APPENDIX B: *HYDRODYNAMIC MEASUREMENTS AND ANALYSES*

The five study sites in our model lagoon ecosystem experienced persistent cross-reef flow in the offshore to onshore direction due to the momentum input from offshore waves. An Acoustic Doppler Current Profiler (ADCP) was deployed at each of the five sites along this gradient. Each instrument was mounted to a flat PVC plate secured to the underlying coral pavement using stainless steel bolts epoxied into the substrate. All five ADCPs were deployed simultaneously and continuously for 56 days (December 11, 2006 to February 5, 2007) but our analyses are based on data collected over the two-week period when the coral growth and predation measurements were made (December 13-27, 2006). The ADCPs were programmed to burst sample every hour at 2 Hz, collecting and recording 2048 velocity measurements of the bottom 0.75-m of the water column.

The current profilers measured three velocity components (*u*, *v*, and *w*) and prior to further analyses we examined the relative contributions of each component. At each site the velocity data were rotated into the principal axes of flow direction (Emery and Thomson 2001), corresponding to *across-reef*, *along-reef*, and *vertical* velocities. At all sites, the across-reef velocity component contributed >95% of the total velocity (Fig. B1). The strong directional dominance is due to the simple geometry of the reef flat, small astronomical tides, and since refraction of offshore waves causes the incident wave crests to be nearly shore parallel prior to breaking. Moreover, the offshore wave motions that propagate through to the back reef behave as “shallow water” waves (where the wavelength is large compared to the water depth, and thus have nearly flat oscillatory velocities rather than the circular wave orbits that “deep water” waves exhibit). In the interest of conciseness and to more clearly illustrate the dominant physical forcing mechanism, we only used the *across-reef* velocity component in the calculations below. However we note that water velocities in other reef systems may be more equally partitioned between u, v, and w. In those cases, other velocity metrics that combine these components (e.g., u_{rms}) may be more appropriate.

Means and standard deviations were computed at each site for the duration of the study (Fig. B2). The record captured a range of conditions, but show persistent mean across-reef velocities with standard deviations in velocity of comparable magnitude. As water moves across the back reef, flow is disrupted by coral colonies across a range of sizes creating turbulent eddies which can also be transported shoreward in the cross-reef flow (Falter et al. 2007). Given a reef flat depth (H) of 2 m, the scale of the largest turbulent eddies (L) is about 1 m. Assuming a typical current velocity (U) of 10 cm s^{-1} would imply a turbulent eddy turnover time scale ($T_{turb} \sim L/U$) of 10 s. Since a typical surface wave period (T_{wave}) in Moorea is also on the order of 10 s, the time-scales of waves and turbulence overlap. Thus, while the mean current velocity is readily quantified, there is a continuum of temporal and spatial scales within the flow such that labeling observed velocity fluctuations as “waves” or “turbulence” can be problematic (Trowbridge 1998).

Since the time-scales of waves and turbulence overlap at our field site we did not attempt to make a distinction between the two. Instead, the data were partitioned into a set of frequency bands, each representing different time-scales of across-reef velocity variability on the reef. For each hourly burst of 2048 2Hz velocity measurements, power spectra were computed using Welch’s averaged periodogram method (Emery and Thomson 2001) using a Hann window with 50% overlap. Hourly spectra were then ensemble averaged over the entire record (Fig. B3A). The total variance in the cross-reef velocity was obtained by integrating the area under the mean velocity spectrum, which we used to represent the total range of motions that the corals and fish experienced during the experiment. To better understand which types of water velocity fluctuations produced by waves and turbulence most affected coral growth and corallivory, the variance was further broken down (by piecewise integration of the spectra; see below) into three frequency bands: "low", "medium", and "high", which roughly correspond to water motions in the infra gravity wave band (90-sec to 30-sec), the wave band (30-sec to 4-sec), and the frequency range associated with short waves and the largest scale turbulence (4-sec to 1-sec) on the shallow reef flat. This approach has been previously employed on wave-driven flow on reefs (Hench and Rosman 2013) and provides a useful proxy for measuring combined motion created by waves and turbulent eddies. Turbulent fluctuations on coral reefs occur at time scales less than 1-sec (Hench and Rosman 2013), but these were not resolved by our measurements.

To obtain a proxy to represent water velocity fluctuations at different time scales, the contributions to the total variance from low ($0.01 < f < 0.033$ Hz), medium ($0.033 < f < 0.25$ Hz), and high ($0.25 < f < 1$ Hz) frequency velocity fluctuations were computed by integrating those regions of the spectrum:

$$\mathrm{var}_{u,f_1 f_2} = \int_{f_1}^{f_2} S_{uu}(f)\,df$$

where S_{uu} is the power spectrum of the cross-reef velocity, f is frequency, and $\mathrm{var}_{u,f_1 f_2}$ is the velocity variance in the range from frequency f_1 to f_2. If the integral is evaluated over to the entire spectrum, then $\mathrm{var}_{u,f_1 f_2}$ is equal to the total variance. The integrals were evaluated numerically using a trapezoid rule. The variance for each frequency band was then converted to standard deviation, which represents the deviations in velocity from the mean flow for a given frequency band:

$$\sigma_{u,f_1 f_2} = \sqrt{\mathrm{var}_{u,f_1 f_2}}$$

with standard deviations designated as $\sigma_{u,low}$, $\sigma_{u,med}$, and $\sigma_{u,high}$, each having units of cm s^{-1} (Fig. B3B).

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FIGURE CAPTIONS

Figure B1. Time series of water velocity components measured at five back reef sites (L1- L5). The three velocity components (*u*, *v*, and *w*) have been rotated into the principal axes of flow direction (Emery and Thomson 2001), corresponding to *across-reef*, *along-reef*, and *vertical* velocities.

Figure B2. Time series of water velocity measurements at five back reef sites (L1- L5). (A) Mean velocities computed from hourly bursts of 2048 measurements recorded at 2 Hz. (B) Hourly standard deviation of velocities about the mean, computed from hourly burst samples.

Figure B3. Variability in across-reef velocities at each of the cross-reef coral transplant sites. (A) Power spectra computed from cross-reef velocities. Individual spectra were computed for each hourly burst, and averaged over the three-week record. (B) Velocity standard deviations (σ_u) derived from power spectra shown in (A). The σ_u values describing different time scales for velocity fluctuations were computed by piecewise integration of power spectrum for each frequency band (low-, medium-, and high-frequency).

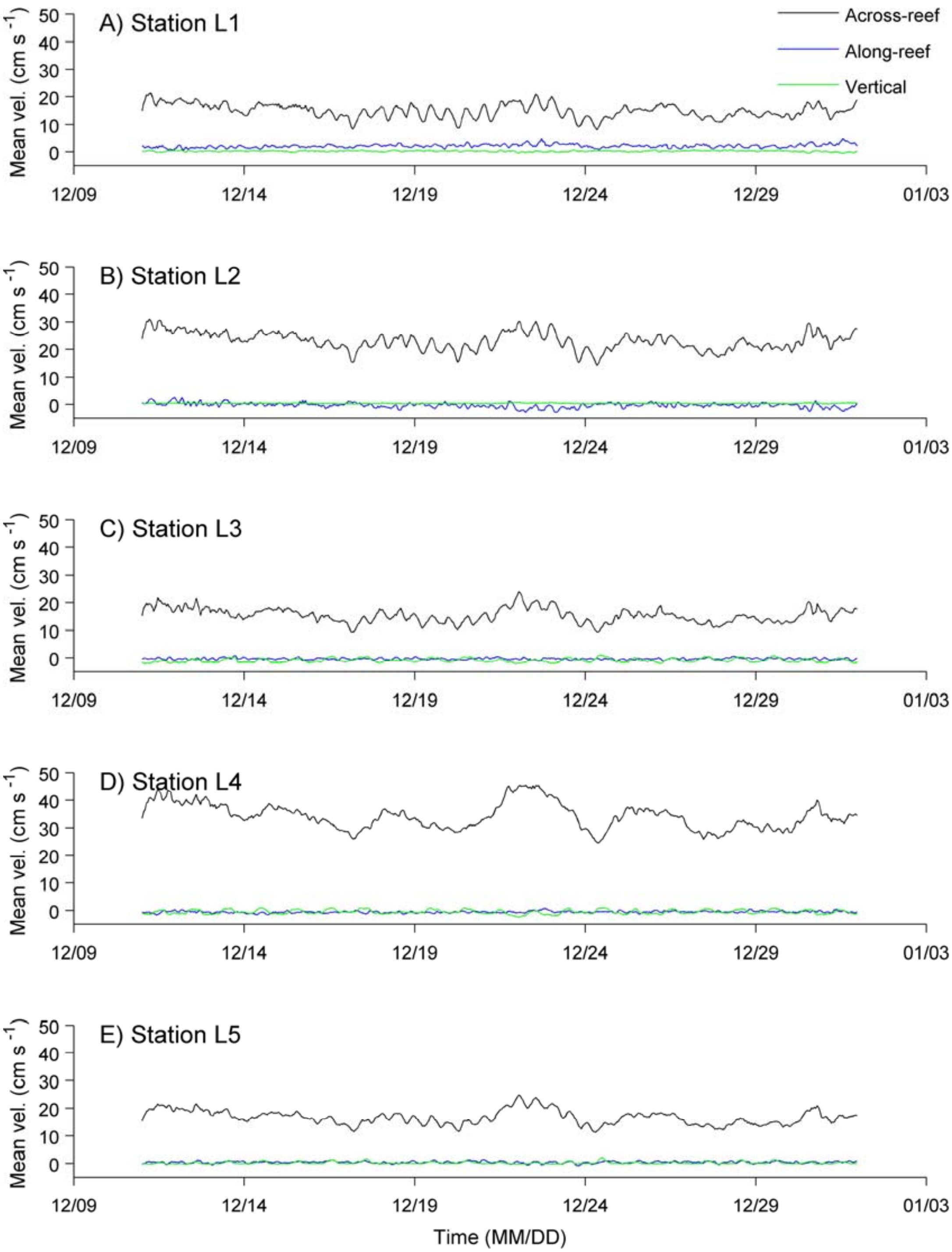
A) Station L1
B) Station L2
C) Station L3
D) Station L4
E) Station L5
Across-reef
Along-reef
Vertical
Mean vel. (cm s $^{-1}$)
50
40
30
20
10
0
12/09
12/14
12/19
12/24
12/29
01/03
Time (MM/DD)

Figure B1

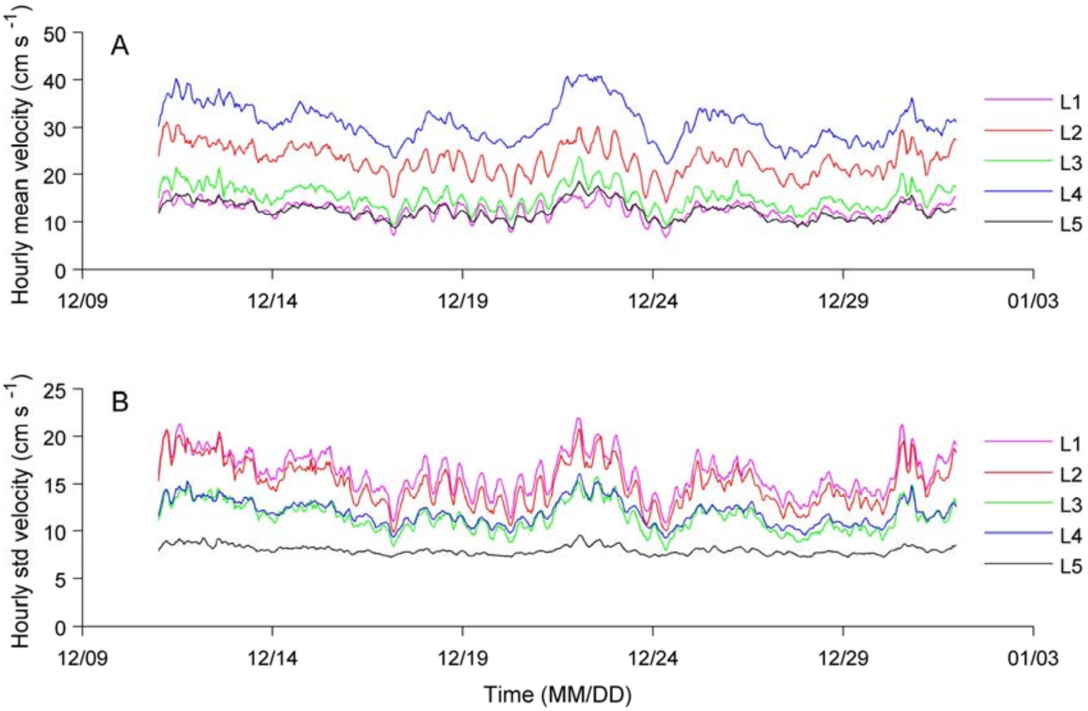
A
B
Hourly mean velocity (cm s -1)
Hourly std velocity (cm s -1)
50
40
30
20
10
0
25
20
15
10
5
0
12/09
12/14
12/19
12/24
12/29
01/03
Time (MM/DD)
L1
L2
L3
L4
L5

Figure B2

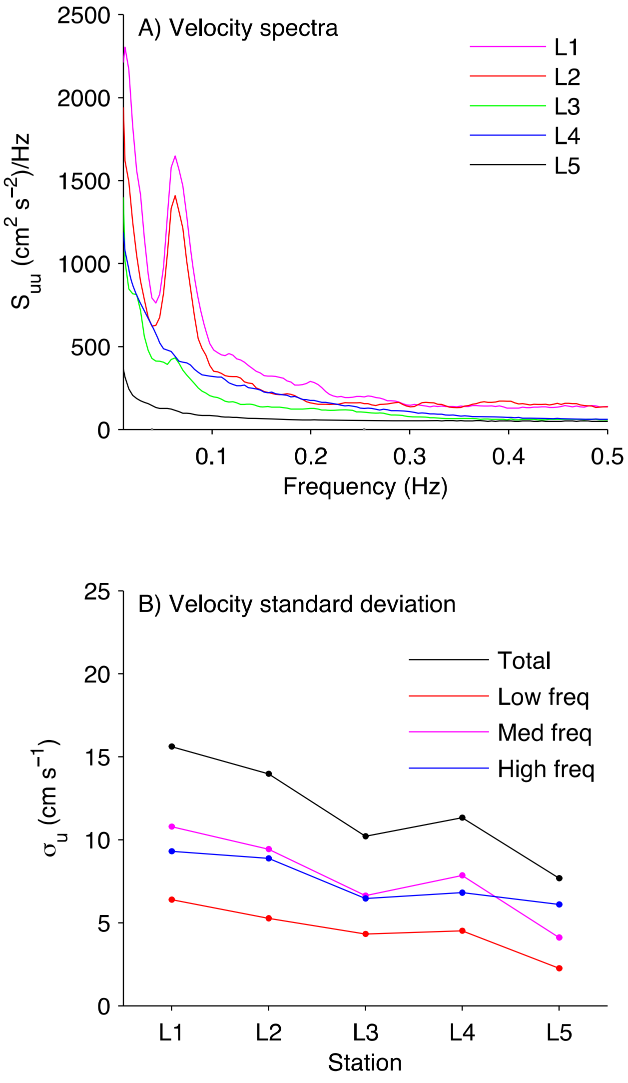
A) Velocity spectra
L1
L2
L3
L4
L5
S_{uu} (cm^2 s^{-2})/Hz
2500
2000
1500
1000
500
0
0.1
0.2
0.3
0.4
0.5
Frequency (Hz)
B) Velocity standard deviation
Total
Low freq
Med freq
High freq
σ_u (cm s^{-1})
25
20
15
10
5
0
L1
L2
L3
L4
L5
Station

Figure B3