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Letter to the Editor

Dear Editor,

The paper published in Aquaculture 306, 101–107 (2010), entitled "Does bivalve mollusc polyculture reduce marine finfish farming environmental impact?" and authored by F. Navarrete-Mier, C. Sanz-Lázaro and A. Marín, adds to existing and growing literature on integrated multi-trophic aquaculture (IMTA). There is certainly a need for increasing our understanding about the behavior of integrated aquaculture systems, particularly in more open ocean conditions, and the effort by Navarrete-Mier et al. is therefore appreciated. However, the categorical conclusions they drew from their single, short-term experiment are not well justified, and the fact that they do not make reference to previous studies, that specifically addressed the research question being investigated, is troublesome.

Integration of extractive organisms (suspension-feeders, seaweeds, deposit-feeders, etc.) with fish cage farming is complex. Even if the nutritional quality of fecal and feed wastes from fish is suitable for suspension-feeders like mussels and oysters, many challenges remain for making co-culture practical. Besides spatial and temporal differences in hydrodynamic conditions between sites, pelagic primary productivity, water seston concentrations and farm waste characteristics are also different and will influence the site-specific success of co-cultivation. This has largely been overlooked by Navarrete-Mier et al. The fact that studies on co-culture of fish and suspension-feeders obtained different results has spurred research looking closer into environmental and farming dynamics with the aim of explaining the contradicting results (Troell and Norberg, 1998; Troell et al., 1999, 2009). Navarrete-Mier et al., fail to reference these studies and, instead of trying to explain the discrepancies, they give a definitive conclusion based solely on their own results from a three-month study at one fish farm. Existing studies demonstrating that under the right conditions mussels, oysters and clams can grow better adjacent to fish farms (Wallace, 1980; Jones and Iwama, 1990; Mazzola and Sara, 2001; Lander et al., 2004; Kullman et al., 2007; Peharda et al., 2007; Sará et al., 2009), are thereby simply ignored for no apparent reason.

The hydrological characteristics of a site are of key importance for the distribution of wastes (feed waste and fish faeces). Considering that the cages in the study by Navarrete-Mier et al. reach 19 m in depth, it is questionable that a single current meter at 15 m depth, adjacent to the farm (exactly where is unknown), could generate a good understanding about current characteristics of the area (including test sites up to 1800 m away). It is also very important to demonstrate and characterize the existence, or not, of a "plume" of nutrients, and if present, whether it reaches the extractive organisms for recapture potential. Is the plume present all the time? Is the plume clearly detectable in a region otherwise characterized as oligotrophic or is the farm in a region already nutrient rich and where organisms are already near or at satiation? Does its direction change over time, as a consequence of current gyration? Is the feeding of the finfish performed in a manual or automated manner, being synchronized with the direction of currents (and, consequently, the plume) along the supposed transectorial direction (and proper depth) along which the extractive species were experimentally placed? Navarrete-Mier et al. seem not to have considered these aspects, despite the facts that they have been recognized as important in previous work (*e.g.* Troell and Norberg, 1998).

Navarrete-Mier et al. make a general statement about increased primary production due to increased nutrient availability from fish farms. They do not, however, go into any detail, which is needed for any deeper understanding about how this could affect co-cultured bivalves. Increased primary production can be triggered either by direct dissolved nutrient waste from the fish, or through release of nutrients from enriched sediments adjacent to the fish cages. Only when water currents are weak, or when the current pattern keeps the water volume contained (*i.e.* in an embayment or similar water body), will increased nutrients affect bivalve growth positively through increased phytoplankton growth (Troell and Norberg, 1998).

Magill et al. (2006) reported the mean size of settleable particles from sea bream and sea bass between 0.3 to 2.5 mm (1.4 mm mean) and 0.3 to 6.2 mm (1.12 mm mean), respectively. Setteleable organic material collected under and near cages showed that faeces from sea bass had 69% of the faecal particle volume settling at less than 2.0 cm/s while only 15% of sea bream particle volume settled at less than 2.0 cm/s. Such data raise the questions as to what portion of the organic load in the study by Navarrete-Mier et al. was within the filtration size range of the shellfish and what current speeds would be needed to deliver the organic load to the sampling locations. With mean current speeds at the study site of 0.07 m/s, little of the settleable material would be expected to reach 15 m depth at the 120 m sampling location or beyond. The depositional data in Navarrete-Mier et al. paper seem to support this, showing no discernable difference in deposition from 100 m outward. Consequently, only two locations in the study would have the potential for any significant exposure to settleable solids (0 and 25 m) even at the appropriate particle sizes. This, then, leaves only potential exposure to suspended particulates at the remaining study locations. It is not possible to determine the proportion of suspended vs. settleable solids exiting fish cages at any given time. However, in high abrasion environments such as land-based culture systems, suspended organic particulates can exceed 25% of the particle load (Wong and Piedrahita, 2000). Replication of such an environment in open-water cages is unlikely and, consequently, the suspended particle portion is most likely well below 25% of the solid organic load. These issues, combined with the fact that feed fines and defecation during surface feeding, most likely resulted in suspended solids released well above 15 m depth, and dilution effects at a distance, could be a major factor in the lack of growth response.

The inclusion of heavy metals lacks any detailed description of how these enter the water, *i.e.* in what forms. The feed contains heavy metals and this is shown analytically, but since the bulk of the wastes from a fish farm consists of fish faeces and other excretion products, it is difficult to know how much that actually enters the water and in what forms, and then also whether it is in a size fraction bioavailable to the filter-feeders. This is important to know when speculating about how the waste will influence organisms at any distance or depth. Also important here is how much accumulation can be expected in only a three month time period. The best that can be said from the existing data set is that there is no evidence of accumulation of heavy metals from the fish food in the filter-

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feeders. There is not enough of an understanding of the dynamics of heavy metals at the fish farm to make any further conclusions on their fate.

The inclusion of stable isotope work is interesting, as this could potentially increase our understanding about food sources. However, we find some limitations with the experimental setup and the analysis. Firstly, an isotopic analysis should consider all potential sources of organic matter present in the area. Navarrete-Mier et al. should have considered at least phytoplankton, terrigenous continental inputs and other potential sources of detritus (*e.g.* fish faeces). Instead the isotopic signature used to indicate influence from fish farm wastes was only that of the feed. This is not representative of what the bivalves potentially consume as they usually rely on a mixture of naturally occurring seston, fish faeces and feed waste. The feed waste from a modern fish farm is likely to be less than a 15% of the dry matter load (Reid et al., 2009). Thus, if the type of sources and their signatures are different along this gradient, then measuring signatures only in consumers does not allow for unambiguous conclusions. The fact that no other organic source apart from feed was considered makes any interpretation of the results difficult. Secondly, this isotopic study is based on the analysis of only 3–4 individuals per every distance. Individual variability is generally so large that it is impossible to get valid and definitive conclusions just from a few specimens (Fukumori et al., 2008). Thirdly, the authors concluded that stable isotope analysis proved that "bivalves did not change their diet because of the closeness to the farm", and that "$\delta^{13}C$ and $\delta^{15}N$ values for oysters and mussels were very different from the values of the feed, which had a lower $\delta^{13}C$ (-22.3 ± 0.5‰) and a higher $\delta^{15}N$ (5.3 ± 0.4‰)". Moreover, they also concluded that "the isotopic composition of both bivalve species was not influenced by the fish farm wastes". These conclusions are tenuous given present limitations with stable isotope research. This expectation that isotopic composition of species near fish cages would likewise reflect isotopic fish feed composition, upon significant consumption, may not always be valid because it does not consider the effect of isotopic fractionation (Post, 2002). Indeed, if we assume a fractionation degree of about 0.5–1.0‰ (like stable isotope principle affirm), then the $\delta^{13}C$ of mussels and oysters cultivated close to cages was just enriched of about 1.0‰ with respect to the main source (*i.e.* the feed). It is inappropriate to generalise from a three month experiment. Although there is recent evidence that some tissues, like the bivalve's digestive gland, can incorporate the isotopic signature in less than 30 days (Redmond et al., 2010), most research about marine organisms show that the whole soma and mantle tissues of bivalves need more than 90 days for incorporating an isotopic signal from new food sources (*sensu* Post, 2002; Fukumori et al., 2008; Redmond et al., 2010). Stable isotope data from the study of Navarrete-Mier et al., may simply reflect what the shellfish consumed before the transplantation. An additional concern reflects limited tissue growth in the mussels. No detailed data on growth are presented. Estimates of the tissue to shell weight ratios, based on the morphometrics of similar species, would suggest that the animals increased their tissue weight by only 5%. Even if the growth increment was attributed completely to the fish food (and not to any of the natural seston), it would be very hard to detect a signal in stable isotopes, since the 5% increase in weight would be diluted by the existing stable isotope signatures of the animal at the start of the experiment. Some of the reported isotope patterns are also not fully explained, *e.g.* for oysters in Fig. 6 which show a distinct signature within the cages (*i.e.* feeds) for $\delta^{13}C$ but in the opposite direction as what would be expected if fish feed inputs were important for them.

We appreciate the additional research focusing on IMTA. However, we discourage authors presenting clear-cut conclusions based on a single, short-term study, with significant limitations in experimental design and discussion, and without enabling a more objective and broad review of results from previous other studies investigating the same topic.

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