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REPLY COMMENT

'Fair is foul and foul is fair': response to a critique

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The intensive net-pen fish farms that are situated off the north shore of the Gulf of Eilat, Red Sea, employ large fish cages, each of which is 12 m in diameter and 10 m in depth; annual farm production is 2250 t, mostly of gilthead seabream *Sparus aurata*. The farms are located at the mouth of Nahal Arava, a dry riverbed. Winter flash-floods deposit large quantities of alluvial silt and fine sand in the Gulf (Katz et al. 2002), impeding the development of coral reefs by suffocating or burying coral colonies. For that reason, no developed reef structures are found in this area and coral colonies are located only on elevated manmade hard substrates such as automobile tires, concrete sinkers, metal cables and buoys.

For the past 4 decades, the reefs of Eilat have been continuously declining, primarily because of the combined effects of pollution, floods, tourism, shoreline development and urban sewage (Loya 1990, Fishelson 1995, Epstein et al. 1999). The rapid development of fish farming at Eilat during the last decade has spurred concern and debate over its impact on the coral reef reserve, located 8 km south of the farms. Despite the difficulty in discriminating between the effects of the various anthropogenic impacts and their relative contribution to the decline of the coral reef at Eilat, the trendy perception (which, once published, perpetuates itself through media hype, and economic and political interests) is that the fish farms are the major cause for the deterioration. It is therefore disconcerting that no scientific study has been carried out to test, under controlled experimental conditions, the impact of the fish farms on those reefs.

The aim of our studies (Bongiorni et al. 2003a,b) was to test the impact of nutrients (dissolved and particulate) emanating from the fish farm on survivorship, growth rates, and some reproductive aspects of 2 selected coral species. The results revealed higher survivorship, and increased growth and reproductive rates in coral colonies near the fish farm, as compared to colonies growing at the reference site 8 km away. These results contradict the prevailing notion, and Loya & Kramarsky-Winter (2003, this volume) (L&KW 2003) challenged our conclusion. We reject their critique and contend that the points raised in that critique are wrong, self-contradictory and unsubstantial, simplifying complicated ecological situations.

In the first paragraph of their critique, L&KW (2003, p. 299) state: 'We contend that the methodology and experimental design used in that study are unsuitable for obtaining a correct assessment of the impact of commercial fish farms', and, 'we claim that their results actually attest to the opposite…' (p. 299). This argument is self-contradictory, since if our experimental design is wrong, our data cannot be used to reach either conclusion.

Incorrect assumptions and statements. L&KW (2003) incorrectly equate the alluvial substrate of the northern tip of the Gulf of Eilat, where the fish farms are located, with the very different coarse substrate at the coral reef reserve at Eilat. The conditions corals face at these 2 sites are clearly not comparable to each other, disabling any conclusion originating from the unpublished work cited (L&KW unpubl.). Furthermore, L&KW (2003) state that colonies of the genera *Stylophora* and *Acropora* 'are almost the only coral species in the vicinity of the fish farms' (p. 301), as compared to 'ca. 100 coral species' in the coral nature reserve of Eilat. Both figures are incorrect. Coral species diversity and number at the reef of Eilat have diminished substantially since the 1960 census (Wielgus 2003); much of this decline predates the fish farm. Moreover, a recent census (Angel et al. unpubl, cited in Atkinson et al. 2001) identified >450 coral colonies belonging to >22 genera growing on artificial substrates within

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30 m of the fish cages. This census also lists at least 18 *Favia* colonies in the vicinity of the farms (e.g. Fig. 1A,B), declared by L&KW (2003) to be 'absent in the vicinity of the fish farms' (p. 301).

L&KW cite Glassom (2002) to support their argument that reproductive effort is reduced in *S. pistillata* at the reference site, compared to data from Rinkevich & Loya (1979). However, the results in Rinkevich & Loya (1979) are not comparable with the Glassom (2002) study because of methodological differences. Glassom (2002, his Table 7.1) further reported the mean number of planulae released per night from *S. pistillata* colonies during March, April and May 2001 was 114, 108 and 222, respectively (no data is given regarding colony size, although this may critically affect the outcome: Rinkevich & Loya 1979). In a long-term study on S. *pistillata* sexual reproduction in Eilat, Rinkevich & Loya (1987) counted the numbers of planulae shed from isolated coral branches. They recorded in March 1979: 22 planulae per 100 g coral skeleton, and in April and May 1980: 30 and 44 planulae, respectively. Assuming *S. pistillata* colonies have a mean weight of 500 g, the above numbers reveal similar reproductive outputs of S. *pistillata* colonies during 1979–1980 (Rinkevich & Loya 1987) and 2001 (Glassom 2002). Furthermore, the year-to-year variations characteristic of *Stylophora* reproduction invalidate sporadic comparisons as made in L&KW (2003). For example, Rinkevich & Loya (1987) recorded 85 ± 95 (mean ± SD) planulae per 100 g skeleton during February 1979 and only 4 ± 2 planulae in February 1980.

Glassom (2002) found that coral recruitment, monitored for 2 years at 20 sites along the coast of Eilat, was twice as high in the first year compared to the second, and characterized by large spatial variations. During some months of both years (such as September 1999, March 2000; his Fig. 2.2), the recruitment figures at the northern tip of the Gulf (where coral reefs are absent and the fish farms are located) were significantly higher than at the reference site of our study. Furthermore, Glassom (2002) specifically stated that the abundance of juvenile corals at the Eilat reef is high compared to coral reef locations elsewhere in the world. These results may therefore attest to the conclusion that nutrients discharged from the fish cages are beneficial to corals.

To back their statements, L&KW (2003) use literature citations irrelevant to the issue discussed; e.g. when claiming, 'nutrients released from the fish farms were found to reach the reefs further south' (p. 302), they cite Abelson et al. (1999). However, that publication studied the transport of inert particulate matter, not of dissolved organic compounds (the focus of Bongiorni et al. 2003a); the other work cited was published in a non-refereed magazine. L&KW (2003) also claim 'Much of the nutrients released from the fish farms is in the form of particulate materials that accumulate on the sediment' (p. 299). Actual nutrient budgets computed for Eilat's fish farms (Angel et al. 1995, Lupatsch & Kissil 1998), and for intensive fish farming in general (Beveridge 1996, Pearsen & Black 2001), indicate that most of the nutrients are released in dissolved form.

L&KW (2003) also challenged our calculated parameters for the annual discharge of nitrogen and phosphorus 'released from the central and western pontoons' (p. 301) by citing the values in Gordin (2000), a study which presented the total annual nutrient discharge from all fish farms at Eilat, whereas we specifically limited our computation to those pontoons in the vicinity of our experiment, i.e. those that discharged nutrients directly onto the coral colonies studied.

Is L&KW (unpubl.) comparable to Bongiorni et al. (2003a,b)? Clearly not. The focus of our study was the impact of dissolved compounds released by the fish farms. The rationale for placing the corals at 6 m depth next to the fish farm was to maximize their exposure to the fish cage effluents. L&KW (unpubl., therefore impossible to respond to in full) examines a different topic: the impact of fine, unconsolidated terrigenous substrate on corals in the northern Gulf of Eilat. These sediments, which are totally irrelevant to the fish farm, may become resuspended from the seafloor and impair coral growth, reproduction and survival. Bongiorni et al. (2003a,b) did not 'fail' to provide an accurate description of the benthic environment under the fish cages' (p. 299); we simply did not study that question. Moreover, it was not a flaw to conduct studies (Bongiorni et al. 2003a,b) on the influence of fish farm effluents with elevated corals; failing to do so (as in L&KW unpubl.) may lead to inaccurate interpretations.

L&KW (2003) do not refer to a study coauthored by Loya (Lieberman et al. 1995), and 2 similar studies (Meyer & Shultz 1985a,b) that have documented the enhancement of skeleton deposition, tissue growth rates and reproductive efforts in branching corals that harbor schooling fishes. The fishes provide a continuous supply of nutrients to the coral colonies via their excretion. For example, haemulid fish were found to deposit more than 250 mg m^{-2} d^{-1} of particulate organic carbon on the coral colonies on which they rested, exceeding the rates observed in other naturally or artificially enriched ecosystems (Meyer & Schultz 1985a). These examples further disprove the assumption made by L&KW (2003) of 'the detrimental effect that eutrophication has on the coral species' (p. 299).

Choice of *Stylophora pistillata*: 'One of the most important hermatypic species on a global scale' (Loya 2000, p. 1). L&KW (2003) objected to our choice of *Stylophora pistillata* as a model species for testing the impacts of fish farm nutrient release, and have criti-

Fig. 1. (A–C, F) Naturally growing and (D,E) experimentally deployed coral colonies underneath the fish cages. (A,B) 3 healthy looking *Favia* colonies naturally settled and developed on metal chains on the seafloor located, (A) at 10 m depth, 20 m NW of the fish cages; (B) at 8 m depth 30 m NE of the fish cages. (C) Buoy deployed about 2.5 yr ago 15 m from the fish cages, covered by naturally settled *Acropora*, *Pocillopora* and *Stylophora* colonies together with other sedentary organisms such as sponges and tunicates; although it was never cleaned during this period, fleshy algae did not successfully compete with coral settlement and growth. (D) Small branches of *Acropora* and (E) small branches of *Pocillopora* on plastic pins, 2 mo after their installation at 6 m depth between the pontoons carrying the fish cages; no cleaning procedure was employed and the coral branches grew vertically as well as horizontally on plastic substrate, similarly to thousands others. (F) Healthy looking *Acropora* colony ca. 70 cm wide, growing at 6 m depth on a metal chain installed in 1994 about 80 m from the fish cages; this is one of several other large *Acropora* colonies without any sign of infestation or dead branches. Photographs A, B, D–F by D. Gada (September 2003); C by K. Collins (August 2003)

cized us for pre-selecting 'coral species that have the highest chances of surviving and growing in the vicinity of the fish farms' (p. 301). We were nearly convinced by these arguments when to our enjoyment we found that L&KW (2003) relinquished the claim and used the same 'inappropriate' coral species for their experiments. What a triumph to the reproved species! There is not enough space here to emphasize the importance of *Stylophora pistillata* as one of the most widely used model species in coral reef research ('a key species to coral research in many fields, including coral biology, ecology, physiology, biochemistry, geochemistry, immunology, evolution, paleoecology, biogeography and other': Loya 2000, p. 1).

During our study, we cleaned the PVC plates at both sites on a monthly basis, to eliminate potentially competitive interactions with settling algae and encrusting invertebrates that could have influenced the outcome (otherwise, we could have justly been criticized for not cleaning the substrates). Algae growing on small coral colonies are, indeed, one of several possible impacts of water eutrophication. However, L&KW are mistaken when they assert that 'If the plates had not been repeatedly cleaned, it is very likely that the experimental corals would have become overgrown by macroalgae and encrusting organisms, causing their death within a short time' (p. 301); small colonies and coral nubbins thrive near the fish cages (Fig. 1C–E).

L&KW further challenged us to present 'an underwater photograph of the corals growing on the plates *in situ* prior to the monthly cleaning' (p. 301). We oblige with photographs from an ongoing study in the fish farm nutrient-enriched area (Fig. 1D,E), designed to rear stocks of farmed coral colonies for reef restoration purposes, following the concept of 'gardening of the coral reefs' (Rinkevich 1995, Epstein et al. 2001). This study entails ca. 5000 nubbins and coral fragments taken from *Stylophora, Acropora* and *Pocillopora* colonies. It is technically impossible to remove bio-fouling organisms from all the coral fragments, and therefore they are left untouched. Most of these fragments not only grow as fast as before, but it has become evident that the vast majority compete successfully with algae that settle on the same plates, contrary to the prediction made by L&KW (2003).

Another concern raised by L&KW (2003) is the consequence of fast growth rates on coral colonies situated near the fish farms. They claim that the skeletons of live coral colonies there 'have significantly higher levels of infestation by boring organisms' (p. 301); to support their argument they cite Wielgus (2003) which is, yet again, irrelevant to our study, since it was conducted in a different habitat. We have recently surveyed the *Stylophora, Acropora* and *Pocillopora* colonies occurring naturally underneath the fish cages (Fig. 1C,F) and found large and 'healthy' looking corals with neither dead branches nor heavy boring-organism infestation, as recorded at other localities near Eilat where coral species are stressed (Wielgus 2003). It is also ignored in L&KW's (2003) critique that at one of these stressed sites, Wielgus (2003) recorded 19 coral genera, as compared to 14–15 genera in 3 'less stressed' sites further south, finding there the highest genus diversity of the 5 sites studied at Eilat. Their critique, therefore, simplifies complicated ecological situations and depicts selectively only 'favorable' research outcomes.

L&KW (2003) also hypothesize that finding more female gonads per polyp in corals residing near the fish farm is due to reduced fertilization rates that caused unfertilized oocytes to remain and increase in size instead of developing into the planula larva stage. This is an unsubstantiated statement. Is it so difficult to conceive that 'fed corals are happy corals' (cf. Houlbrèque et al. 2003) and that the higher reproductive output recorded by Bongiorni et al. (2003a) is the outcome of improved nutrition provided via fish excretion?

L&KW (2003) criticize the approach used by Bongiorni et al. (2003a) to study *S. pistillata* reproductive effort through histological sections, by claiming that 'The most important parameter in assessing reproductive effort is the number of planulae produced by this brooding coral' (p. 302). We are pleased to see that L&KW (2003) adopt in their own study our exact methodology and time frame: 'Over the next 2 consecutive years, histological studies of the reproductive effort of the experimental corals showed…' (p. 302). Other assertions by L&KW (2003), such as, 'we found that polyps from the IUI colonies contained significantly more…' (p. 302) are scientifically impossible to address, since their data are neither published nor available.

What next? It is 'politically correct' to 'blame' the deterioration of the Eilat reefs on nutrient effluents released from fish farms. This deflects public and scientific attention from the most likely detrimental cause: the uncontrolled development of tourism. Jameson et al. (1999) surveyed diving sites along the Egyptian Red Sea (far away from the fish farms at Eilat) and recorded the significant effects of recreational activities on the reef. At the most popular Egyptian site, Ras Mohammed National Park, 20000 dives per year have damaged >17% of the coral colonies. With 250000 to 300000 dives yr^{-1} ('the highest known frequency of recreational diving on a small reef area anywhere in the world': Zakai & Chadwick-Furman 2002, p. 184), the coral reef at Eilat is exposed to far greater impairments. When surveying the behaviour of SCUBA divers on the coral reefs of Eilat on the basis of 1 h as average diving time, Zakai & Chadwick-Furman (2002) found that ca. 400000 coral colonies per year are being broken! In addition, divers' activities resulted in >2 million cases per year of sediment deployment or fin contacts, >1.4 million cases per year of hand contacts, and about 1 million cases per year of coral–SCUBA gear contacts. The impact on the reef at Eilat is 'ecologically unsustainable' (Zakai & Chadwick-Furman 2002, p 184). This is merely one facet of the impact of tourism. In addition, local agriculture, rampant coastal and municipal development, sewage spillage and many other human activities contribute to the deterioration of the reef environment. In contrast to the popular belief, Glassom (2002) recorded higher recruitment rates at the Eilat reef, as compared to most other reefs worldwide, revealing the resilience of these reefs.

We uphold our suggestion that the fish farms off Eilat are not the major cause of reef decline, and submit that a closer look at the impact of tourism on the reef is warranted. The reefs of Eilat are indeed facing devastation, but key experiments on environmental hazards are missing. In view of this conspicuous shortage of knowledge, we hope that Loya and Kramarsky-Winter would join us in the iconoclasm of the trendy tenet for the cause of reef degradation in Eilat, and participate in increasing scientific efforts for the benefit of our reefs.

Note: Fig. 1 in L&KW (2003) was added in proof, and depicts natural events (Fig. 1B–D) and selected unpublished data (Fig. 1E,F) not related to our study.

LITERATURE CITED

Ableson A, Shteinman B, Fine M, Koganovsky S (1999) Mass transport from pollution sources to remote coral reefs in Eilat (Gulf of Aqaba, Red Sea). Mar Pollut Bull 38:25–29

Angel DL, Krost P, Gordin H (1995) Benthic implications of net cage aquaculture in the oligotrophic Gulf of Aqaba. Eur Aquacult Soc Spec Publ 25:129–173

Atkinson MJ, Carlson B, Crow GL (1995) Coral growth in high-nutrient, low pH seawater: a case study of corals cultured at the Waikiki Aquarium, Honolulu, Hawaii. Coral Reefs 14:215–223

Atkinson MJ, Birk Y, Rosenthal H (2001) Evaluating pollution in the Gulf of Eilat. Report for the Israeli Ministries of Infrastructure, Environment and Agriculture, Jerusalem

Beveridge MCM (1996) Cage aquaculture. Fishing News Books, Oxford

Bongiorni L, Shafir S, Angel D, Rinkevich B (2003a) Survival, growth and reproduction of two hermatypic corals subjected to *in situ* fish farm nutrient enrichment. Mar Ecol Prog Ser 253:137–144

Bongiorni L, Shafir S, Rinkevich B (2003b) Effects of particulate matter released by a fish farm (Eilat, Red Sea) on survival and growth of *Stylophora pistillata* coral nubbins. Mar Pollut Bull 46:1120–1124

Epstein N, Bak RPM, Rinkevich B (1999) Implementation of a small-scale 'no use zone' policy in a reef ecosystem: Eilat's reef lagoon six years later. Coral Reefs 18:327–332

Epstein N, Bak RPM, Rinkevich B (2001) Strategies for gardening denuded coral reef areas: the applicability of using different types of coral material for reef restoration. Restor Ecol 9:432–442

Fishelson L (1995) Eilat (Gulf of Aqaba) littoral: life on the red line of biodegradation. Israel J Zool 41:43–55

Glassom D (2002) Reproductive ecology and reef dynamics: a study on corals at Eilat, northern Red Sea. PhD thesis, Bar-Ilan University, Ramat Gan

Gordin H (2000) Environmental effects of mariculture in the Gulf of Eilat. Evol Env 6:124–127 (In Hebrew)

Houlbrèque F, Tambutté E, Ferrier-Pagès C (2003) Hungry corals are not happy corals. Abstract, 7th Int Conf Coelenterate Biol, 6–11 July, Lawrence, KS

Jameson SC, Ammar MSA, Saadalla E, Mostafa HM, Riegel B (1999) A coral damage index and its application to diving sites in the Egyptian Red Sea. Coral Reefs 18:333–339

Katz T, Herut B, Angel DL (2002) Grey mullets ameliorate organically enriched sediments below a fish farm in the oligotrophic Gulf of Aqaba (Red Sea). Mar Ecol Prog Ser 234:205–214

Lieberman T, Genin A, Loya Y (1995) Effects on growth and reproduction of the coral *Stylophora pistillata* by the mutualistic damselfish *Dascyllus marginatus*. Mar Biol 121:741–746

Loya Y (1990) Changes in a Red Sea coral community structure: a long-term case history study. In: Woodwell GM (ed) The earth in transition: patterns and processes of biotic impoverishment. Cambridge University Press, Cambridge, p 369–383

Loya Y (2000) Homage to *Stylophora pistillata*: an important coral in coral reef research. Abstract, 9th Int Coral Reef Symp, October 23–27, Bali

Loya Y, *In situ* eutrophication caused by fish farms in the northern Gulf of Eilat (Aqaba) is beneficial for its coral reefs: a critique. Mar Ecol Prog Ser 261:299–303

Lupatsch I. Kissil GW (1998) Predicting aquaculture waste from gilthead seabream (*Sparus aurata*) culture using a nutritional approach. Aquat Living Resour 11:265–268

Meyer JL, Shultz ET (1985a) Migrating haemulid fishes as a source of nutrients and organic matter on coral reefs. Limnol Oceanogr 30:146–156

Meyer JL, Shultz ET (1985b) Tissue condition and growth rate of corals associated with schooling fish. Limnol Oceanogr 30:157–166

Pearson TH, Black KD (2001) The environmental impacts of marine fish cage culture. In: Black KD (ed) Environmental impacts of aquaculture. Sheffield Academic Press, Sheffield, p 1–31

Rinkevich B (1995) Restoration strategies for coral reefs damaged by recreational activities: the use of sexual and asexual recruits. Restor Ecol 3:241–251

Rinkevich B, Loya Y (1979) The reproduction of the Red Sea coral *Stylophora pistillata*. II. Synchronization in breeding and seasonality of planula shedding. Mar Ecol Prog Ser 1:145–152

Rinkevich B, Loya Y (1987) Variability in the patterns of sexual reproduction of the coral S*tylophora pistillata* at Eilat, Red Sea: a long-term study. Biol Bull 173:474–488

Steven DL, Broadbent AD (1997) Growth and metabolic responses of *Acropora palifera* to long-term nutrient enrichment. Proc 8th Int Coral Reef Symp, Panama, 1:867–872

Wielgus J (2003) Estimation of ecological and economic damage of anthropogenic coral reef stressors in the Gulf of Eilat. PhD thesis, Bar-Ilan University, Ramat Gan

Zakai D, Chadwick-Furman NE (2002) Impact of intensive recreational diving on reef corals at Eilat, Northern Red Sea. Biol Conserv 105:179–187

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