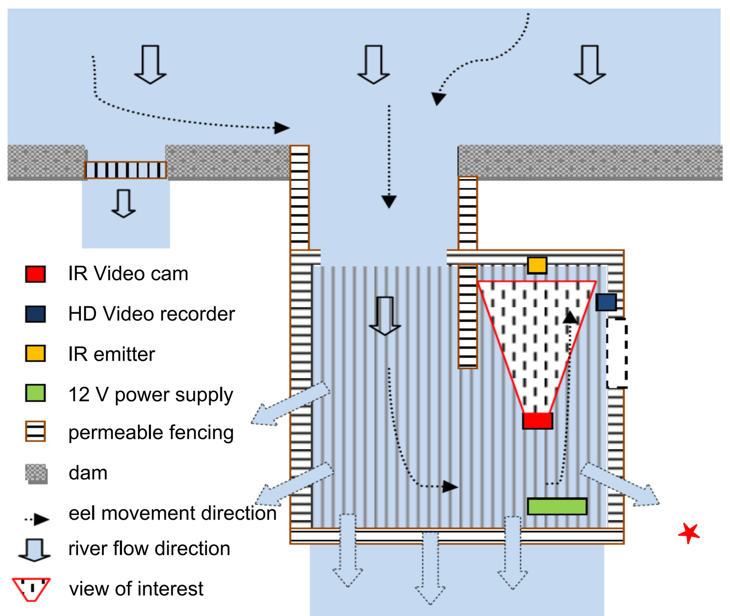


Fig. 3: Sketch of the stationary eel trap in Skärhultaån. All electrical units are stored in waterproof boxes (Hübner & Stein 2013)

Fig. 4: Stationary eel trap in Skärhultaån at high discharge. Position of photographer is marked as ✶ in Fig. 3 (Stein 2011)

Study site
small creek Skärhultaån that drains several lakes, Ätran river system (Halland County, SW Sweden)

Duration
Fall 2011 (06.08.-04.11)
Fall 2012 (21.08.-30.10)

Eel migration
stationary eel trap that covers entire discharge of the creek (N 57° 10.262', E12° 47.143')
Eel arrivals were accurately filmed by an Infrared video camera, recorded on HD recorder.

Environmental parameters

water temperature
onset® HOBO Pendant Temperature/Light Data Logger 64K

water level
onset® HOBO U20 Water Level Logger
Odyssey™ Capacity Water Level Logger

precipitation
onset® HOBO Micro station H21-002

moon illumination
http://aa.usno.navy.mil/data/docs/MoonFraction.php

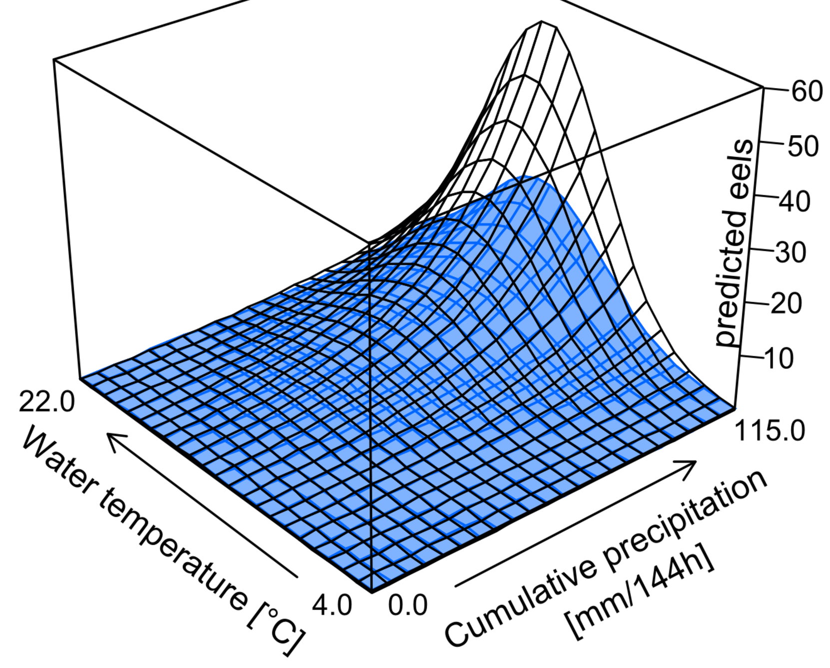
Data Analysis
Based on the measured environmental parameters additional cumulative and mean variables were generated for the consideration of their dynamics. Differences between the current measurements and the measurements of 1 to 7 days ago were calculated for water temperature and water level. Cumulative precipitation was calculated in the same time intervals. New variables were added to the data set as independent variables. Generalized Linear models (GLMs) were estimated in 'R' (R Development Core Team 2008) and variable selection was based on AIC. Binomial models were weighted in order to avoid zero inflation.

Model name	response variable	predictor variables	family
Model A&B	daily eel abundance	daily resolved environmental data	quasipoisson
Model C&D	eel arrival time	5 min resolved environmental data	binomial

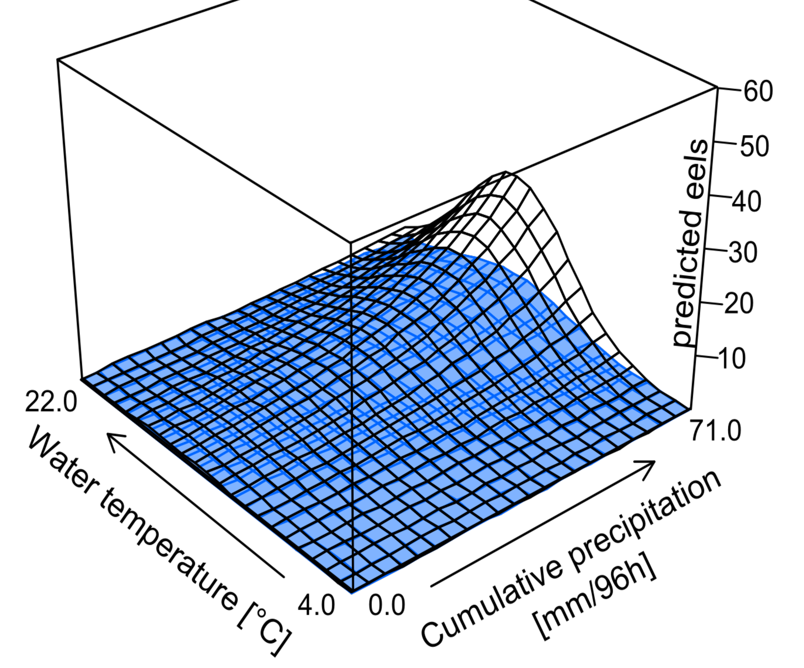
Model surfaces of the quasipoisson data sets were llustrated by wireframe (package 'lattice' Sarkar 2013) and surfaces of the binomial data sets by the open source program LRMesh (Rudner 2004).

3. RESULTS

Fall 2011



Fall 2012



Model Coefficients (Model A)	Estimate	Std. Error	t value	Pr(>ltl)
(Intercept)	-9.70712	2.49446	-3.89	0.00020 ***
Water temperature	1.39802	0.35224	3.97	0.00015 ***
Water temperature²	-0.05044	0.01237	-4.08	0.00010 ***
Cumulative precipitation	0.03497	0.00425	8.22	2e-12 ***
Moon illumination	-0.82165	0.38177	-2.15	0.03422 *

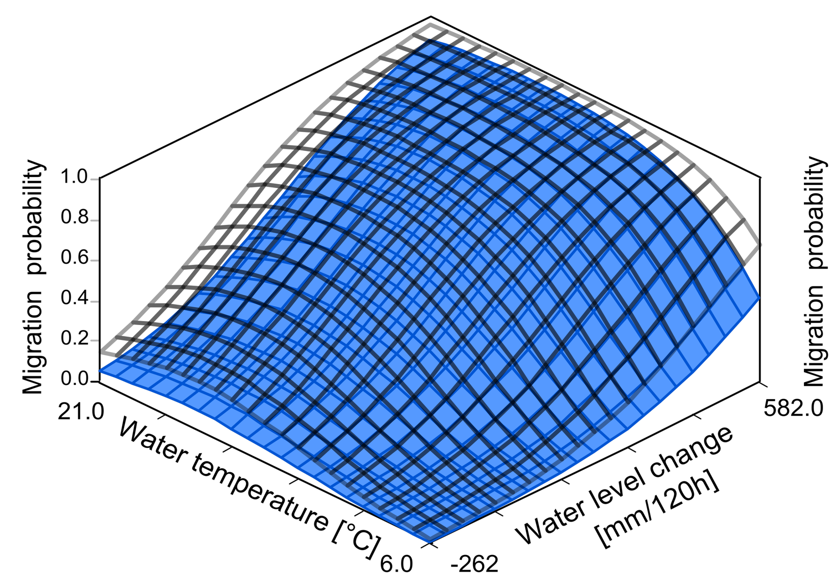
Explained deviance 0.76
Spearman R² 0.68

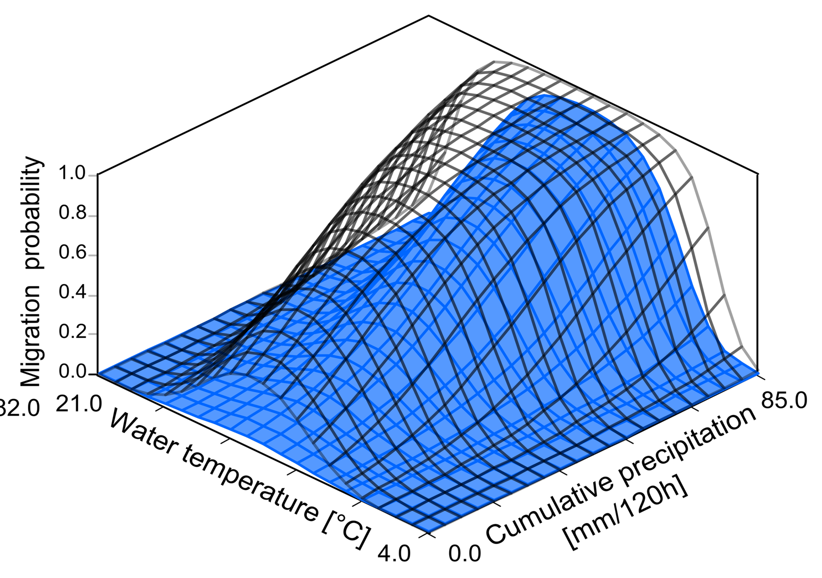
Fig. 4: Model A - Eel abundance prediction on daily data. The two surfaces represent the model response for the predictor variables Water temperature in °C and Cumulative precipitation of the last 6 days in mm. Surface **A I** ◆: Fraction of moon illuminated is set to constant 1 (full moon); surface **A II** ◇: fraction of moon illuminated is set to constant 0 (new moon)

Model Coefficients (Model B)	Estimate	Std. Error	t value	Pr(>ltl)
(Intercept)	-10.09785	5.54050	-1.82	0.074 .
Water temperature	1.41528	0.90338	1.57	0.124
Water temperature²	-0.04805	0.03587	-1.34	0.187
Cumulative precipitation	0.04128	0.00862	4.79	1.6e-05 ***
Moon illumination	-1.40037	0.59983	-2.33	0.024 *

Explained deviance 0.63
Spearman R² 0.68

Fig. 5: Model B - Eel abundance prediction on daily data. The two surfaces represent the model response for the predictor variables Water temperature in °C and Cumulative precipitation of the last 4 days in mm. Surface **B I** ◆: Fraction of moon illuminated is set to constant 1 (full moon); surface **B II** ◇: fraction of moon illuminated is set to constant 0 (new moon)





Model Coefficients (Model C)	Estimate	Std. Error	t value	Pr(>ltl)
(Intercept)	-7.314041	2.014866	-3.63	0.00028 ***
Water temperature	-1.029802	0.377844	-2.73	0.00642 **
Water temperature²	-0.005886	0.000886	-6.64	3.1e-11 ***
Water level change	-0.028633	0.011297	-2.53	0.01126 *
Moon illumination	0.936270	0.306617	3.05	0.00226 **

Explained deviance 0.29
Spearman R² 0.85

Fig. 6: Model C - Eel migration probability predicted on high resolved data. The two surfaces represent the model response for the predictor variables Water temperature in °C and Water level change of the last 5 days in mm. Surface C **I** ◆: Fraction of moon illuminated is set to constant 1 (full moon); surface C **II** ◇: fraction of moon illuminated is set to constant 0 (new moon)

Model Coefficients (Model D)	Estimate	Std. Error	t value	Pr(>ltl)
(Intercept)	-18.6798	5.0290	-3.71	0.00020 ***
Water temperature	2.7892	0.8003	3.49	0.00049 ***
Water temperature²	-0.1074	0.0313	-3.44	0.00059 ***
Cumulative precipitation	0.0648	0.0129	5.04	4.7e-07 ***
Moon illumination	-2.5211	0.7926	-3.18	0.00147 **

Explained deviance 0.32
Spearman R² 0.85

Fig. 7: Model D - Eel migration probability predicted on high resolved data. The two surfaces represent the model response for the predictor variables Water temperature in °C and Cumulative precipitation of the last 5 days in mm. Surface D **I** ◆: Fraction of moon illuminated is set to constant 1 (full moon); surface D **II** ◇: fraction of moon illuminated is set to constant 0 (new moon)

Models on daily data sets from 2011 (**A**) and 2012 (**B**) show similiar tendencies. Maximum abundances are predicted if cumulative precipitation of several days is maximal while water temperature ranges between ~ 10 and 18°C. Abundance level is generally higher under new moon condition. The predictions roughly match the recorded abundances (2011: max 46; 2012: max. 18).

Model **D**, estimated on the high resolved data set, shows a similiar tendency. Migration probabilty gains the maximum if water temperature ranges within a certain range and cumulative precipitation is maximal. The effect of new moon seems to be more distinctive under low precipitation conditions. The temperature range is clearly marked with no migration probability below 6 °C and above 20 °C under full moon conditions (**D I**) and a very low probability under new moon conditions (**D II**).

Model **C** does not show a clear temperature range and the effect of moon illumination is lower. The cumulative precipitation does not appear significant but the correlated (0.77) variable water level change does.

4. CONCLUSIONS

1. Increased migration activity under new moon conditions matches with their noctural behaviour. Both behavioral patterns lead to the conclusion that eels tend to avoid illumination in order to minimize exposure to predators.

2. Moderate water temperatures usually appear in spring and fall - seasons of heavy rains and floods. The results match with the assumption, that eels are quite inactive during hot summer and cold winter temperatures.

3. High discharge conditions (also expressed in water level and precipitation) can temporarily connect lentic waters to river systems for the migrant escapement. Additionally, the conditions enable the eels to save energy by using the water flow for a passive downstream migration ('passive drift').

4. The application of GLMs seems to be a reliable method to identify preferable migration conditions on the basis of a low number of environmental parameters.

5. REFERENCES

IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. www.iucnredlist.org. Downloaded on 08 May 2013
R Development Core Team 2008. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Version 2.12.0
Rudner M. 2004. LR-Mesh: Visualization of logistic regression models. Version 1_0_5 2004
Sarkar D. 2013. Lattice: Lattice Graphics R Package Version 0.20-13.2013
Tesch F.-W. 2003. The eel. Oxford, UK, Blackwell Science Ltd. 408 pp.

6. ACKNOWLEDGEMENT

DAAD, ELFORSK
Aina Andersson, Jonas Christiansson, Tony Sahlberg

Florian Stein
Department of Ecology and Ecosystem Management
Technische Universität München
Emil-Ramann-Str.6
85354 Freising

phone: +49 331 977 2776
E-mail: florian.stein@tum.de

ELFORSK
SVENSKA ELFÖRETAGENS FORSKNINGS- OCH UTVECKLINGS - ELFORSK - AB

Eric Hübner
Institute of Earth and Environmental Science
Universität of Potsdam
Karl-Liebknecht-Str. 24-25
14476 Potsdam

E-mail:
ehuebner@uni-potsdam.de