CHAPTER 20

Causes of Turbidity on the Moloka‘i Reef Flat and Resulting Sediment-Transport Patterns

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Turbidity and sedimentation are generally recognized as important factors that can impair coral health (Acevedo and others, 1989; Fortes, 2000; Rogers, 1990; Buddemeier and Hopley, 1988). Turbidity on reefs is a difficult parameter to characterize, because it concerns not only the amount of sediment suspended in the overlying water column (suspended-sediment concentration), but also the frequency and duration of resuspension and the types of particles in suspension. In general, the physical environment controls the factors that regulate turbidity on reefs. Four important factors that control the sedimentary regime are tides, waves, currents, and amount of available sediment, all of which vary over time on hourly, daily, seasonal, and longer scales.

Between January 2000 and August 2002, we studied these processes and their influence on turbidity on the Moloka‘i reef flat (fig. 1), a topographically rough, nearly horizontal surface ranging from 0 to 2 m (0 to 6.5 ft) in depth, that extends almost 1 km (0.6 mi) from the shoreline outward to the reef crest. The reef crest itself is a shallow, irregular barrier between the reef flat and the open ocean. Our studies identified a suite of processes and their temporal changes, using a small instrumented tripod (ReefProbe, fig. 2) deployed at 1-m (3.3 ft) water depth approximately midway across the reef flat. The instruments collected a 2-year record of water-surface elevation, water properties (temperature and salinity), currents (due to waves, tides, and winds), and suspended-sediment concentration. To complement the single-point time-series data, in May and August 2002 we used a portable instrument package (Backpack, fig. 3) to measure currents and water properties for a few minutes at multiple sites along transects spanning the reef flat and reef crest between One Ali‘i Park and Kaunakakai Wharf (fig. 1).

In this chapter, we summarize the results of these investigations to illustrate the processes that contribute to turbidity on the Moloka‘i reef flat and the resulting sediment-transport patterns. For a more detailed analysis, see reports by Ogston and others (2004), Storlazzi and others (2004), and Presto and others (2006).

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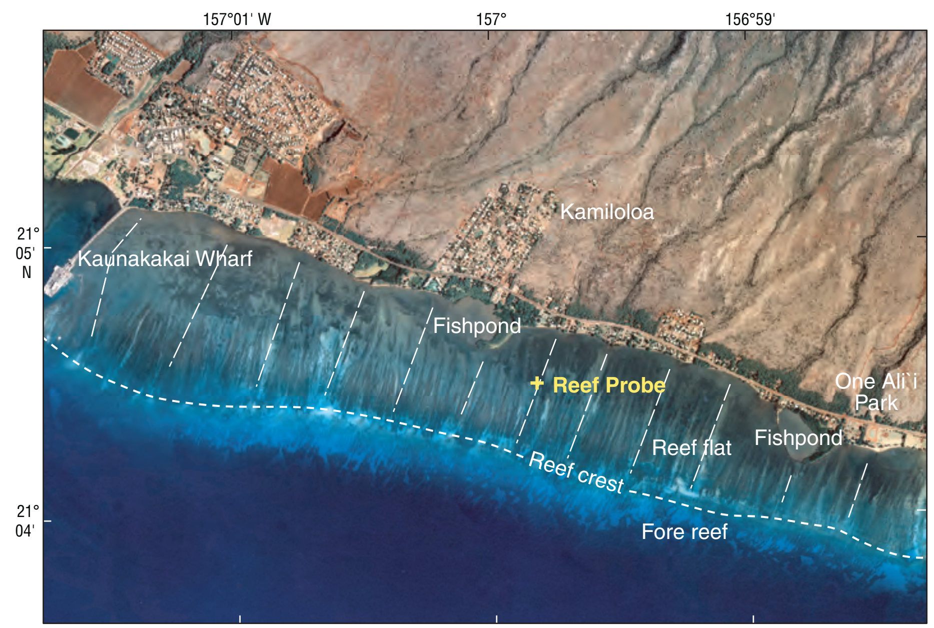

Figure 1. Moloka‘i reef flat, showing general location of study area. Data were obtained from two sources: (1) a small instrumented tripod, the ReefProbe, placed on the mid reef flat collected time-series data for almost 2 years; and (2) a portable instrument package, the Backpack, was used to collect measurements at multiple sites along transects (dashed lines) during high and low tides when trade winds were active.

Transport of Sediment and Water on the Reef Flat

Typical Environmental Conditions

The amount of sediment suspended in the water column and how rapidly sediment transport occurs depend on environmental conditions related to the weather. The most conspicuous feature of the weather pattern in the tropical Pacific Ocean is the persistent trade winds that blow generally northeast to southwest. Their effect is greatest across Hawai‘i during the trade-wind season (May-November), when they are prevalent 80–95 percent of the time; during the non-trade-wind season (November-May), trade winds still blow across the islands much of the time, though with decreased frequency. Storms bring heavy rains and strong winds to the Hawaiian Islands, generally during the non-trade-wind season. In particular, Kona storms from the south generate large waves offshore and rainfall that brings freshwater and sediment from the uplands to the reef on southern Moloka‘i. Storms over the open ocean to the south of the Hawaiian Islands generate large waves that can propagate as swell to the south coast of Moloka‘i.

To illustrate the effect of environmental conditions over the year, we classified the data from the ReefProbe according to the four environmental conditions that occur most frequently on the Moloka‘i reef flat: (1) trade winds, (2) storms, (3) swell, or (4) light winds of varying direction without swell (referred to simply as light winds). We compared the magnitude, direction, and duration of winds, as well as offshore wave conditions, during the period May 2001–May 2002 to evaluate which environmental condition dominated. We divided the periods over which each of these environmental conditions occurs by season (fig. 4). For example, during the trade-wind season, the trade-winds environmental condition occurred 83 percent of the time, while the swell environmental condition occurred only 13 percent of

Figure 2. Time-series data on the Moloka‘i reef flat were obtained by using the ReefProbe deployed on the mid reef flat at 1-m (3.3 ft) water depth. The ReefProbe contained sensors that measured current (electromagnetic current meter), tidal elevation and wave height (pressure sensor), turbidity or suspended-sediment concentration (optical-backscatter sensor and transmissometer), and salinity and water temperature (conductivity and temperature sensor).

Instrument	Height above bed (cm)
Electromagnetic current meter	20
Pressure sensor	30
Optical-backscatter sensor	20
Transmissometer	20
Conductivity and temperature sensor	55

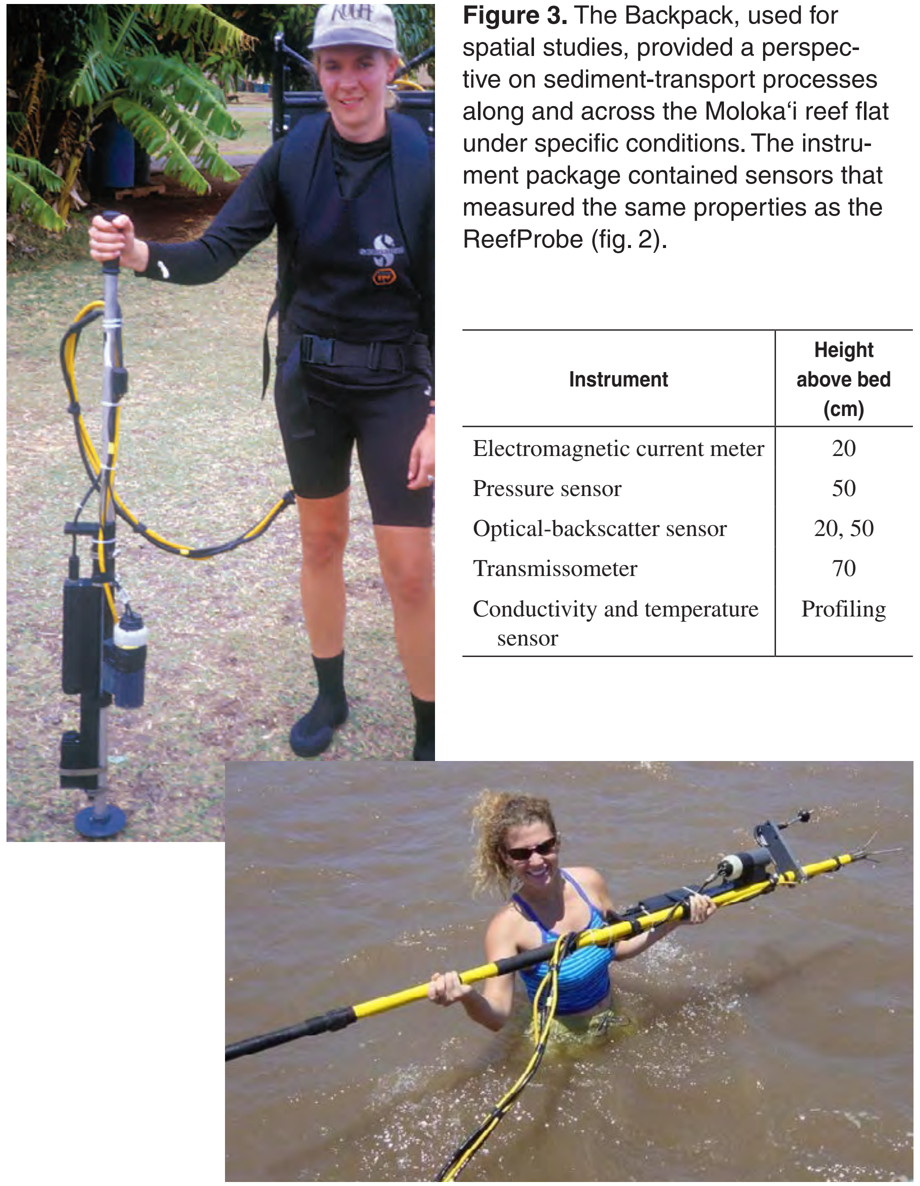

Figure 3. The Backpack, used for spatial studies, provided a perspective on sediment-transport processes along and across the Moloka‘i reef flat under specific conditions. The instrument package contained sensors that measured the same properties as the ReefProbe (fig. 2).

Instrument	Height above bed (cm)
Electromagnetic current meter	20
Pressure sensor	50
Optical-backscatter sensor	20, 50
Transmissometer	70
Conductivity and temperature sensor	Profiling

the time, although historically the swell environmental condition is much more frequent (Andrews and Pickard, 1990). Sheltering of the south-central coast of Moloka‘i by other islands (Maui and Lana‘i) partly accounts for the limited occurrence of the swell environmental contribution. The light-winds and storms environmental conditions rarely occurred (2 percent each).

During the non-trade-wind season, the light-winds environmental condition dominated the record (51 percent), while the trade-winds environmental condition occurred 37 percent of the time and the swell environmental condition 7 percent of the time. The storms environmental condition, which occurred only 5 percent of the time, was more prevalent during this season; a strong Kona storm struck Moloka‘i in November 2001, and smaller storms in December 2001 and January 2002. Although their strength varies, trade winds are the principal factor controlling sediment-transport processes on the Moloka‘i reef flat throughout the year, as is also true on other shallow-reef-flat environments where tidal currents and wave energy are relatively small (Pickard, 1986; Andrews and Pickard, 1990).

Currents and What Drives Them

Currents provide the stress (force per unit area) required to erode sediment from the seabed, create turbidity in the water column, and move the sediment elsewhere. On the Moloka‘i reef flat, currents are principally driven by winds, tides, and waves, each producing a different sediment-transport pattern.

Wind-Driven Currents

In general, wind-driven currents are the strongest unidirectional currents on the reef flat. Throughout the year, these currents are driven by trade winds (Nov. 16–26, 2000, figs. 5*A*, *B*), with flow toward the west and offshore at the ReefProbe site (fig. 1). The offshore component is not a persistent feature along the reef flat but can be explained by the position of the instruments relative to the orientation of the shoreline, as indicated in the Backpack studies discussed below. During the trade-winds environmental condition (fig. 5*A*), mean currents at the ReefProbe site were influenced by the speed and duration of the winds, resulting in a flow (>10 cm/s) to the west and slightly (~2 cm/s) offshore on the reef flat, regardless of tidal cycle. These currents occurred predominantly during the afternoon for approximately 70 percent of the year, during both the trade-wind and the non-trade-wind seasons. Under the light-winds environmental condition, slow (1–3 cm/s) currents were observed. During Kona storms, wind speeds were high, and currents were strong (>10 cm/s) but varied in direc-

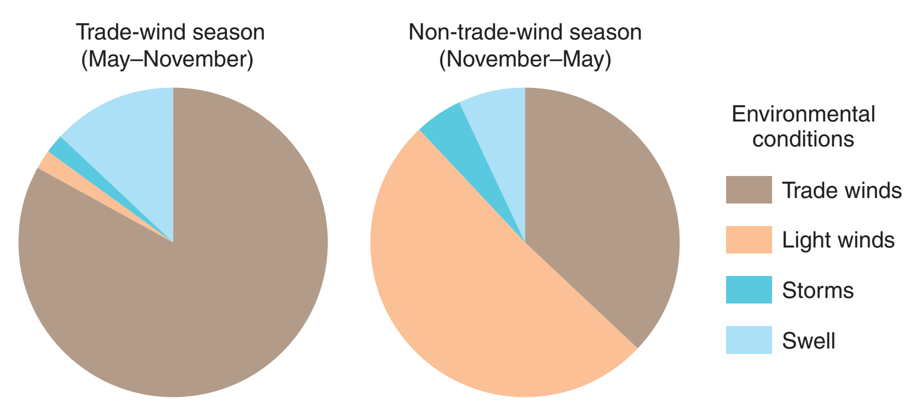

Figure 4. The distribution of four environmental conditions as measured by the ReefProbe on the Moloka‘i reef flat in a typical 1-year period (2001-2002) during trade-wind (May-November) and non-trade-wind (November-May) seasons. Environmental conditions were determined by examining the direction, speed, and duration of winds as measured by a sensor at the end of Kaunakakai Wharf, as well as by offshore wave conditions.

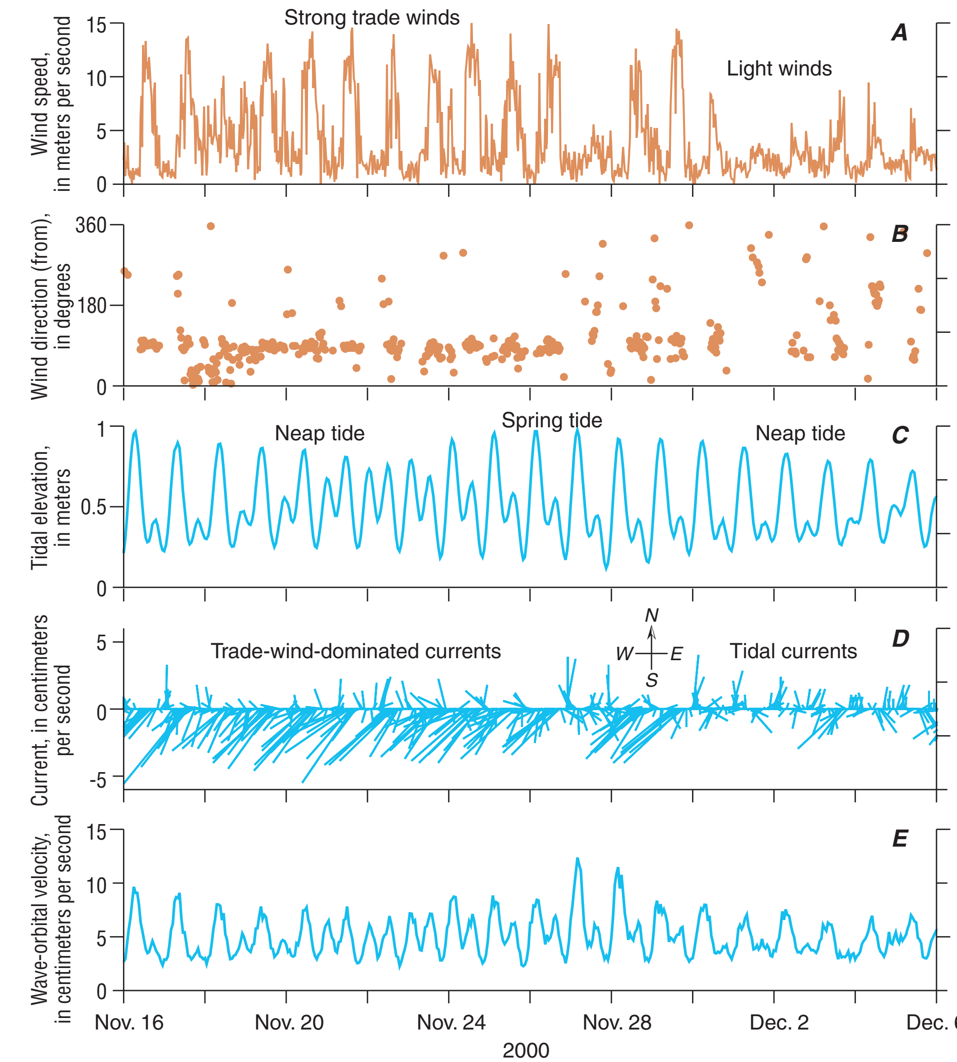

Figure 5. Environmental factors that contribute to sediment resuspension on the Moloka‘i reef flat include winds and tides. In this example from a time series in late November 2000, both trade-winds and light-winds environmental conditions are prevalent. During the trade-winds environmental condition, winds were strong and varied on a daily cycle, peaking in the afternoon (*A*), and were in a direction along the reef flat of ~110˚ (*B*). During light-winds environmental condition, the winds were weaker and had no specific direction. Tides are defined as microtidal and have a range of ~0.6 m (~2 ft) with a mixed semi-diurnal signal, varying on a fortnightly cycle between neap and spring tides (*C*). Response of water on the reef flat to trade winds and tides is complex. Trade winds generate along-reef currents with a small offshore component (*D*). During light winds, currents are weak and vary in direction. Winds also create waves on the sea surface that, in turn, cause wave-orbital motions at the sea bed; wave-orbital velocities (*E*) are controlled by both winds and water depth.

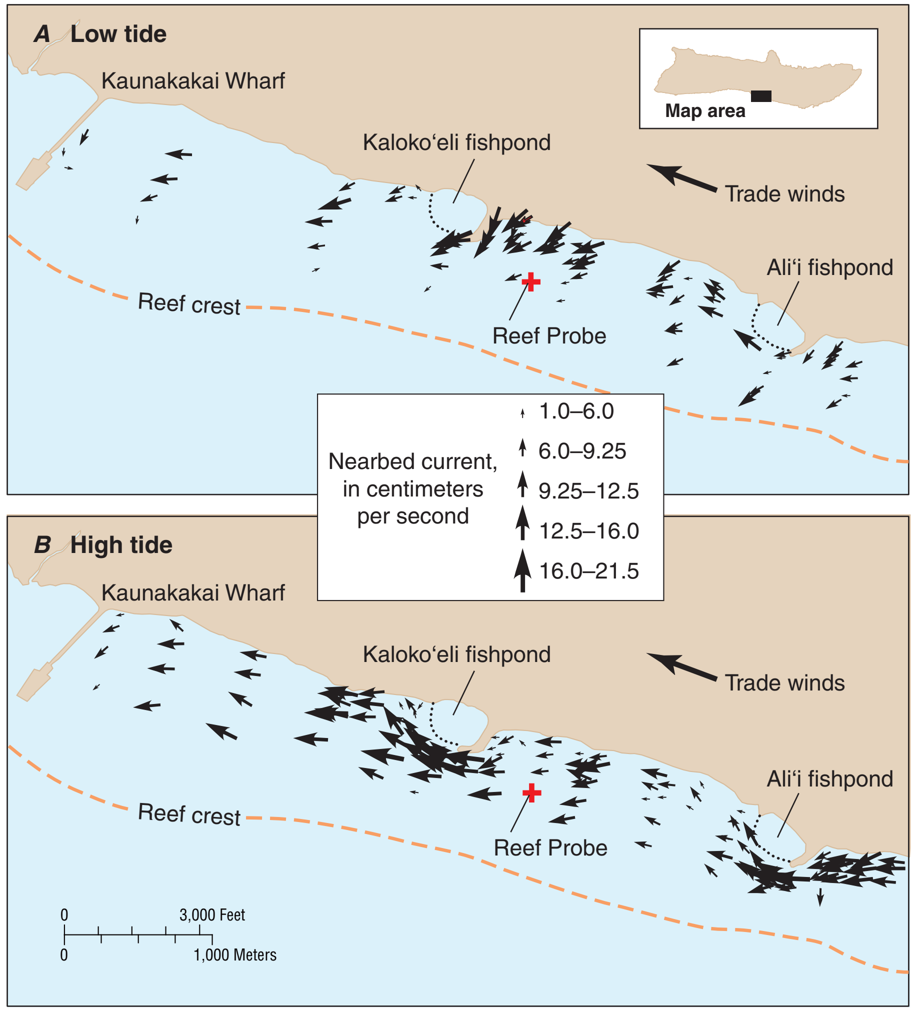

Figure 6. Observed nearbed (20 cm or 7.9 in above seabed) mean currents on the Moloka‘i reef flat during trade-winds environmental condition vary spatially and with tidal stage, as seen in measurements at low tide (*A*) and high tide (*B*). Dominant current direction is alongshore to the west at most survey points on the reef flat, with a slight offshore flow on the east (upwind) side of fishponds and onshore flow on the west (downwind) side at both tidal stages. All measurements were taken in <2-m (<6.6 ft) water depth.

tion as the storms passed, resulting in relatively minor net currents in both the alongshore and cross-shore directions. Under the swell environmental condition without the presence of trade winds, wind-driven currents were slow (<5 cm/s), with flow slightly eastward and shoreward.

From Backpack measurements, the pattern of trade-wind-driven currents over the Moloka‘i reef flat was observed to be strongly alongshore to the west, following the coastline in the direction of the trade winds, with a minor offshore component at the fishponds and wharf (fig. 6). Currents ranged from ~1 to 25 cm/s, faster where the reef flat is narrow and deep, slower over the broader, shallower parts of the reef flat, and significantly slower near Kaunakakai Wharf, indicating some stagnation of water against the wharf. A more detailed analysis of these data was presented by Presto and others (2006).

The spatial maps of currents in figure 6 allow an approximation of a water-transport rate for various sections of the Moloka‘i reef flat by moving water at the speed and in the direction measured at one transect to a position on the next transect. For a pathway approximately halfway across the reef flat, water is transported from One Ali‘i Park to the Kaunakakai Wharf (fig. 1), a distance of ~5 km (3.1 mi), in 13 hours (average speed, 9.7 cm/s) during high-tide and high-wind conditions. Typically the trade-winds environmental condition occurs, on average, 6 hours per day. Thus, a parcel of water flowing on the mid reef flat would take about 2 days to travel the 5 km from One Ali‘i Park to the wharf. For a pathway on the inner reef flat, water is transported during high tide and under the trade-winds environmental condition in about twice the time (>4 days), owing to the much slower currents (average speed 6.4 cm/s) and the slightly longer pathlength due to obstructions (fishponds). Because water moves slower on the inner reef flat than on the mid reef to outer reef flat and the distance traveled in the pathway around the fishponds is greater, alongshore flushing rates are significantly slower on the inner than on the outer reef flat.

Tidal Currents

The tides in Hawai‘i are defined as microtidal (tidal range, <2 m or 6.5 ft) and have a mixed semidiurnal signal, with two daily highs and lows, dominated by one extreme high and low each day (fig. 5*C*). Though small in range, the changing tidal elevation is particularly important because of its influence on waves and currents on the Moloka‘i reef flat, owing to the reef’s broad, shallow shape. The observed tidal range on the reef flat was typically 0.6 m (2 ft), with a maximum of ~1.0 m (3.3 ft). Although the tidal range off southern Moloka‘i is small relative to elsewhere in the world, it represents more than a doubling in water depth over much of the reef flat. This tidal variation over the reef flat is important for sediment resuspension and transport because wave heights are limited by the depth of water. At higher tides, the effects of offshore waves are greater on the reef flat because more offshore wave energy can be transferred through the deeper water over the reef crest. The greater water depth also allows for larger local wave formation on the reef flat.

Tidal currents on the reef flat have both semidiurnal (12.4 h) and diurnal (24.8 h) components. We evaluated data recorded at the ReefProbe site (fig. 1) during light-winds environmental conditions to estimate the tidal currents. Tidal currents on the reef flat were generally slow (3–5 cm/s) relative to wind-driven currents (max 15 cm/s; fig. 5*D*).

Wave-Orbital Currents

The waves on the Moloka‘i reef flat are small and result from offshore waves that propagate over the reef crest, from waves that are generated locally by wind stresses, or from some combination of both factors. Wave heights in the open North Pacific Ocean can be large because they are not influenced by the landmasses of the islands, and significant wave heights average 2 to 3 m (6.6 to 9.8 ft) throughout the year. The waves offshore of the south-central coast of Moloka‘i are much smaller, typically averaging ~0.5 m (~1.6 ft), because the surrounding islands of Lana‘i and Maui protect south Moloka‘i from large, open-ocean waves. As waves off the coast approach the reef, they significantly decrease in height as they

Figure 7. Photographs taken from an autonomous camera mounted above Kamiloloa show the difference in waves breaking on the Moloka‘i reef crest at low (*A*) and high (*B*) tides. At low tide, waves break on the reef crest, and little wave energy from offshore waves reaches the reef flat, whereas at high tide, some offshore wave energy can propagate through the reef crest to generate wave-orbital velocities on the reef flat.

break on the reef crest. The waves that we observed on the reef flat were small (~0.1–0.2 m or ~0.3–0.7 ft during high tide), and their height was more influenced by tidal elevation than offshore wave height (fig. 7).

Waves cause the water to move in oscillating (or orbital) patterns, which were measured on the Moloka‘i reef flat as the wave-orbital velocity. Nearbed wave-orbital velocities varied on a daily basis at tidal periods (fig. 5*E*), with a maximum of ~15 cm/s. At low tidal elevations, the wave-orbital velocity was low (<5 cm/s), whereas at high tidal elevations, it was higher (max 10–15 cm/s) and less predictable. The high degree of correlation between tidal elevation and wave-orbital velocity implies that the wave-orbital velocity on the reef flat is strongly controlled by water depth, irrespective of whether the waves are generated offshore or locally on the reef flat by trade winds.

The combination of high water elevation (due to tides and storm surge—an increase in water elevation caused by wind and low atmospheric pressure) and high offshore waves caused the highest wave-orbital velocity at the seabed of the reef flat; however, this combination of factors occurred only over relatively short periods. The trade-winds environmental condition, with lower wave-orbital velocities on the reef flat, occurs persistently during the trade-wind season and intermittently during the non-trade-wind season.

Suspended-Sediment Concentrations

The amount of sediment suspended in the water column (suspended-sediment concentration) can be attributed to resuspension of sediment from the seabed or its advection (transport) from another area, or a combination of both these processes. Suspended-sediment concentration, which is expressed in units of weight per volume of seawater (milligrams per liter), increases in response to stresses on the seabed caused by wave-orbital velocities and/or mean currents. Currents measured on the reef flat are generally insufficient alone to resuspend even fine silt from the seabed. Wave-orbital velocities observed on the Moloka‘i reef flat, in the absence of currents, also are generally insufficient to resuspend the finest seabed sediment. When waves and currents act together (wave-current interaction), however, their combined stress is sufficient to resuspend sediment on the reef flat. Thus, the daily resuspension of sediment observed on the reef flat is typically generated by wave-current interaction.

Suspended-Sediment Concentrations Under Typical Environmental Conditions

Suspended-sediment concentrations on the Moloka‘i reef flat are responsive to the daily variations in winds, tides, and waves under the four typical environmental conditions. Thus, during the trade-winds environmental condition, sustained strong winds generate currents of >10 cm/s that flow westward alongshore, regardless of the tidal cycle. Peak suspended-sediment concentrations during the trade-wind season were measured at high tide, when the greater water depth over the reef flat allowed the generation of substantial wind-driven waves in addition to strong alongshore wind-driven currents. A typical daily peak in suspended-sediment concentration during the trade-wind season was ~20 mg/L on the mid reef flat (fig. 8).

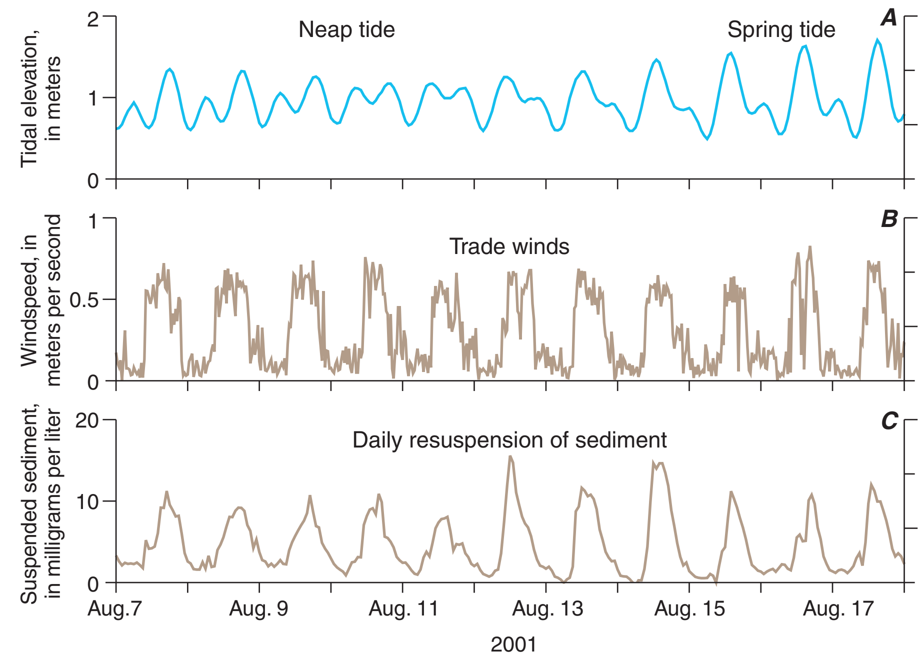

Figure 8. During trade-winds environmental condition, sediment is resuspended from the seabed, owing to a combination of wave-orbital velocities and wind-driven currents. During the period shown here, the water-surface elevation varies because of the tides (*A*) and strong trade winds (*B*), which control the wave-orbital velocity and wind-driven current (not shown). Resulting suspended-sediment concentrations (*C*) measured at the ReefProbe site on the Moloka‘i reef flat vary on a daily basis, with peak suspended-sediment concentrations resulting from strong winds and high tidal elevation.

Storms environmental conditions on the reef flat were infrequent, but the large storm waves that propagated onto it during high tide resuspended large amounts of sediment from the seabed, with peak suspended-sediment concentrations of 100 mg/L on the mid reef flat. Similarly, suspended-sediment concentrations under the swell environmental condition were also high (~40 mg/L) because wave-orbital velocities were high (>10 cm/s), especially during high tides, when larger deep-water waves are able to propagate over the reef crest and onto the reef flat. The nearbed mean currents under the swell environmental condition, in the absence of trade winds, were small and driven primarily by tides. Under the light-winds environmental condition, mean and tidal currents and wind-generated wave-orbital velocities were minimal. Although some sediment was still suspended, concentrations were quite low (<10 mg/L) and generally fluctuated with the tidal cycle (fig. 9).

Patterns of Suspended-Sediment Concentration

Backpack measurements at low and high tides under the trade-wind environmental conditions show the spatial relation between tidal stage and suspended-sediment concentration over the study area (fig. 10). During low tide (fig. 10*A*), the suspended-sediment concentration measured on the reef flat ranged from <5 to >70 mg/L, generally decreasing with distance off-

Figure 9. Photographs taken from same camera as in figure 7 show the difference in suspended-sediment concentration on the Moloka‘i reef flat at low tide under calm-wind conditions (*A*) and at high tide under trade-wind conditions (*B*). At low tide, turbidity of water is low, and the reef-flat surface is visible, whereas at high tide, wave-current interaction causes sediment to be suspended from the seabed, and turbidity of water is high.

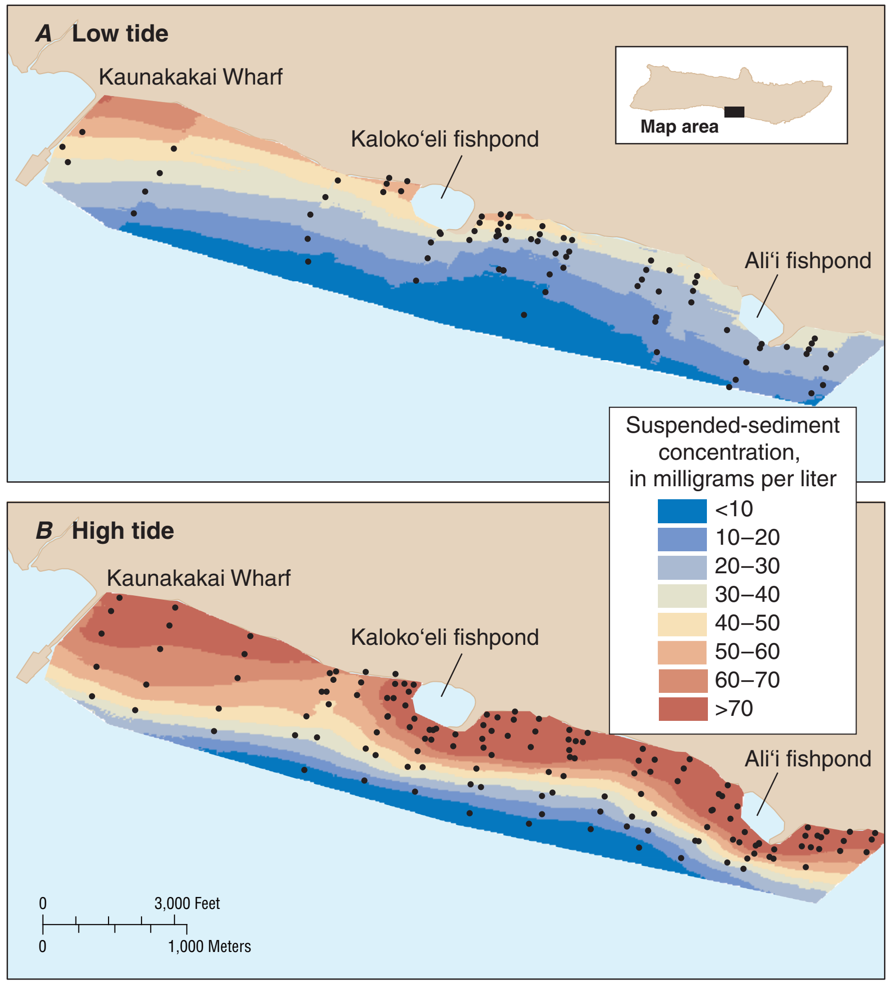

Figure 10. Amount of sediment resuspended under trade-winds environmental condition depends on location on the Moloka‘i reef flat and tidal stage, as shown by the spatial measurements at low tide during the period May 11–16, 2002 (*A*), and at high tide during the period August 18–22, 2002 (*B*). Peak suspended-sediment concentrations (>70 mg/L at low tide and >80 mg/L at high tide) observed at 20 cm (7.9 in) above seabed are shown in a nearshore band that widens around fishponds and to the east of Kaunakakai Wharf. Suspended-sediment concentration is relatively uniform throughout water column and rapidly decreases with distance offshore, indicating that most resuspendable fine sediment is contained on the inner reef flat. All measurements were taken in <2-m (<6.6 ft) water depth.

shore. The highest suspended-sediment concentrations were measured near shore and to the east (upwind) of Kaunakakai Wharf.

During high tide and under the trade-winds environmental condition (fig. 9*B*), the suspended-sediment concentration ranged from <5 mg/L offshore to >130 mg/L near shore and to the east (upwind) of the fishponds and wharf (fig. 10*B*). Higher suspended-sediment concentrations during high tide are due to greater water depths over the reef flat that allow deep-water waves to propagate over the reef crest, trade-wind-driven waves to be generated on the reef flat, and trade-wind-driven currents to speed up over the reef flat. Most suspended sediment is confined between the coastline and the mid reef flat (~600 m or 2,000 ft from shore), owing to the shallow, broad, low-relief morphology of the reef flat and the alongshore wind-driven currents. Suspended-sediment concentrations decreased to <10 mg/L near the reef crest, indicating that only small amounts of sediment were in suspension and possibly being transported to the fore reef during the study period. The only area on the reef flat where suspended-sediment concentrations >20 mg/L extended farther offshore was just to the east (upwind) of the wharf.

Sediment Flux: Where is the Sediment Going?

We evaluated the sediment flux (or sediment-transport rate) along and across the Moloka‘i reef flat by multiplying the current and suspended-sediment concentration together over a specific period. These two factors must be correlated over time to contribute to the sediment flux (for example, suspended-sediment concentration may be high, but if there is no water movement, the sediment flux is zero). Hourly records of sediment flux were calculated, then summed over the year-long data record, to get the net sediment flux for the year.

The data on net sediment flux were classified according to the four environmental conditions for the period May 2001–May 2002 (fig. 11). The trade-winds environmental condition is prevalent for most of the year (fig. 4), and the ability of trade winds to suspend moderate amounts of sediment, drive strong wind-driven currents, and persist over the study period resulted in their dominant contribution to the total sediment flux. The trade-winds environmental condition was subdivided into two parts: normal trade winds with no new sediment added, and trade winds following storms that introduce significant amounts of sediment onto the reef flat. Although the sediment flux on the Moloka‘i reef flat during the November 2001 Kona storm was small, under the trade-winds environmental condition in the subsequent days (and with subsequent sediment-input events), large amounts of sediment were transported westward, owing to the high sustained suspended-sediment concentrations (>50 mg/L) and strong currents (Field and others, this vol., chap. 21), illustrating the effect of readily available fine sediment on the sediment flux.

Environmental conditions other than trade winds contribute less to the total sediment flux on the Moloka‘i reef flat. The sediment flux associated with the storms environmental condition (to the west and offshore) was relatively small during the study period, owing to its infrequent occurrence, and although windspeeds were high, wind directions shifted over the event, causing current directions to vary during periods of high suspended-sediment concentrations and resulting in little net sediment flux. During the swell environmental condition, the net sediment flux was relatively low, owing to weak, varying tidal currents and resulting in net sediment flux to the east, moving sediment opposite to the prevailing trade-wind direction. The infrequent occurrence of this environmental condition on the reef flat (fig. 4), in combination with minimal sediment flux, leads to a low contribution to the

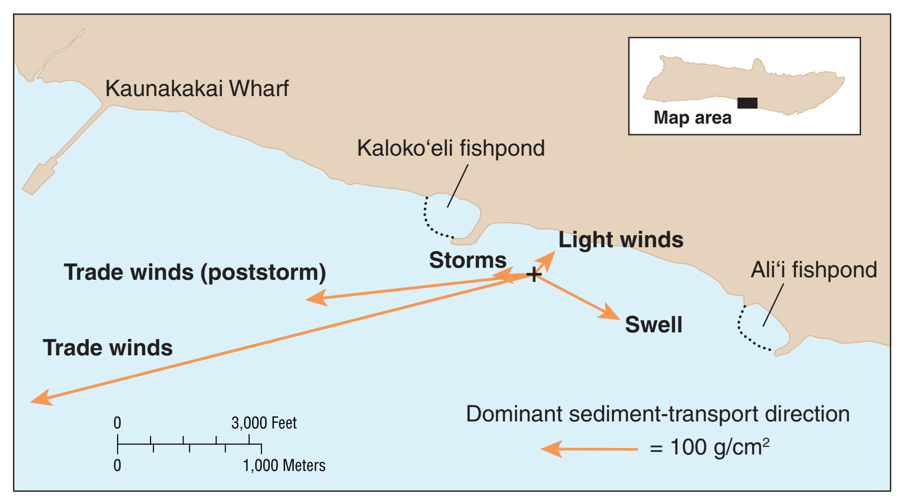

Figure 11. Dominant sediment-transport direction on the Moloka‘i reef flat is southwestward under trade-winds environmental condition at the ReefProbe site, consistent with mainly along-reef transport shown by Backpack measurements. Lengths of vectors, shown for various environmental conditions, are scaled to sediment flux through a square centimeter of water column summed over the time period of the condition from the May 2001–May 2002 dataset. Trade-wind sediment flux was further divided to show sediment flux following a large Kona storm (Field and others, this vol., chap. 21). Although swell and light-winds environmental conditions contributed only a minor amount to total sediment flux, they are important in that they can move sediment in directions opposite to trade winds.

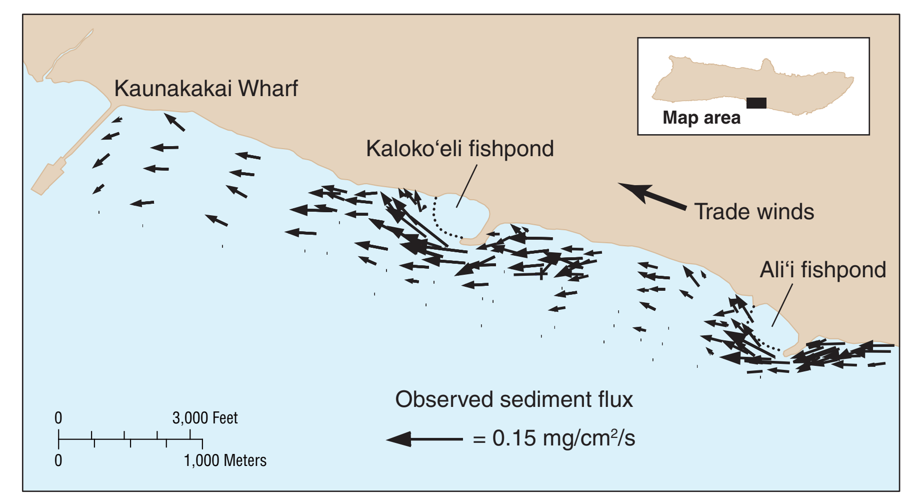

Figure 12. Observed sediment flux on the Moloka‘i reef flat under trade-winds environmental condition is dominantly within an inner-reef band, as indicated by measurements made at high tide. Sediment flux is calculated from current and suspended-sediment concentration at each survey point on the reef flat. Dominant direction of sediment flux is alongshore to the west for most survey points. Peak sediment fluxes were calculated for areas just seaward of fishponds, where current velocities are high, as well as for areas on the inner reef flat to the east and west of fishponds, where suspended-sediment concentrations are high.

total annual sediment flux. The south-central part of the Moloka‘i reef flat is generally blocked from deep-water ocean waves, minimizing the effect of offshore waves relative to many other reefs in Hawai‘i. The light-winds environmental condition, though frequent on the reef flat, resulted in minimal sediment flux, owing to low suspended-sediment concentrations and weak nearbed currents (generally due only to tidal ebb and flood). Thus, over the study period, trade-wind-driven processes were the dominant control on reef-flat sediment transport.

Distribution of Sediment Flux on the Reef

Backpack measurements of sediment flux under the trade-winds environmental condition indicate that much of the terrigenous sediment resuspended on the Moloka‘i reef flat is transported predominantly alongshore and is confined to the inner to middle reef flat (fig. 12), mainly owing to the higher suspended-sediment concentrations on the inner reef flat and the relatively constant windspeeds across the mid reef flat. Little crossreef mixing of water and sediment by the dominantly alongshore wind-driven currents occurs under the trade-winds environmental condition, as evidenced by the marked cross-shore gradients in suspended-sediment concentration and composition. In areas where flow is impeded by obstacles (east of the fishponds and wharf, fig. 1), currents are very slow, resulting in trapping of water and sediment there.

Sediment-Deposition Rate Over a Tidal Day

During the trade-wind season, sediment-suspension events occur on the Moloka‘i reef flat on a daily basis. Most of the sediment in the water column settles out of suspension when the winds and wind-driven waves subside, generally in the late afternoon. A sediment-deposition rate can be estimated over a 24-hour period to simulate the amount of sediment that would settle out of suspension and be deposited on the reef flat (fig. 13). Using an average daily suspended-sediment concentration of 20 mg/L on the mid reef flat, the mean daily sediment-deposition rate on the reef flat is estimated at 2 mg/cm^2 per day. Using the maximum measured suspended-sediment concentration of 100 mg/L, the sediment-deposition rate during these times is estimated at 10 mg/cm^2 per day, approaching the limit of acceptable rates for coral growth, as suggested by Rogers (1990).

An important point is that the sediment deposited in one day at the above rates may get resuspended the next day—it cannot be viewed as a long-term accumulation that results in burial of individual corals. Fine sediment has been shown to be trapped temporarily by macroalgae (Stamski and Field, 2006), and presumably, some of the sediment deposited on the reef flat gets trapped in selected areas, resulting in net accumulation over time. This analysis also highlights the difficulty in interpreting sediment-trapping data as a net flux (Bothner and others, 2006).

Sediment Recharge to the Reef Flat

If sediment were constantly being resuspended and transported along the Moloka‘i reef flat without new sediment being injected, over time the reef flat would clear out and become a dominantly carbonate system, with sediment originating only from the offshore reef system. Terrestrial sediment however, is recharged into the system, and local sinks store sediment on the reef flat (for example, near shoreline structures). Although only a few storms occurred during the study period, the runoff from these storms transported significant amounts of sediment from the land to the reef flat (Field and others, this vol., chap. 21). Thus, as the upland sources discharge sediment at point sites onto the inner reef under the storms environmental condition, the subsequent trade winds act over longer periods to redistribute the sediment westward in a thin band constrained relatively near shore. The sediment on the reef flat, though resuspended and transported on a daily basis, is replenished by episodic storms.

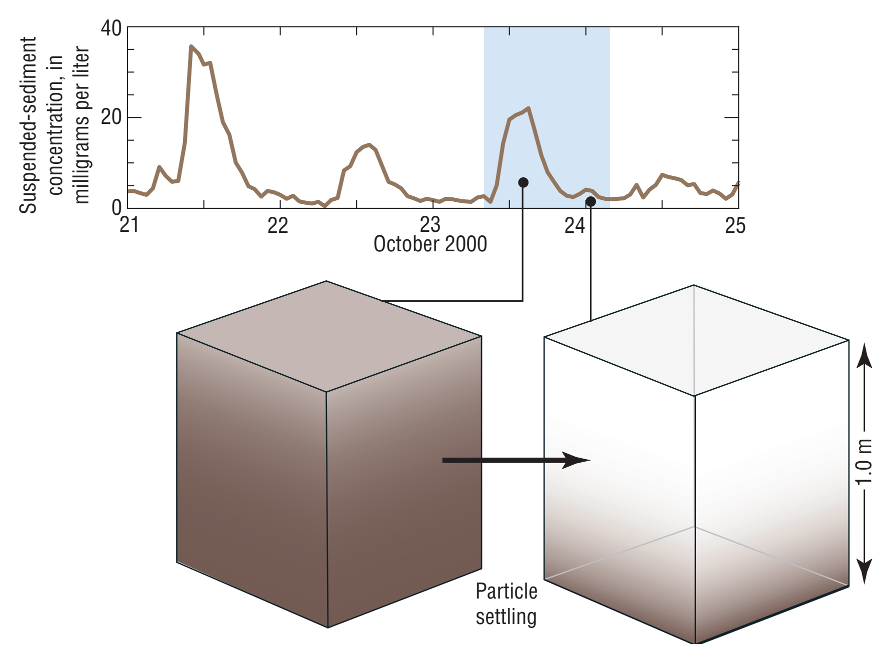

Figure 13. In each daily tidal cycle on the Moloka‘i reef flat, sediment is suspended in the water column and redeposited back onto the seabed, as illustrated by the variation in suspended-sediment concentration over a single day (for example, one day highlighted in blue). For a typical suspended-sediment concentration in the water column and a typical water depth of 1 m (3.3 ft), an average of ~20 mg/L of sediment settles out of suspension, and the short-term sediment-deposition rate is 2 mg/cm^2 per day. For higher suspended-sediment concentrations, a maximum of ~100 mg/L of sediment settles out of suspension and the sediment-deposition rate increases to 10 mg/cm^2 per day. Note that sediment deposited in a daily cycle will likely be resuspended in the following daily cycle.

Implications for Reef Flat Management

Rogers (1983, 1990) demonstrated that variations in suspended-sediment concentration affect coral growth and health. Our study adds to that understanding by documenting that suspended-sediment concentration varies across a reef flat and that a single measurement in both space and time is inadequate to describe conditions on a reef flat where, on a daily basis, seasonally varying winds and waves resuspend sediment. Thus, the effect of a discharge of even minor amounts of sediment onto the reef flat may be significant because this sediment can be resuspended many times before finally leaving the reef-flat environment.

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