The nutrient budget of closed and semi-open aquaculture systems

Assessment of contributions from different nutrient sources based on permutation analysis

Anıl A. Tellbüscher

Last updated: 14.02.2024

Permutation analysis

Let's assume that a hypothetical integrated aquaculture facility can be built anywhere in Europe (see Figure 1). While the tap water quality at the chosen location is likely to be subject to comparatively small fluctuations, the system operator can theoretically choose from any feed available on the market. This feed could be used to fatten a range of fish species relevant to aquaculture, which in turn differ in the retention of the nutrients supplied. This results in a large number of combinations (= permutations) that must be taken into account in order to be able to make a reliable statement about the proportion of the total nutrient input that can be utilised for secondary cultivated organisms that is attributable to the feed and the water. This information can then be used to derive which nutrients are effectively supplied by changing the feed composition and which are not.

Assumptions

The following assumptions have been made:

- the feed input was standardised to 1 kg
- feed nutrient levels based on metadata (commercial and experimental fish feeds; $n > 50$ for N, P; $n < 10$ for all other elements)
- three nutrient retention levels; means according to Roy et al., 2022 (TILAFeed), Sugiura et al., 2018, $\pm 5\%$
- water nutrient compositions based on metadata (water analysis reports; $n > 50$ for most elements)
- makeup water 10, 100, and 1000 L per kg of feed input (Kloas et al., 2015, Dalsgaard et al., 2013)
- at a feeding rate of 2% BW/day, the resulting biomass of the stock from 1 kg feed input is 50 kg

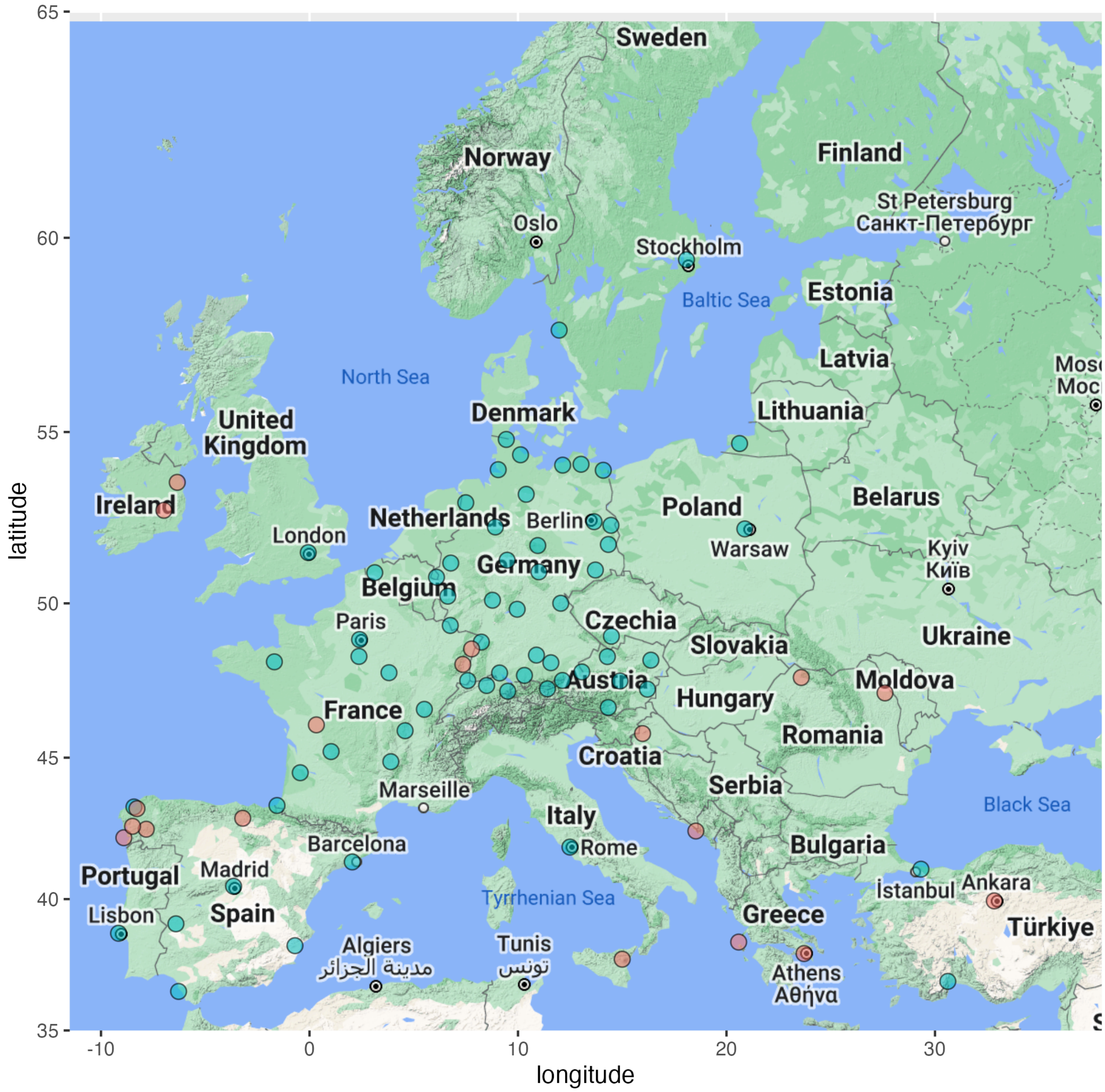

Figure 1: Geographical distribution of water analysis reports included in the source water dataset. Green: analysis of municipal tap water (n = 71); Red: rainwater analysis (n = 18).

- at a stocking density of 50 kg/1000 L, this results in a system of 1000 L
- considering the makeup water input, this would correspond to water exchange rates of 1%, 10%, and 100%.

Outcomes

Figure 2 and 3 show the results of the permutation analysis of tap water in form of a density plot and an empirical cumulative distribution function (ECDF).

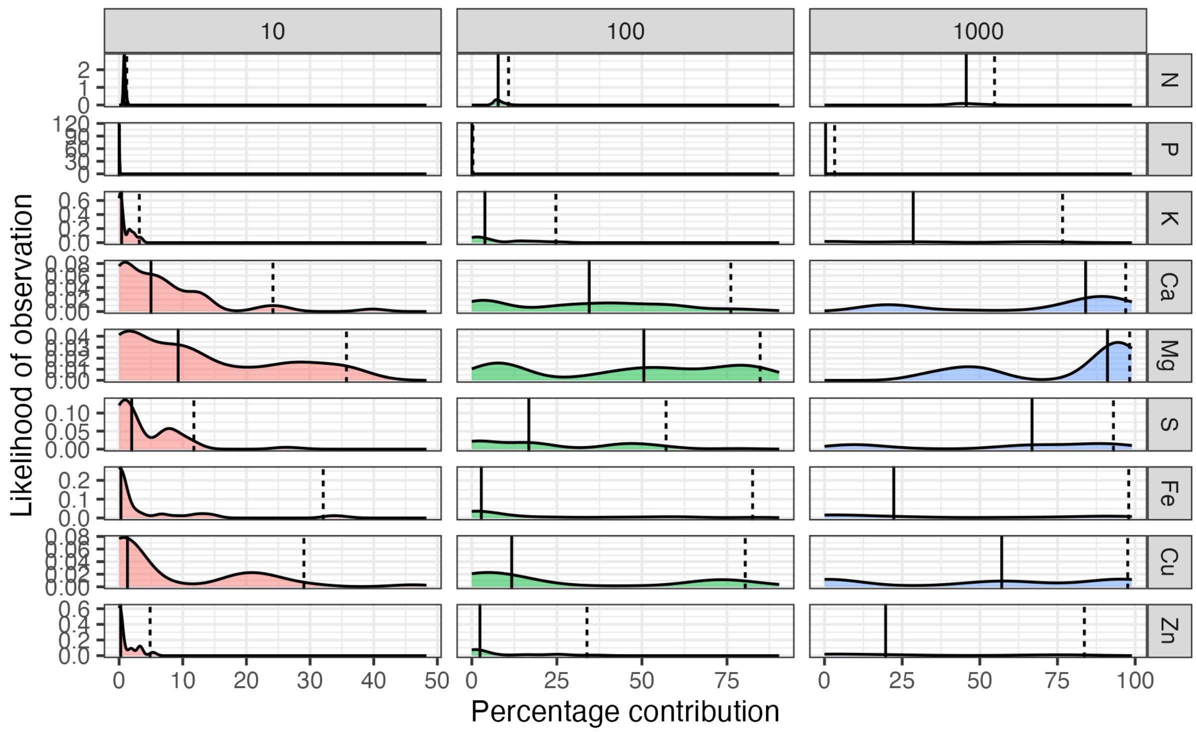

Figure 2: Permutation analysis of the percentage contribution of tap water to the net nutrient input at different makeup water levels (10, 100, and 1000 L/kg of feed input). The density plots visually display the probability density function of the percentage contribution of tap water to the total daily nutrient input, illustrating the likelihood of observing different values. Dashed line marks the 95% percentil, while the solid line marks the median of the data.

In the following, only the markup water of 100 L/kg of feed is considered, equaling a water exchange rate of 10%.

The permutation analysis of the tap water data clearly shows that tap water contributes below 10% of the total inputs of N, P, K, Fe, Cu, and Zn in 50% of the cases (everything left from solid vertical line). The least variability in this picture is found for N and P, with 95% of the data being very close to the median value of approx, 10% contribution to the total N and P input. K and Zn are slightly more variable, with

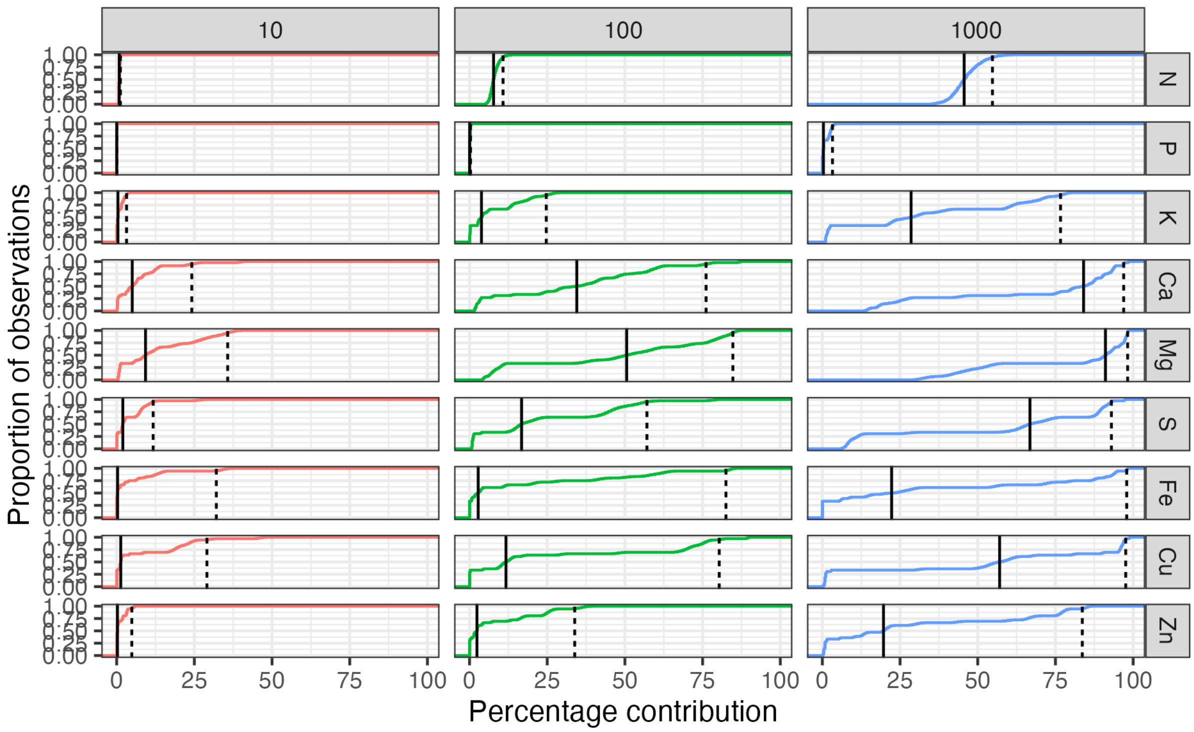

Figure 3: Empirical cumulative distribution functions of the percentage contribution of tap water to the net nutrient input at different makeup water levels (10, 100, and 1000 L/kg of feed input). Dashed line marks the 95% percentil, while the solid line marks the median of the data. Data is based on permutations.

contributions ranging up to 25% and 30%, respectively. The majority of those nutrients can thus be assumed to originate from the feed with almost 100% probability. Consequently, an increase in the inclusion rate of those nutrients into aquafeeds will likely result in a similar response in the "net nutrient input", irrespective of where in Europe this feed is applied.

A different picture emerges for Ca and Mg. Here, the contribution of tap water was found to be up to 35% and 50% of the total nutrient input in 50% of the cases, respectively, and it went as high as 75% and 90% of the total input in 95% of all possible combinations. Contributions of S, Fe, and Cu from tap water are relatively low, ranging between 2% and 12.5% of the total input in 50% of the cases. Though, the S input from tap water can result in up to 50% of the total input, while it was found that around 80% of Fe and Cu can enter the system via the tap water.

The variability in the results can be partly traced back to the variability found in the aquafeeds, but also to the high variability in element concentrations found in the water. It is thus not meaningful to consider those nutrients for inclusion into specialty feeds, because the resulting response in nutrient levels will not depend on the nutrients supplied via feed in all cases, but also on those that are entering the system via the water. Management strategies for the nutrients mentioned must therefore probably be adapted to the specific conditions of a plant, as a generalised overall solution will almost always be the worse compromise.

Questions/Suggestions

- **Suggestion:** Focussing on 100 L/kg of feed (10% water exchange rate) only and making a dynamic plot via RShiny that can be linked as supplementary material and hosted on the University website or on ShinyApps.io to keep the "big picture" clean.
- **Question:** Which metric can better describe the variability in contributions? *Effect size*?

Rationale

The few studies that assess the contribution of different nutrient sources to aquaculture systems (e.g., Delaide et al., 2017; Strauch et al., 2018) have several flaws when thinking of integrated aquaculture systems:

1. They report data from a single set of nutrient inputs that is only representative for their particular combination of feed and water composition and daily mass flows.
2. They do not take into account that the amount of nutrients that is available for further use in an integrated system is not the gross feed input, but the feed input corrected for the retention of nutrients by the fed animals.

Overall, there is considerable variation in the composition of aquafeeds and water and also in their mass flows (water exchange). It was shown that African catfish and European eel can be reared under a water replacement as low as $30\,\mathrm{L\,kg^{-1}}$ of feed without impairment of the feed intake (Mota et al., 2015). Nile tilapia was successfully reared at a water replacement rate of $100\,\mathrm{L\,kg^{-1}}$ of feed (Kloas et al., 2015). In other species such as Rainbow trout and Sturgeon, a water replacement rate of $1000\,\mathrm{L\,kg^{-1}}$ of feed is common (Dalsgaard et al., 2013). A single scenario such as in the studies mentioned initially is thus not representative.