

## Use of the Coral-sel Technique in the Study of Small Scale Water Flow Environments on Coral Growth

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**Abstract.** When flow experiments are carried out in open flow-through systems, several non-targeted variables may also change with varying flow rate, including temperature, oxygen level, and food availability. In order to keep these factors constant across flow treatments, it is necessary to place all corals into a single water system while still exposing them to different flow rates. In order to accomplish this, a rotating “coral-sel” was constructed at the University of Miami’s Aplysia Resource Center. The coral-sel allowed corals to experience specific flow rates based on distance from the center of rotation while being immersed in a common water system. Clod card techniques were used in order to test differences in flow rates at each of the specified distances prior to attachment of coral to each position. Fragments of *Montastraea faveolata* were studied during pilot experiments. The coral-sel allowed observations of the effects of water flow on growth, zooxanthellar activity, and morphological characteristics of corallites. Preliminary findings show that water flow alone can influence a coral’s growth in terms of surface area, weight gain. Additionally, flow influenced the photosynthetic activity of symbiotic zooxanthellae.

**Key words:** water flow, coral, growth, photosynthesis.

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### Introduction

As sessile organisms, the water that surrounds and moves over coral serves a number of important functions that assist in maintaining their existence. These functions include the delivery of dissolved gases and nutrients. Surrounding waters also provide zooplankton and particulate material that the coral may use as sources of heterotrophic nutrition. Additionally, moving water serves to remove harmful chemicals and waste products. Gaining an accurate understanding of the ways in which water flow rates influence coral’s health and growth rates will allow for better prediction of the ways that coral, in both natural and artificial habitats, may behave under a variety of flow conditions.

As water moves past an object, a momentum boundary layer forms due to fluid viscosity. The thickness of the boundary layer is inversely related to the speed of water flow past an object (Patterson et al. 1991). The exchange of dissolved materials in and out of the coral is influenced by water motion, largely due to the effects of water motion on the formation and density of this boundary layer and the related influences on diffusion rates of materials through it (Patterson 1992; Patterson and Sebens 1989; Patterson et al. 1991; Bruno and Edmunds 1997; Gardella and Edmunds 1999; Gardella and Edmunds 2001; Kuffner 2001). Water flow rate and its influence on boundary layer thickness and exchange

of dissolved materials can influence metabolic rates of coral and the symbiotic zooxanthellae contained within their tissues. Water flow can influence the rates of respiration, photosynthesis, and calcification of corals (Dennison and Barnes 1988). Water acts as a source of nutrition by providing essential chemicals as well as zooplankton for heterotrophic feeding. In this way, water flow can impact coral growth and survival through its influence on the prey capture method and success of coral colonies (Abelson, Miloh et al. 1993; Helmuth and Sebens 1993; Johnson and Sebens 1993; Helmuth et al. 1997; Sebens et al. 1998; Piniak 2002).

The manner in which differing water flow rates and boundary layer thicknesses will influence growth rates and/or morphological development of coral is species specific (Helmuth and Sebens 1993; Bruno and Edmunds 1997; Helmuth, Sebens et al. 1997). In order to accurately determine the influence of the water flow rate and the associated boundary layers on coral growth, it is necessary to reliably isolate water flow as the only variable in an experiment. This is a difficult task using standard laboratory or field methods.

In addition to the effects of water flow experienced under “ordinary” conditions, recent studies have found that increased water flow rates can temper the severity of the damage caused by a variety of stresses on corals. For example, the negative effects of

increased temperatures and photoinhibition can be alleviated by water flow in species and locally specific manners (Jones, Hoegh-Guldberg et al. 1998; Nakamura and van Woessik 2001; Nakamura et al. 2003; Nakamura et al. 2005). Given the current concerns about coral survival under changing climate and water chemistry conditions, gaining a better understanding of any factor that could alleviate stress on these animals may provide valuable information for preservation practices.

Investigating the effects of flow on coral growth under current water chemistry conditions and those predicted to occur in the future, will serve a two-fold purpose. First, by determining the flow conditions that are most conducive to coral growth and survival under current water chemistry conditions, we will be able to create more efficient coral nurseries. These nurseries may in turn serve as a source of coral for both scientific experimentation and reef restoration. This will minimize possible deleterious effects of these activities on natural populations.

Secondly, we may be able to determine the conditions best suited to preserving coral in natural areas under current and possible future water conditions. We would then be able to choose areas that fit these conditions to be set aside as marine protected areas. These protected areas may serve as refugia and possible source populations for corals during the stressful conditions likely to occur in the coming years.

In the past, most flow studies have been carried out either in natural habitats or controlled flumes. In natural habitats, a multitude of factors may vary between study sites. In most flume-based studies of flow effects on coral growth, the partition of treatments into separate systems can be a source of dissimilarity in factors other than the intended study variable. Changing the speed of water movement in an open or flow through flume system may lead to differences in temperature, nutrients, and oxygen levels experienced by each experimental colony. In order to remove this source of error, a research method was needed that allowed all experimental fragments to be exposed to the same conditions, yet still experience different flow speeds.

This paper introduces a new method of research and its possible uses and benefits in flow investigations.

### Material and Methods

The method that was devised to reduce the difficulties mentioned above was the “coral-sel”. This consists of a rotating structure that can hold a number of corals within a single water tank, but allows the attached corals to experience flow rates that vary based on their distance from the structure’s center of rotation

The prototype coral-sel (Fig. 1) was constructed at the University of Miami’s Experimental Hatchery and placed in an outdoor circular (3.7 m diameter) tank. The coral-sel consisted of a rotating column with ten arms at five separate heights (each level separated by 15 cm). The positions of the arms around the central axis of rotation were staggered to minimize possible effects of the movement of one plate or arm on a coral at any other position.

Each arm was approximately 95cm in length from the center of rotation, and held three ceramic tiles (experimental units) along its length (Fig 2). Tiles were placed at distances of 15, 50, and 85 cm from the center of rotation. This allowed the experimental units to experience water flow rates of 4.7 +/- 0.5cm/s, 15.7 +/- 1.4 cm/s, and 26.7 +/- 2.4 cm/s when the coral-sel spun at 3 rpm.

A large bicycle wheel was attached to the top of the central rotation column in a horizontal position. The wheel rim was lined with rubber to create friction for the chain that would cause it to turn. A table was positioned along-side of the tank that held a PVC frame attached to a wooden base that held a second bicycle wheel (with tire and gears) horizontally and held on an axle. The frame allowed the wheel to spin freely. A series of bicycle chains were connected to create a single chain long enough to connect the gears on the balanced tire and reach around the outside edge of the rubberized tire on the coral-sel. The frame also held a ½ horsepower motor with the spindle placed in contact with the outside edge of the balanced tire. When the motor was activated, the balanced tire spun at 32 rpm. Use of the attached gears allowed the rotational speed of the coral-sel to be adjusted to the desired 3rpm.



Figure 1: The Coral-sel in position at the UM Aplysia Resource Center. Each attachment site bears experimental plates at positions 15, 50, and 85 cm from the axis of rotation.

Each experimental unit consisted of a ceramic tile (10.8cm x 10.8cm) with limestone blocks (7.6cm x 7.6cm x 0.6cm) secured to its upper (rough) surface. A round (2.5cm diameter x 0.6cm height) plug of live *Montastraea faveolata* was inserted into a matching

hole that had previously been drilled into each square limestone tile (Fig. 2). The plug height was adjusted until it was flush with the surface of the limestone square. Each fragment used in this experiment came from the same parent colony. This colony was relatively flat and had been monitored for over a year in a shallow outdoor tank. Taking all fragments from this single colony maximized the likelihood that variability in responses would be a result of the experimental treatments rather than a result of prior genetic differences, life history, or initial zooxanthellar complement.

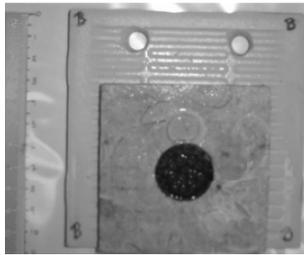


Figure 2: Experimental plate from coral-sel at the initiation of the study. The holes in the ceramic tile allowed attachment to the coral-sel arms with two nylon bolts. The smaller limestone tile is attached using marine sealant. The coral plug sits in a circular hole in the limestone and is attached to the ceramic tile using marine epoxy.

To determine the possible effects of moving the corals in a circular motion compared to passing water linearly over a stationary coral, controls using submersible pumps were tested. Two submersible pumps were each plumbed to allow four nozzles to pump water over stationary coral plates at speeds equal to those experienced by corals 50 cm from the coral-sel's axis of rotation (15.7cm/s). Growth experienced by corals placed in the "pump" treatments could then be compared to that experienced by those in coral-sel treatments.

After construction, and prior to the beginning of experiments, the flow rates at each position were examined using the clod card technique to determine if flow rates at those sites were equal at equivalent positions on the coral-sel (i.e. all 85 cm positions experienced equal flow). This method was also used to verify that the flow rates that the pump platform positions experienced were equal to those experienced by the experimental units in the medium flow treatment on the coral-sel.

All experimental units were removed from the coral-sel bi-weekly. Each was cleaned using a small brush to remove any sediment and algae that had accumulated on the tile. Care was taken when removing material close to the coral in order to minimize the possibility of damaging new coral growth.

After cleaning, excess water was removed from the experimental units using paper towels. The corals themselves were lightly "dabbed" dry, but no pressure was applied. This was to avoid inflicting damage on the delicate coral and skeleton.

Each plate was then weighed on an electronic top loading balance. The weight of each original unit (minus the coral) was subtracted from the measured weight in order to determine the true weight of the fragment at the time of weighing. Weights of coral fragments under different flow conditions were compared statistically using ANOVA.

Each experimental unit, along with a standard metric ruler, and color standard was then photographed using a digital camera. Each photograph was analyzed using the Image J computer program. Using the program, the perimeter of each fragment's surface was traced, and the surface area calculated. The surface areas of fragments were compared statistically using ANOVA.

## Results

The experiment ran for a total of 18 months, but three months was adequate to observe significant differences in growth rates based on flow rate (Fig. 3). These preliminary findings showed that flow rate caused significant differences in surface area growth ( $p=0.0051$ ). The lowest flow speed yielded the greatest increase in surface area and the highest flow speed yielded the lowest. The change in area exhibited by the "control" corals placed in front of the pumps, did not vary significantly from that of the corals placed under an equivalent flow rate on the coral-sel ( $p= 0.5757$ ).

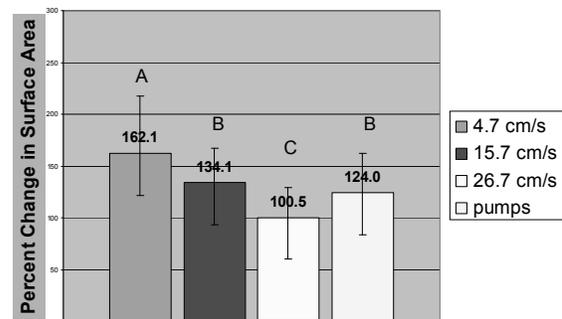


Figure 3: Average percent change in surface area of fragments after sixteen weeks (9/5/2005 - 12/26/2005). Groups labeled with the same capital letter are not significantly different. ( $p = 0.5757$ ).

Corals experiencing 15.7cm/s of flow showed the highest weight gain over the same period (Fig. 4). Therefore, under these conditions, weight gain was not necessarily dependent on increase in area. In fact, during these early weeks of the experiments when weight increases were standardized to increases in area, the greatest weight/unit area increase was seen

in the high flow speed treatments, though this pattern was altered later in the study.

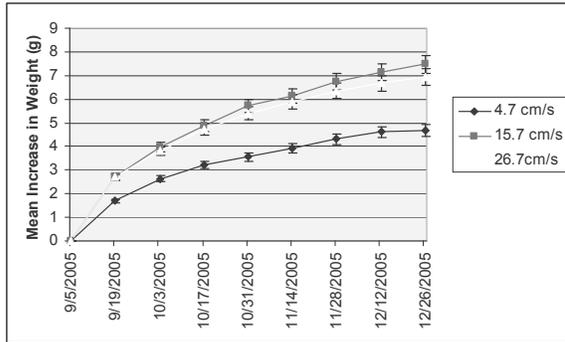


Figure 4: Mean cumulative weight gain over a sixteen week period.

In order to determine whether the water flow rate over a coral fragment influenced the photosynthetic abilities of the zooxanthellae, the electron transport rates of the zooxanthellae contained in each fragment were calculated using the light curve program of a Walz Diving PAM fluorometer. The fluorometer produced a series of light pulses of increasing intensity, and the fluorescence of the zooxanthellae in response to each pulse was measured and recorded. These values were used to calculate response curves similar to those seen in Fig. 5. Measurements were taken in the morning hours (approximately 0800 to 0930 local time). The ETR curves produced using this method were similar to those seen in figure 5. In general, the maximum electron transport rates of corals on the coral-sel were seen in fragments experiencing the highest flow rates. Under the experimental conditions, the  $P_{max}$  level appears to be directly related to the flow rate.

Further examination of the light curves for all fragments reveals that the minimum saturating irradiance for zooxanthellae in these fragments show the same inverse relationship to water flow rate.

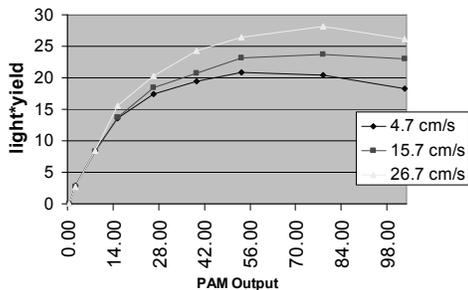


Figure 5: P-I curves exhibited by corals as a function of flow rate.

## Discussion

The movement of water over a coral colony can influence its growth and survival through effects on boundary layer thickness. The boundary layer in turn influences polyp movement and prey capture ability (Sebens *et al.* 1998), gas, nutrient, and waste exchange rates, as well as products used in metabolic activities (Kuffner 2001). In addition, flow has been seen to influence the accumulation of mycosporine like amino acids (MAAs) within coral tissues (Jokiel *et al.* 1997, Kuffner 2001).

While flow has been shown to influence each of the above factors, previous methods of studying flow effects both in the field and in flume systems were unable to completely isolate flow rate itself as an experimental variable. In flume studies, corals experiencing different water flow rates are placed in complete isolation from one another, and water being used to create the flow rates does not mix. This may lead to additional differences in the treatments that vary due to flow, such as temperature and oxygen levels. In the field, corals in areas with different flow rates may also experience different nutrient and food availability conditions.

These confounding factors have made flow as an experimental variable exceedingly difficult to isolate for examination. The solution to this difficulty explored in this study was the “coral-sel method” which allowed fragments of coral to be placed in a common fluid environment, yet still experience different flow rates. The finding that growth on the coral-sel did not vary significantly from growth by corals under similar flow rate conditions in a stationary position add validity to this process as a method to investigate water flow influences on coral.

The coral-sel method allowed water flow effects to be examined with confidence that all other factors, including temperature, light availability, oxygen levels etc. remained equal for corals in all flow treatments. Examination of the corals on a biweekly basis allowed monitoring of changes in coral fragment surface area, weight, and photosynthetic ability. Upon completion of the study, the fragments can be examined to determine whether they have experienced a change in zooxanthellar complement through use of genetic methods. In addition, the fragments can be examined to determine if basic corallite structure changed based on water flow rate alone.

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## References

- Abelson A, T Miloh, and Y Loya (1993) Flow patterns induced by substrate and body morphologies of benthic organisms, and their roles in determining availability of food particles. *Limnol Oceanogr* 38(6): 1116-1124
- Brown BE (1997) Adaptations of reef corals to physical and environmental stress. *Adv in Mar Biol* 31:221-299
- Bruno JF and PJ Edmunds (1997) Clonal Variation for Phenotypic Plasticity in the coral *Madracis mirabilis*. *Ecology* 78(7): 2177-2190
- Dennison WC and DJ Barnes (1988) Effect of water motion on coral photosynthesis and calcification. *J Exp Mar Biol Ecol* 115: 67-77
- Gardella DJ and PJ Edmunds (1999) The oxygen microenvironment adjacent to the tissue of the scleractinian coral *Dichocoenia stokesii* and its effects on symbiont metabolism. *Mar Biol* 135(2): 289-295
- Gardella DJ and PJ Edmunds (2001) The effect of flow and morphology on boundary layers in the scleractinian *Dichocoenia stokesii* (Milne- Edwards and Haime). *J Exp Mar Biol Ecol* 256 (2): 279-289
- Helmuth B and K Sebens (1993) The influence of colony morphology and orientation to flow on particle capture by the scleractinian coral *Agaricia agaricites* (Linnaeus). *J Exp Mar Biol Ecol* 165(2): 251-278
- Helmuth BST, KP Sebens, and TL Daniel (1996) Morphological variation in coral aggregations: ranch spacing and mass flux to coral tissues. *J Exp Mar Biol Ecol* 209: 233-259
- Johnson C and KP Sebens (1993) Consequences of a flattened morphology: effects on flow and feeding rates of the scleractinian coral *Meandrina meandrites*. *Mar Ecol Prog Ser* 126: 123-143
- Jokiel PL, MP Lesser, and ME Ondrusek (1997) UV absorbing compounds in the coral *Pocillopora damicornis*: Interactive effects of UV radiation, photosynthetically active radiation, and water flow. *Limnol Oceanogr* 42(6): 1468-1483
- Jones RJ, O Hoegh-Guldberg, AWD Larkum, and U Schreiber (1998) Temperature-induced bleaching of corals begins with impairment of the CO<sub>2</sub> fixation mechanism in zooxanthellae. *Plant Cell and Environ* 21: 1219-1230
- Kuffner IB (2001) Effects of ultraviolet radiation and water motion on the reef coral *Porites compressa* Dana: A flume experiment. *Mar Biol* 138(3): 467-476
- Nakamura T and R van Woesik (2001) Water-flow rates and passive diffusion partially explain differential survival of corals during the 1998 bleaching event. *Mar Ecol Prog Ser* 212:301-304
- Nakamura T, H Yamasaki, and R van Woesik (2003) Water flow facilitates recovery from bleaching in the coral *Stylophora pistillata*. *Mar Ecol Prog Ser* 256: 287-291
- Nakamura T, H Yamasaki, R van Woesik (2005) Photoinhibition of photosynthesis is reduced by water flow in the reef-building coral *Acropora digitifera*. *Mar Ecol Prog Ser* 301: 109-118
- Patterson (1992) A mass transfer explanation of metabolic scaling relations in some aquatic invertebrates and algae. *Science* 255: 1421
- Patterson MR and KP Sebens (1989) Forced convection modulates gas exchange in cnidarians. *Proc. Natl. Acad. Sci. USA* 86: 8833-8836
- Patterson MR, KP Sebens, and RR Olson (1991) In situ measurements of flow effects on primary production and dark respiration in reef corals. *Limnol Oceanogr* 36(5): 936-948
- Piniak GA (2002) Effects of symbiotic status, flow speed, and prey type on prey capture by the facultatively symbiotic temperate coral *Oculina arbuscula*. *Mar Biol.* 141(3): 449-455
- Sebens KP, SP Grace, B Helmuth, EJ Maney, and JS Miles (1998) Water flow and prey capture by three scleractinian corals, *Madracis mirabilis*, *Montastrea cavernosa*, and *Porites porites*, in a field enclosure. *Mar Biol* 131: 347-360