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BEHAVIORAL RESPONSE OF YELLOWFIN TUNA, *Thunnus albacares* AND KAWAKAWA, *Euthynnus affinis*, TO TURBIDITY

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As a part of the Deep Ocean Mining Environmental Study (DOMES), the following studies were designed to investigate the effects of the surface discharge of bottom sediments on tuna behavior. Tuna schools may react to the increased turbidity caused by the suspended sediments. My study examines the behavioral responses of captive tuna to varying turbidity levels. Other non-behavioral investigations should be necessary only if behavioral data indicate that tuna will spend significant amounts of time in turbid areas. In the following experiments, I assumed that, depending upon motivational and environmental factors, there exists a level of turbidity that tuna will avoid.

Pairs of or single yellowfin tuna, *Thunnus albacares*, and kawakawa *Euthynnus affinis*, were held in outdoor 7.3 m diameter by 1.2 m deep tanks. The tanks were supplied with a continuous flow of low turbidity seawater in the range of 0.6 to 1.0 Nephelometric Turbidity Units (NTU). Tuna were fed frozen smelt at a rate of approximately 10% of body weight per day. Details of catching, transporting, and maintaining live tuna in captivity are available elsewhere.[1]

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[1] Nakamura, E. L., 1972. Development and uses of facilities for studying tuna behavior. *In* H. E. Winn and B. L. Olla (editors), Behavior of marine animals. Current perspectives in research 2: Vertebrates, p. 245-277. Plenum Publishing Corporation.

A trial consisted of a 6-min control observation period (which sometimes included a 1-min control feeding period) followed by the introduction of the suspended material into the tank, and a 6- to 15-min observation period of the responses of the tuna to the resulting cloud. The observation period ended when the cloud dispersed, or when the tuna consistently ignored the cloud.

The water depth in the tank was lowered to 0.5 m for kawakawa and about 0.6 m for yellowfin tuna prior to a trial (in the first study on the single large yellowfin tuna, water depth was maintained at 1.2 m). The lowered water level minimized vertical variations of turbidity within the cloud. The inflow of seawater was shut off at the beginning of each trial to reduce the cloud dispersion rate. Trials were done between 1030 and 1530 h, either once or twice per day, and usually on alternate days.

Preliminary trials were monitored visually by a hidden observer in a tower overlooking the tank. Later trials were monitored with a videotape system mounted on the roof of the tower, and supplemented by an audio record made by the observer. Periodically, water samples were taken from the cloud and other areas of the tank by a second experimenter. If feeding was included in the trial, the second observer also threw food into various areas of the tank. This experimenter and sampling were, of necessity, plainly visible to the tuna. The suspended material was deep sea mud from DOMES site C. The mud was weighed, mixed with seawater in a blender, diluted to 3.8 liters, and poured into the tank from a bucket. Sample turbidities were measured with a nephelometric turbidimeter.[2] A series of dilutions of a suspension of DOMES mud was analyzed to determine the relationship between turbidity and concentration of suspended sediments. Dry weights of suspended sediments were determined by total residue.[3] There is a linear relationship between the measured turbidity in NTU's and sediment concentration in milligrams per liter of DOMES site C mud. One NTU corresponds to about 1.4 mg/liter of DOMES mud.

Trials without videotape documentation consisted of eight turbid trials and two control trials (plain seawater) with a pair of kawakawa, and seven turbid and two control trials on a single large yellowfin tuna. Most of these trials included feeding--the tuna were fed in and out of clouds to determine how feeding motivation affects avoidance. Videotape documented trials included 15 turbid and 2 control trials on a pair of kawakawa, and 16 turbid and 2 control trials on a pair of yellowfin tuna. These trials were designed to determine avoidance reactions independent of feeding motivation. In six final trials the yellowfin tuna pair were fed, but only in the turbid clouds.

OBSERVATIONS

Turbidity clouds were often very irregular in shape; each was different due to the wind speed and direction, water current, activity of the tuna, and amount of material added. The cloud circled the tank

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[2] H.F. Industries model DRT-1000 calibrated against Formazin solutions.

[3] Total residue dryed at 103°-105°C; American Public Health Association, 1975. Standard methods for the examination of water and waste water including bottom sediments and sludges. 14th edition. A.P.H.A., New York.

1 to 2 times per trial. Thus cloud position could not be predicted by the tuna or avoided by using one specific swimming pattern. Early trials with both species of tuna usually resulted in some initial probing or passing through clouds at high turbidities. After a few of these passes, and after a few trials, tuna would often turn away from the cloud at a distance; however, avoidance responses while in cloud peripheries or centers were also observed.

The results of the non-videotaped trials are summarized in Tables 1 and 2. The kawakawa pair behaved and were treated as a unit. The behavioral categories are based primarily on the physical position of the tuna with respect to the cloud. The "avoid" categories show the lowest measured turbidity levels which were avoided; and the "pass through" category represents the highest turbidity through which the tuna regularly swam. At turbidity levels in the "pass/not eat" category, the tuna usually entered the cloud to reach food, but did not eat the food. Abnormal behavior indicative of stress was observed frequently, especially in the early kawakawa trials. Both kawakawa and yellowfin tuna would eat in the clouds, although they were fed both in and out of the clouds. However, in one trial when fed live anchovies (rather than dead smelt); the kawakawa passed through higher turbidities (4.0 NTU) than before. Otherwise, feeding motivation did not result in a greater willingness to enter turbid areas. Kawakawa generally passed through higher turbidities than the yellowfin tuna. In one instance, the yellowfin tuna refused to eat in a 1.2 NTU cloud relative to 0.85 NTU surroundings.

The results of the videotaped trials are recorded in Tables 3 and 4. "Avoid-1" is the turbidity at which complete physical avoidance occurred; "Avoid-2," the level at which the tuna avoided the cloud more often than they passed through; "Avoid-3," the level at which pass throughs occurred more frequently than avoidance; and "Pass through," the level which the tuna passed through the cloud in virtually all cases. At turbidity levels in the last category, the tuna were often reacting behaviorally to the cloud (speed changes, turns, fin movements, etc.), but in all cases were passing through. The recorded turbidity levels avoided were not necessarily the absolute minimum levels actually avoided, because often samples were not taken on the last avoidance before a pass through. However, turbidity levels at which the tuna passed through represent true maxima, as samples were always taken immediately after a pass through.

In all but a few trials with the kawakawa, the pair of tuna were treated as a unit. Generally one tuna followed and reacted exactly like the leader. However, in three kawakawa trials, one of the pair of videotaped individuals was tested with a new but sick tuna. The sick fish was less efficient at avoiding (discriminating) the clouds; and thus, the two tuna were examined individually. In a final trial the healthy kawakawa was tested alone.

In the yellowfin, but not the kawakawa, the initial amount of sediment introduced (10 versus 25 or 50 g) correlated with the turbidity levels avoided and tolerated. This correlation is related to the larger size of the clouds which were formed from greater amounts of sediments. For example, in a 25 g trial, the turbidity dropped to a level of 3.0 NTU when the cloud covered a much larger area than a 3.0 NTU, 10 g cloud. The yellowfin tuna avoided larger clouds with less frequency than smaller clouds with similar turbidities. Perhaps the relatively large yellowfin tuna (3,121 and 3,517 g in weight, versus about 1,500 g for the kawakawa) were less agile in avoiding a large cloud within the confines of the tank.

The yellowfin tuna consistently avoided the 10 g clouds until the turbidity dropped to 1.6-2.2 NTU, whereas kawakawa tolerated turbidities up to 4.4 NTU. In a few feeding trials, the yellowfin tuna entered turbidities up to 7.4 NTU in order to feed. In these trials food was thrown exclusively into the clouds. Unlike all other trials, the turbidity levels tolerated in these feeding trials increased over the period of testing (5 days). This appears to be a learning phenomena; it is likely that tuna could be trained to enter extremely high turbidities to feed.

CONCLUSIONS

From the data it is clear that tuna can avoid areas of suspended site C sediment. Kawakawa were more tolerant of high turbidities than were yellowfin tuna. This can possibly be explained by the more coastal distribution of kawakawa, and the almost exclusively open sea distribution of yellowfin tuna. Based upon their ecology, skipjack tuna, *Katsuwonus pelamis*, will most likely show avoidance behavior similar to yellowfin tuna.

Occasionally avoidance reactions to the higher turbidities were extremely abrupt. Yet, the clouds did not seem exceedingly aversive or toxic since the tuna usually did not get extremely upset or ill as a result of short-term exposure to turbidities in the range tested. At sufficiently low turbidities the tuna would even feed in the clouds (up to 7.4 NTU). Of course the high turbidities were encountered only in the form of a cloud which left a large portion of the tank relatively clear. Preliminary experiments indicated that in turbidities filling the entire tank (2-3 NTU), the tuna often became sufficiently upset to cease feeding. It often appeared that in addition to initial probing of the clouds, the tuna were attracted to cloud regions at low turbidities in the non-feeding trials. However, the present experiments were not designed to measure such an effect; and the attraction could represent mere curiosity. Captive tuna may tolerate higher turbidity levels than they would in the open ocean. All experimental animals were regularly exposed to high turbidities due to tank cleaning. In addition, the two yellowfin tuna observed in the video-taped trials had been exposed to more than 2 weeks of turbid water (approximately 1.5 NTU) when our water system broke down. Although oceanic tuna may find low levels of turbidity aversive, they may be inefficient at avoiding low levels due to an inability to detect the gradual gradients within the clouds. (An ongoing study is attempting to determine thresholds for turbidity detection.) However, the avoidance responses seen in captivity appeared to be visually mediated; and tuna have acute visual capabilities. Thus, tuna should be able to detect gradual gradients of turbidity. The actual response in the ocean will depend on the absolute level and gradients of turbidity encountered, on critical levels of turbidity for the species in question, and on the motivational state of the tuna.

Table 1.--Non-videotaped kawakawa trials.

DOMES mud added (g)	Avoid-not eat (NTU)	Pass-not eat (NTU)	Pass and eat (NTU)
25			3.5
50	4.45	2.2	1.3
50	6.0		3.2
100	2.9	2.1	0.88
200	4.5		2.85
[1]200	6.9	4.0	
200	3.2	2.9	
[2]300			2.5

[1] Live bait used; it was difficult to determine where it was eaten but feeding did occur.

[2] In this case cloud dispersed over entire tank. Tuna willing to feed, but not avidly.

Table 2.--Non-videotaped yellowfin tuna trials.

DOMES mud added (g)	Avoid-not eat (NTU)[1]	Pass-not eat (NTU)	Pass and eat (NTU)
25	7.0	1.2, 1.5	.85
100	2.15	2.1	.97
100		2.1, 1.5	2.1
100	2.9		2.6
150	3.4		2.3
[2]300	2.1 / 1.6	2.2	2.2
400	2.75 / 2.0		1.9

[1] If two values x/y are given, x is the turbidity of the cloud and y is the turbidity in the less turbid part of the tank, if different from normal ambient (.6-1.1 NTU).

[2] No food was introduced during this trial.

Table 3.--Videotaped kawakawa trials.

DOMES mud added (g)	Avoid-1 (NTU)	Avoid-2 (NTU)	Avoid-3 (NTU)	Pass through	Maximum turbidity measured[1]	
					(NTU)	Time (sec)
10	10.2	3.7	4.1, 5.2	2.4	10.0	35
25	3.0, 5.2		3.4	2.9	15.5	30
25		6.1		2.83	6.1	95
25	12.0			4.1	12.0	50
50	32.0	4.4	3.8	2.05	32.0	55
50	25.0			3.5	25.0	37
50	18.0	5.9	3.9	1.9	18.0	60
50	3.3			2.7	14.5	180
100	8.8	5.6		3.3	36.0	55
100	4.3	5.4		3.3	58.0	38
100	4.8	4.3, 3.5		4.43	42.0	70
[2]25A	3.3			2.9	10.0	55
25B			10.0	3.3	10.0	55
50A	4.9	6.9	3.3	3.3	23.0	63
50B	4.9	7.5	6.9	3.3	23.0	63
100A	3.9			4.5	32.0	45
100B	32.0			23.0	32.0	45
[3]50A	3.2	2.5	2.4	2.3	11.0	45

[1] Maximum turbidity measured and time after the addition of mud when the measurement was taken.

[2] Tuna in subsequently listed runs treated separately due to differences in their responses. "A" was healthy and feeding; "B" was sick, not feeding, and died soon after.

[3] Last trial was done with tuna "A" alone in the tank.

Avoid-1 - Complete avoidance of cloud.
Avoid-2 - Avoided more than passed through.
Avoid-3 - Passed through more than avoided.
Pass through - Consistently passed through turbidity cloud.

Table 4.--Videotaped yellowfin tuna trials.

DOMES mud added (g)	Avoid-1 (NTU)	Avoid-2 (NTU)	Avoid-3 (NTU)	Pass through (NTU)	Feed (NTU)	Maximum turbidity measured[1]	
						(NTU)	Time (sec)
Non-feeding trials							
10	3.2			1.6		6.7	22
10	2.9		1.9	1.7		5.9	26
10	2.9			2.2		7.0	33
10	2.9	1.5		1.9		5.9	20
10	2.6		2.3	1.9		6.1	27
10	2.8		2.1	1.6		14.0	25
10	2.2			2.1		6.5	22
25	3.1			2.7		11.5	39
25	2.9			3.0		9.8	25
25	2.8			2.1		6.6	30
25	3.6		2.8	2.7		16.2	21
25	2.9	3.9	2.05	2.7		18.0	35
25	6.0		3.9	2.85		8.6	35
25	11.7		5.3	3.0		14.0	32
50	3.3			2.6		28.0	32
50	19.0	4.2		2.9		19.0	34
Feeding trials (in chronological order)							
50	8.2		4.4	3.9	3.9	30.0	25
25	16.5		5.0	3.2	[2]5.5	16.5	40
25	10.5		14.5	6.9	6.3	14.5	33
50			14.5	6.0	6.0	14.5	54
50	28.5			8.2	7.3	28.5	44
25		9.6		7.4	7.4	9.6	52

[1] Maximum turbidity measured and time after the addition of mud when the measurement was taken.

[2] Cloud was avoided except for feeding.

Avoid-1 - Complete avoidance of cloud.
Avoid-2 - Avoided more than passed through.
Avoid-3 - Passed through more than avoided.
Pass through - Consistently passed through cloud.
Feed - Passed through and fed in cloud.