Hajime Kayanne et al. (1) investigate diurnal changes in CO₂ partial pressure (Pₜ₀) and community metabolism on Shiraho reef (Ishigaki Island, Japan) and conclude that “reefs might serve as a sink, not a source, for atmospheric CO₂,” because of high net organic production relative to net calcification (Table 1). This conclusion is at odds with recent reports (2, 3, 4) and data (5) suggesting that reefs are net sources of atmospheric CO₂, albeit of limited importance in the current carbon budget. Furthermore, it is well established that the value of gross primary production (P₀) is close to that of respiration (R) in most coral reef flats, and that the net production (Pₙ) is around zero (6). One would expect some reefs to depart from this general trend, but consideration of currents and community distributions suggests that the data in the report by Kayanne et al. (1) represent neither the whole Shiraho reef nor all coral reefs.

The reef flat at Shiraho comprises five different benthic communities and is under strong tidal influence (1, 7). Because Kayanne et al. measured Pₜ₀ at a single station over several days, the water masses at hand had different origins and crossed different communities depending on the direction of the current. Therefore, the observed changes in Pₜ₀ likely did not result from the metabolic activity of the entire reef flat but, rather, from a variable combination of the communities located around the study site.

Also, Kayanne et al. calculated mean daytime and nighttime reef water Pₜ₀, with the use of a predictive regression equation

\[ Pₜ₀ = 352 - 0.13 (I) \]

where I is light intensity, N = 13, and \( r^2 = 0.41 \). Our computation indicates that the local oceanic Pₜ₀ (322 μatm) lies within the 95% confidence intervals for both values (daytime = 279 ± 103 μatm and nighttime = 352 ± 97 μatm), which prevents us from drawing any conclusion with regard to source versus sink.

Kayanne et al. measured community metabolism during slack-water periods. Kinsey (8, p. 439) pointed out that this technique provides metabolic parameters which are “related to a very precisely defined community because of the limited mixing which occurs with water from adjacent zones.” Suzuki et al. (9) also used this technique and found Pₙ/R = 1.4 at Shiraho reef (Table 1), a value much higher than those commonly found on reef flats [Pₙ/R = 1.0 ± 0.1, that is, Pₙ ≈ 0 (6)]. The study (1) seems to be located in an area dominated by algal turf and brown algae, which may explain the relatively high value for Pₙ. Nakamori et al. (7) investigated the metabolism of various communities on the same reef and estimated production and calcification for the whole system. They found Pₙ to be much less (×0.217) than the value reported by Kayanne et al. (1). The localized observations of Kayanne et al. (1) confirm well-known spatial and temporal variations of metabolic processes within reef ecosystems.

Calculations based on a recent model (4), and estimates of the larger community metabolism from Nakamori et al. (7), predict that the Shiraho reef was, at the time of measurement, a net source of CO₂ for the atmosphere (with an evasion of 12 mmol CO₂ m⁻² d⁻¹).

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Kayanne et al. (1) interpret their observations as evidence that coral reefs may be net sinks for atmospheric CO₂, but specific and general evidence counter this interpretation.

Kühlmann (2, p. 19) described the Ishigaki Island reefs as “greatly stressed by human activity” and affected by siltation and agricultural chemicals. Anthropogenic stress increases the ratio of organic production to calcification, and the behavior of stressed or transitional reef communities is not representative of normal coral reef metabolism (3, 4).

Estimates of unstressed source-sink relationships can be derived from reef sediment characteristics. A carbon sink relevant to climate would have to take up atmospheric CO₂ and sequester it from atmospheric exchange for centuries or millennia. Reef sediments provide an integrated view of the stored products of past reef metabolism. In a “pure” coral reef environment where organic-inorganic fractionation and nonreef contributions to sediments are negligible, a reef that is an atmospheric CO₂ sink would have to deposit sediments that average more than 12 weight % organic matter or more than 6 weight % organic C [if one assumes 0.6 mol of CO₂ evolved per mole of CaCO₃ precipitated (5); one mole of CO₂ consumed per mole of CH₂O photosynthesized; and organic matter dry weight ≈50% organic C]. However, organic C typically constitutes less than 1% of the dry weight of carbonate-dominated reef sediments (6). Biogenic carbonate skeletons normally contain only a few percent organic matter by weight (7).

Reef sediments thus fall far short of the composition required for a CO₂ sink, which indicates that normal reef metabolism has probably been a net CO₂ source during the recent geologic past. A reservoir of high-organic reef sediments that contained enough organic C to transform the system into a sink would have to be unrealistically rich in organic material in order to make up for the low organic C content of most sediment. Export of dissolved as opposed to particulate organic C (DOC/POC) from reef to ocean or export by downslope sediment transport would not provide a credible mechanism for differential sequestration of organic C that could account for the discrepancy.

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**Table 1. Available data on community metabolism of the Shiraho coral reef (Ishigaki Island, Japan).**

<table>
<thead>
<tr>
<th>Source</th>
<th>P₀</th>
<th>R</th>
<th>Pₙ</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. Nakamori et al., 1992 (7)</td>
<td>302</td>
<td>278</td>
<td>24</td>
<td>60</td>
</tr>
<tr>
<td>H. Kayanne et al., 1995 (1)</td>
<td>—</td>
<td>—</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>A. Suzuki et al., in press (9)</td>
<td>460</td>
<td>320</td>
<td>130</td>
<td>160</td>
</tr>
</tbody>
</table>

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**Table 2.**
Loss of coral reef habitat is often associated with transitions to benthic communities dominated by noncalcareaeous benthos (4, 8). The results of Kayanne et al. (1) reveal metabolic measures to be sensitive indicators of reef health (9), but the findings more likely reflect the condition of the local sampling site than the normal behavior of healthy reef communities.

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Response: We are grateful for the comments we have received about our report (1). They bring up points that we did not fully discuss in the report.

Gattuso et al. stressed that our measured values of productions are remote from the common reef production rate. His reference of "standard performance" of P/R = 1.0 ± 0.1 (2). The standard performance of coral reefs are a first-order estimation; it is not a precise indicator with regard to the CO₂ sink versus source problem. The threshold between CO₂ sink or source is very sensitive to precise organic and calcium carbonate production rates, and thus direct measurement of PCO₂ changes provides better information. We should obtain more direct measurements of PCO₂ changes to better address the reef sink versus source problem. Moreover, the idea that P/R is close to 1 is partly based on the fact that the tropical ocean is depleted in nutrients for supporting net organic production. However, as we stated in our report, recent studies have revealed the importance of nitrogen fixation in coral reefs, which provides new nutrients to coral reefs.

As stated in our report, different reef zones might act differently as CO₂ fluxes. The whole-reef production values in the reef—acts as a sink of CO₂. However, we cannot comment on the statement “export of DOC/POC from reef to ocean or export by downslope sediment transport would not provide a credible mechanism for differential sequestration” without conducting actual measurement of these fluxes.

Gattuso et al. also question the representativeness of our study site. We agree that our report did not provide adequate explanation of which part of the reef community metabolism our measurements represented in relation to the flow regime. During high tides, our current measurements showed that water comes steadily from north-northeast with a current speed over 5 cm s⁻¹ [figure 2 in our report (1)]. This water comes from the outer ocean over the reef crest north of the study site and runs over turf algae and living coral communities [figure 1B in (1)]. During low tide stagnant periods, we observed a slow current with an average of 3 to 4 cm s⁻¹, which mixed well the water around the study site surrounded by living coral patches. Therefore, our measurements likely show the metabolism of corals and algae on the reef flat at Shiraho. We are carrying out further measurements of currents at other points to clarify the flow regime.

Gattuso et al. also point out that errors of the mean daytime and nighttime PCO₂ values overlapped with the offshore value. The purpose of this estimation was to convert the visually conspicuous relations of PCO₂ and light intensity into a quantified discussion, but the data were too small to make a statistically rigorous conclusion; we agree that we should obtain more data in the future. However, we would like to point out that the light intensity in March, when we made the observations and estimations, is relatively low compared to other months in this island (mean light intensities are 552 and 864 μmol m⁻² s⁻¹ in March and in August, respectively). Productions depend primarily on light intensity, and we have obtained higher productions in August.

Gattuso et al. point out the discrepancy between our estimates of production and those of Nakamori et al. (9). Their estimates of organic production and calcium carbonate production, however, depend only on one daytime (4-hour) set and one nighttime (3.5-hour) set of measurements of pH and alkalinity changes. From these data, they estimated the whole day net production on the basis of the tentative assumption that the daytime length is 7.5 hours. After the publication of their study, we have accumulated numerous measurements on organic production and calcium carbonate production of Shiraho reef and have related them with actual change in light intensity. In addition to the conventional pH-alkalinity method to estimate the productions, we computed them from more measured alkalinity and PCO₂ changes, six times through PCO₂ observation.
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