Chapter 13:

Quantitative Underwater Ecological Surveying Techniques: A Coral Reef Monitoring Workshop

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Abstract

QUEST is a coral reef workshop taught at the University of Hawai'i at Hilo that is designed specifically to train students in a comprehensive suite of modern reef monitoring techniques. The classroom curriculum is designed to provide students basic background on faunal identification, coral reef ecology, surveying methods, experimental design, statistics, data processing, report writing, and oral presentation. The surveying methods taught were selected because they are widely utilized by the scientific community, easy to teach, and logistically practical in most field situations. Methods employed include: fish strip transects and rapid visual transects; quadrat intersects, percent area estimation, and photoquadrat and video quadrat method for sampling attached epi-fauna and -flora; and quadrat search and nearest neighbor method for mobile invertebrates. In addition to providing trained personnel for coral reef monitoring, the course generates data useful for detecting large-scale changes in coral reef communities.

Keywords

community-based monitoring, volunteers, environmental education, reef fish, coral cover

Introduction

Coral reefs are complex communities that exhibit high spatial and temporal variation. As a result, collecting information useful towards the management of reefs is particularly challenging. The focus of this paper is to describe one of the few workshops in the world designed specifically to train students in a comprehensive suite of modern reef monitoring techniques.

Each May students and faculty from around the State of Hawai'i travel to the University of Hawai'i (UH) at Hilo to participate in QUEST, Quantitative Underwater Ecological Surveying Techniques. QUEST also attracts students and professionals from the Pacific Basin and the mainland (Russell 1997). This course, which has an annual enrollment of about 30, teaches students using SCUBA, methods of surveying biota on shallow subtidal reefs.

QUEST was offered for the first time in 1982 as a noncredit workshop on Maui, which was conceived and sponsored by the UH Marine Option Program (Maynard 1985; Russell 1997). The site of the workshop eventually was moved to the Hawai'i Institute of Marine Biology on Oahu and remained there until 1991 when it was moved to the UH at Hilo and offered for credit through a partnership between the Marine Option Program and UH Hilo's Marine Science Summer Program.

The fundamental mission of QUEST is to promote and facilitate coral reef conservation, monitoring, and research through experiential, hands-on education (Russell 1992). The proximal goals of QUEST are twofold; 1) to teach participants basic practical in situ reef surveying methods, and 2) to provide a pool of well-trained individuals to assist with various coral reef monitoring and research projects around the state. QUEST graduates have, in fact, gone on to participate in numerous subtidal studies and projects either as paid employees or volunteers (Russell 1992).

In this paper, we will focus on the curriculum and field methods taught in QUEST. Surveying methods practiced in the field were selected because they are widely utilized by the scientific community, easy to teach, and logistically practical in most field situations. The classroom curriculum is designed to provide students basic background on coral reef ecology, faunal identification, experimental design, statistics, surveying methods, data processing, report writing, and oral presentation (Maynard 1985).

Course Prerequisites

A prerequisite for enrollment in QUEST is certification in the UH Scientific Diving Program as, at the minimum, a Diver In Training (DIT). To meet this standard, each student must meet AAUS (American Academy of Underwater Sciences) criteria for DIT status: possession of a basic SCUBA certification, successful completion of a SCUBA medical examination, and an in-water check-out dive with the UH Diving Safety Officer or his representative.

Additionally, students from within the UH/community college system are required to demonstrate competence in faunal identification prior to being accepted to QUEST. Each participating campus offers a series of identification workshops to introduce students to common Hawaiian coral reef organisms. The current species identification list, supported by a species ID videotape, consists of approximately 80 species of fishes, 65 invertebrates, and 50 algae. Students coming from outside the UH system are taught species identification during QUEST prior to field application of surveying methods.

Curriculum

QUEST begins with three and a half days of full-time classroom instruction, which prepares students for field training. Lectures are one to two hours and cover aspects of diving safety and protocol, faunal identification, the ecology of coral reefs, physical processes on the reef, surveying methods, photography, experimental design and statistical analyses (Table 1).

The class then travels to west Hawai'i to conduct five days of field training in which students survey the reefs at Puako, using methods selected from those discussed in class. Students are split into six teams of divers; each accompanied by an instructor. Teams search permanent 50 m transect lines on the Puako reef. There are six lines that run approximately parallel to the shoreline: two lines each on the reef flat (<3 m deep), at 7.5 m, and 12.5 m. Training dives include: general reef reconnaissance; surveying of coral, algae, macroinvertebrates, and fish; comparison of sampling methods; photo/videoquadrat techniques; and a surveying dive in which students utilize many of the techniques they have learned to survey the biota on the reefs at Mahukona (Table 2).

Table 1 Chronological list of lecture topics given during the QUEST workshop

1. Dive orientation
2. Dive safety and accident management
3. Hawaiian reef fish identification
4. Hawaiian macroinvertebrate identification
5. Coral reef ecology
6. Reef fish biology
7. Geomorphology
8. Coral reef sedimentology
9. Seaweed diversity
10. Coral reef physical oceanography
11. Hawaiian seaweed identification
12. Hawaiian coral identification
13. Fish surveying techniques
14. Benthic surveying techniques
15. Tow board surveying techniques
16. Video surveying techniques
17. Photographic surveying techniques
18. Underwater photography
19. Basic statistics
20. Statistical analyses
21. Experimental design
22. Introduction to MINITAB
23. Dive planning
24. Dive protocol
25. UH research diver responsibilities

Table 2 Chronological list of dives conducted during QUEST workshop and a brief description of activities carried out

1. Reconnaissance dive
2. Invertebrate surveying dive
3. Seaweed surveying dive
4. Coral surveying dive
5. Fish strip transect dive
6. Fish rapid visual transect dive
7. Photo/Videoquadrat dive
8. Sampling methods
9. Baseline reef survey

Upon completion of field training, students and faculty return to the UH Hilo campus to spend three days reducing, analyzing, and reporting on the data collected during field exercises. Each of the six dive teams are assigned a specific segment of the data; fishes, corals/seaweeds, macroinvertebrates, photo/videoquadrats, sampling methods, and Mahukona baseline data. The course culminates with each team preparing a written report of their data analysis and giving a presentation at a mini QUEST Symposium.

Evaluation of Field Methods Taught at QUEST

Surveying methods taught at QUEST are widely cited in the scientific literature, easy to learn, and easy to use in the field. With the exception of photoquadrat and video, equipment costs are negligible. The pros and cons of each method are discussed in more detail below.

Surveying Fishes

In the field, QUEST students practice two fish surveying methods: strip transect (SST) and rapid visual transect (RVT). Both are nondestructive, relatively inexpensive and efficient methods based on in situ visual surveying of fishes. They are also relatively unbiased, compared to many destructive sampling techniques like hook & line and nets (see Sale 1980 for a discussion of destructive vs. nondestructive sampling).

Both methods are best employed under conditions of good water visibility (>3-4 meters) and low surge (Quast 1968a;b; c; Ebeling et al 1980; Larson and DeMartini 1984; Gotshall 1987). Coral reefs usually meet those criteria and can be visually surveyed almost year-round, except during tropical storms (Ebeling and Hixon 1991).

Strip Transect

Fixed width strip transect is commonly referred to in the literature by a number of names including strip transect, line transect, belt transect, or "Brock" method. The strip transect method is used to estimate densities of fishes, because it not only provides information on species present, but also on their abundance per unit of survey area.

A transect line is deployed on the bottom, most often parallel to shore along a specific depth contour. Divers wait for fishes disturbed by the deployment process to resume normal activity patterns, and then proceed down the transect line, one on each side, recording all fishes seen in the water column and on the bottom on their side of the transect line (Fig. 1). At QUEST, data are recorded onto a pre-prepared data sheet attached to an underwater slate.

At QUEST, each diver searches a lane approximately three meters wide on each side of a transect line extending 50 meters in length. The transect size that is finally decided upon depends upon the community being sampled, although the length should allow transects to be searched completely within the boundaries of a particular habitat type (i.e., lagoon, reef flat, reef slope). Most workers have opted for transect lengths between 25 and 100 m in length (see Sale 1980; Sale and Sharp 1983).

The visual transect, though relatively inexpensive and unbiased, does have several potential sources of sampling error. Perhaps the most common is the underestimation of individuals present (Sale 1980; Brock 1982; Sale and Douglas 1981; Sale and Sharp 1983; Ebeling and Hixon 1991). In addition, cryptic or rare species will often be missed during visual transects (Brock 1982; Sale and Douglas 1981;

Figure 1 Divers searching a strip transect for fishes

Sale and Sharp 1983). Also, shoaling fishes are reported to be consistently underestimated by observers (DeMartini and Roberts 1982; Davis and Anderson 1989). Though less of a problem, mobile species may be overestimated by the visual method because they move around on the transect and may be counted multiple times, especially at slow diver swimming speeds (Lincoln-Smith 1988; 1989).

Transect size can also influence accuracy of density estimates and is hence another potential source of bias. Sale and Sharp (1983), working on the Great Barrier Reef, visually surveyed transects of variable width (1 to 3m wide). They found that a higher percentage of individuals were missed on wider transects and proposed a technique for correcting this source of bias (see also McCormick and Choat 1987 for an evaluation of the influence of transect size on accuracy and cost-efficiency of visual transects).

Rapid Visual Transect

Jones and Thompson (1978) developed the rapid visual transect or "RVT" method for estimating the relative abundance of fishes. RVT, like all techniques for estimating relative abundance, is based on the assumption that the probability of encountering a species increases with its abundance (Jones and Thompson 1978; Sale 1980; Coyer and Witman 1990). Stated another way, the more common the species, the sooner the researcher is likely to encounter it after entering the water or starting a transect. All relative abundance-estimating methods are based on this inverse relationship between abundance and the average time to first encounter.

In RVT, the observer swims freely within the target habitat for a specified period of time (e.g., 50 mins). The survey period is divided into intervals (e.g., 10 mins). Each species sighted is recorded only once and assigned to the time interval in which it was first seen. Species are assigned scores based on the interval in which they were seen:

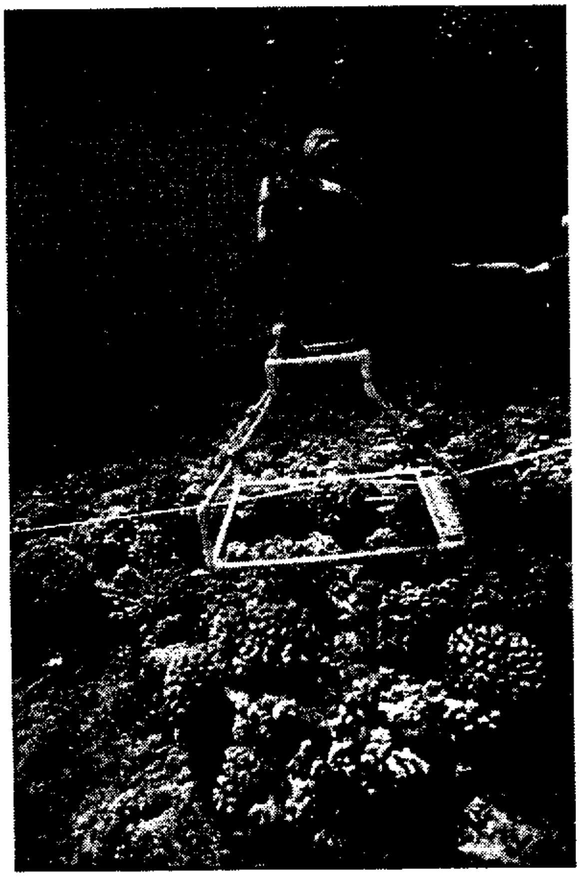

Figure 2 Using a Nikonos camera mounted on a PVC photoquadrat stand, a diver photographs the bottom

Time	Interval	Score
00:00 - 09:59	1	5
10:00 - 19:59	2	4
20:00 - 29:59	3	3
30:00 - 39:59	4	2
40:00 - 49:59	5	1

The species with the highest average score is the most abundant, while the species with the lowest average score is regarded as the rarest species.

Compared to strip transects, RVT overemphasizes the importance of widespread, though rarer species, while under-estimating patchy but abundant fishes (DeMartini and Roberts 1982). On coral reefs where ichthyofauna would best be characterized as having a large number of relatively rare species, the RVT method is likely to overestimate the relative abundance of many species (Ebeling and Hixon 1991). Sanderson and Solonsky (1986) compared RVT to strip transect (STT) and found RVT to be less precise (i.e., subject to higher among-replicate variance).

Surveying Attached Epifauna and Epiflora

Four methods of surveying attached organisms like corals and algae are taught during QUEST: quadrat intersect search, percent cover estimation, photoquadrat, and videoquadrat. Quadrats used during QUEST to survey organisms are square, and range in area of coverage from 0.25 to 1.0 m^2 (see Krebs 1989 or Pringle 1984 for methods of determining optimal quadrat size and shape). QUEST quadrats are made of PVC pipe, which has been weighted with lead and drilled to permit water to fill the piping upon submergence (see Reed 1980 or Coyer and Witman 1990 for additional quadrat designs). Photoquadrats are taken with submersible cameras like the Nikonos series mounted on a rigid framework (Fig. 2). Videoquadrats are recorded with Hi-8 video cameras protected by underwater housings. At QUEST, quadrats and photoquadrats are placed at ten random number locations along a 50 m transect line.

Quadrat Intersect Method

The quadrat intersect method utilizes a quadrat that is partitioned by a series of lines which intersect at regular intervals. After the quadrat has been placed on the bottom, organisms or substrate type located under each intersection are recorded. QUEST quadrats are "double-strung", so that one complete set of lines lies about 1" above an identical set. The observer must line up the upper and lower points of intersection before recording what lies under them. This eliminates parallax based on the observer's position.

The quadrat intersect method provides an estimate of the abundance of epibenthic organisms like corals and algae. The principal advantage of this method is that each quadrat can be searched quickly, with many replicate quadrats being searched during a dive, and the method is relatively unbiased. The method's principal disadvantage is that uncommon or rare species seldom fall under intersecting points and are therefore not recorded.

Percent Cover Estimation

Percent cover estimation requires the observer to estimate the percentage of quadrat area filled by each taxon or substrate type. Although this can be done for an entire quadrat, accuracy is enhanced if the quadrat is partitioned into smaller subunits, with percent cover being independently estimated for each subunit. At QUEST, a 0.25 m^2 quadrat is partitioned into 16 equal subunits by the two sets of intersecting lines.

The principal advantage of the percent cover estimation method is that rare or uncommon species are less frequently overlooked in comparison to the point-intersect method. Its primary disadvantage is that it is a time-intensive method, which limits the number of replicate quadrats that can be searched on a dive. Also, since percent cover is being estimated, observer error or bias is a concern.

Photoquadrat

In this method the observer takes photographs of organisms contained within the quadrat formed by the base of the mounting framework (Fig. 2). At each random location along the transect line, a photograph is taken with color transparency film. Later, the slides are projected and analyzed by the desired method; "point-intersect" using randomly generated point locations or percent cover estimation. At QUEST, students use 50 random points in slide analysis.

Within each photographic frame, quadrat location is recorded. A diver holds a card in one corner of the photograph, but outside the actual area of the quadrat. Written on that card in large block letters are the date, a number identifying the transect line, and the random number location of the photoquadrat on the transect line.

Because the photographic process is relatively fast, it is possible to photograph many more quadrats on a dive than could be searched by divers. The photoquadrat method also provides a permanent photographic record of each quadrat. Potential liabilities of this method include cost, equipment failure, or poor quality photographs which may prevent accurate identification of bottom cover.

Video Quadrat

In this method, a quadrat is placed on the bottom and the fauna within its boundaries are videotaped. Each video quadrat is referenced with an information card. As with photoquadrat, the video is analyzed later. The advantages and disadvantages outlined for photoquadrats also apply to video. An additional advantage of video is that it can be analyzed as soon as the dive is complete. Its principal disadvantage is that videographic resolution is still borderline in regard to reliable identification of epifauna.

Surveying Solitary Macroinvertebrates

At QUEST, two methods are employed to survey solitary macroinvertebrates like echinoderms, mollusks, and annelids; quadrat search and nearest neighbor measurements.

Quadrat Search

Quadrats are placed at randomly selected locations along a transect line and searched for macroinvertebrates. At QUEST, quadrats used for this procedure are 1 m^2. To facilitate shoreline entry and exit with this large quadrat, a collapsible quadrat was developed. At the transect line location, it can be quickly assembled and later disassembled.

Using the quadrat search method, larger invertebrates can be accurately counted. With this method, numerous replicate quadrats can be used to calculate how sample organisms are distributed in space, specifically whether they are randomly distributed, aggregated, or uniformly spaced. A disadvantage of this method is the tendency to overlook small, inconspicuous, or rare species when larger sized quadrats are being searched.

Nearest Neighbor Measurements

For invertebrates that are widely spaced over the reef, like some urchin species, any one of several nearest neighbor Distance methods can be used to estimate their density on the reef. Each method has its own biases (see Krebs 1989 pp 126-148 for a more detailed discussion). At QUEST, the random point to nearest neighbor method is taught. A transect line is deployed and the diver proceeds down the line to the first of a series of locations selected by randomly generated numbers. The observer then measures the distance from the transect line location to the nearest target organism (at QUEST the target species is the collector urchin, *Tripneustes gratilla*.

From these measurement data, densities are calculated. In addition, patterns of spacing between organisms can be determined. The major advantage of this method is that surveys can be conducted without a quadrat. Furthermore, this method provides a good estimate of absolute density for rare, or widely dispersed organisms that are not frequently encountered using traditional quadrat procedures. A disadvantage of the nearest neighbor method is that density estimates are sensitive to the spatial distribution pattern of the organism being studied. Distance methods assume a random spatial pattern; deviations from this pattern may under- or over-estimate density (see Krebs 1988 pp 138-140 for ways to eliminate this bias).

Examples of data collected at QUEST

Although QUEST is a training workshop, the data collected during the field surveys can also be useful to detect large-scale changes in the reef community structure. Based on observations of students in the field, the data is probably most accurate for corals and macroinvertebrates and less accurate for fishes and seaweeds. The major inaccuracies are probably due to misidentification of species and undercounting of fishes.

Examples of data collected during QUEST are presented in Figures 3 and 4. The abundance of all fishes at the three surveyed isobaths is depicted in Figure 3A. In general, the abundance of fishes at each depth is similar with the major difference being the increase in fish abundance at the 8m isobath which increased over 100% between 1992 and 1997; Figure 3B depicts changes in surgeonfishes (Acanthuridae) and butterflyfishes (Chaetodontidae) over the same time period. The total number of all invertebrates is examined in Figure 4A for surveys conducted between 1993-1997. In general, abundances are similar

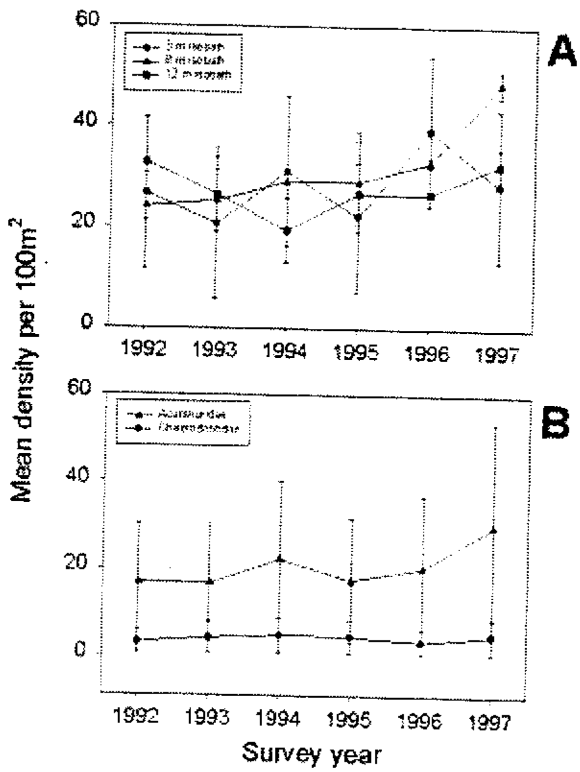

Figure 3 Results of fish surveys at Puako Reef, Hawai'i, 1992-1997. A) Abundance of all fishes observed at three sampled depths, B) Abundance of selected fish families

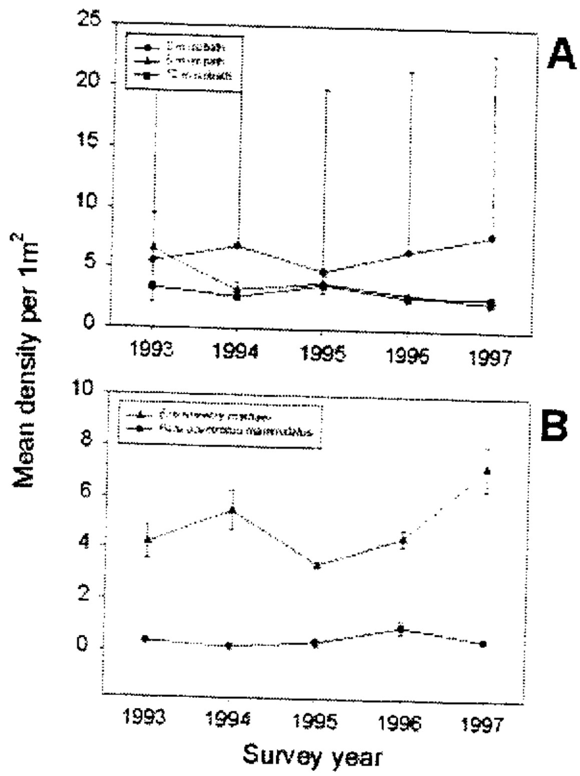

Figure 4 Results of invertebrate surveys at Puako Reef, Hawai'i, 1993-1997. A) Abundance of all invertebrates observed at three sampled depths, B) Abundance of selected invertebrates

among years with the major differences among depth being due to the highly mean abundance and variability of invertebrates on the reef flat (3 m depth); Figure 4B depicts changes in rock boring urchins (*Echinometra mathaei*) and slate-pencil urchins (*Heterocentrotus mammillatus*) over the same time period.

Use of QUEST graduates

Due to the severe shortage of people adequately trained to monitor coral reef communities, QUEST graduates have been involved with many coral reef projects throughout the state for many years (Maynard 1985; Russell 1997). For example, in 1998, QUEST graduates were involved in the following surveys in the state of Hawai'i:

Pin mooring impact study with UH, TORCH and DLNR (Oahu and Hawai'i)

Molokini baseline study with UH and DLNR (Maui)

Kona fish collecting impact study with UH and DLNR (Hawai'i)

Kealakekua Bay sport diver impact study with UH and DLNR (Hawai'i)

Maui reef surveys with the Pacific Whale Foundation (Maui)

It is likely that QUEST graduates will continue to be used in future coral reef surveys throughout the State.

Conclusion

We believe QUEST fulfills its goals in both teaching students a comprehensive array of modern reef monitoring techniques and providing well-trained individuals to assist with various coral reef monitoring and research projects. As Hawaii's population grows, government and the private sector will need to work together to insure that Hawaii's unique coral reef environment is not damaged from ever-increasing demands placed upon it. Informed policy decisions can only be made if reliable data on reef health are available. Training courses like QUEST will insure that the personnel needed to acquire these data are available.

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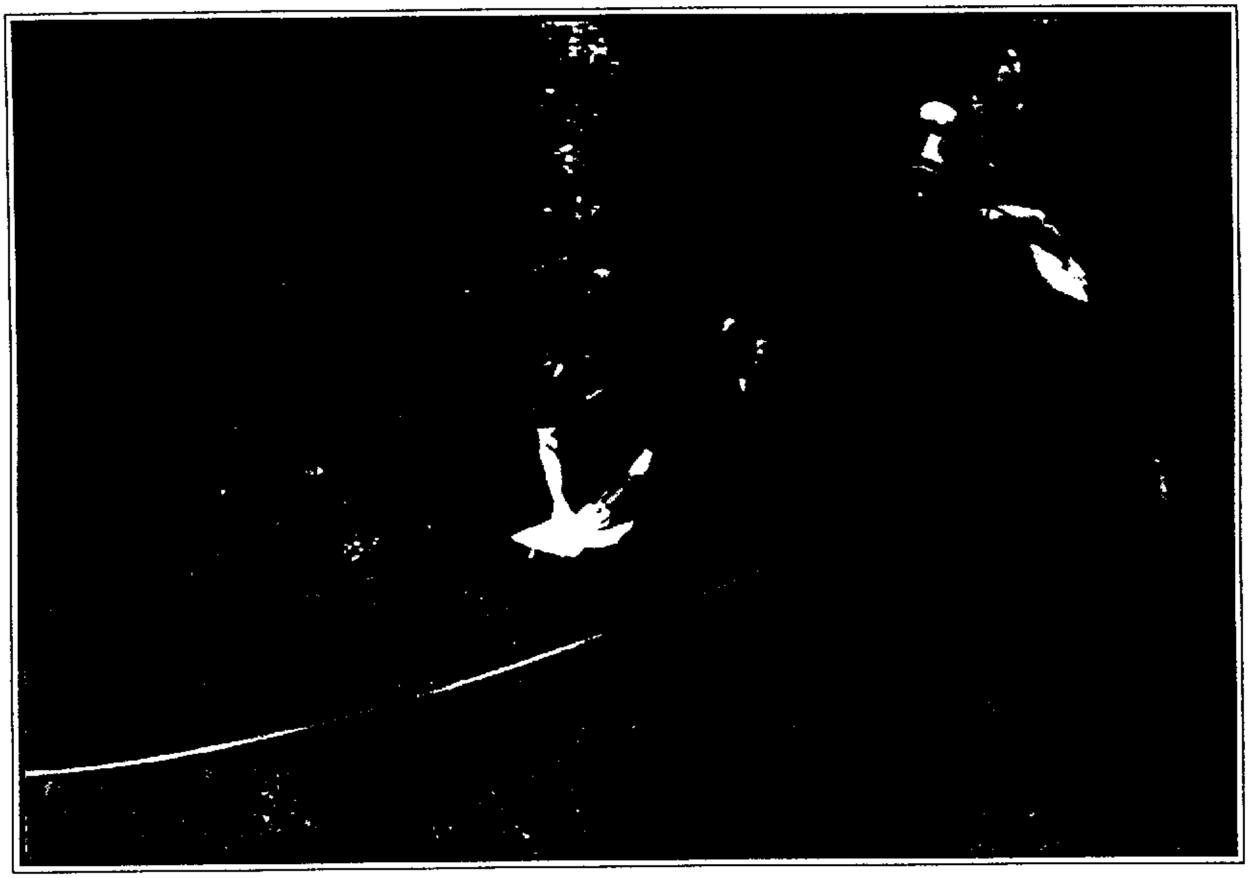

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