Chapter 17
Visual Observation of Fishes and Aquatic Habitat

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17.1 INTRODUCTION

Whether accomplished above the water surface or performed underwater by snorkel, scuba, or hookah divers or remotely operated vehicles (ROVs), direct observation techniques are among the most effective means for obtaining accurate and often unique information on aquatic organisms in their natural surroundings. Many types of studies incorporate direct observation methods, including broad-scale inventories of aquatic organism distribution and abundance (Hankin and Reeves 1988), highly specialized observations of behavior (Drew et al. 1976), evaluations of habitat use (Fausch and White 1981), estimates of population size structure (Griffith 1981), assessments of gear performance (High 1971; Jones et al. 2008), and censuses of surrogate structures such as spawning nests or redds to estimate fish abundance (Dauble and Watson 1997). Visual observation methods fall into three broad categories: direct underwater observation by divers (snorkel, scuba, and hookah), surface observation (land-based, aerial, boat-based, and viewing windows), and remote methods (cameras and ROVs).

Advantages of direct observation methods include their conceptual simplicity, versatility, cost-effectiveness, nonintrusiveness, and ability to obtain in situ behavioral information. Most direct observation methods are straightforward and accessible to both professionals and laypersons. Student volunteers or members of clubs and civic organizations can be trained to conduct counts and basic surveys. For example, the popularity of sport diving with snorkel or scuba has made possible broad-scale surveys of fish presence and relative abundance by laypersons (www.reef.org), similar to nationwide bird counts. Direct observation may be most appropriate when effectiveness of other sampling methods, such as capture by electroshocking, seines, gill nets, or trawls, is compromised by environmental conditions such as extreme conductivity (too low or too high for electrofishing), excessive depth (too deep to seine, conduct electrofishing, or capture fish without barotrauma), thick ice cover, or habitat complexity that can foul trawls or seines. The relatively modest gear requirements of most direct observation methods may reduce equipment costs and facilitate use in remote locations (Thurow 1994). The need for fewer personnel as compared with traditional methods results in less sampling time, thereby reducing cost and enhancing sampling efficiency (Hankin and Reeves 1988). For example, snorkeling requires fewer personnel and substantially less time than does depletion electrofishing (Mullner et al. 1998; Thurow et al. 2006). Direct observation methods also avoid the risks of potentially more destructive methods when sampling threatened, endangered, or sensitive species; because fish are not handled, they do not experience physical damage or barotrauma, and stress is usually minimized. The versatility of direct observation methods enables description of habitat structure and assessment of species distributions without the disturbance generated by capture sampling methods; for example, bottom substrate is not damaged by trawls, and fish are not herded by nets.

Investigators who are unfamiliar with visual observation methods may want to begin by reading section 17.2, which outlines various direct observation approaches and the variety of technologies and techniques available to fisheries biologists. Information about advantages and limitations of various methods is provided. With a basic grasp of what is possible, section 17.3 addresses how to decide if direct observation methods are applicable to your needs. This section outlines the benefits and limitations of visual observation techniques and addresses safety issues. Section 17.4 outlines approaches to validate direct observation methods to improve the reliability of data. Finally, section 17.5 describes quantitative data that can be obtained using direct observation methods and discusses how to apply the methods to meet your sampling needs.

17.2 VISUAL OBSERVATION TECHNIQUES AND EQUIPMENT

17.2.1 Direct Underwater Observation

Direct observations by divers allow rapid, "real-time," cost-effective measurement or estimation of species composition, population abundance, behaviors, and habitats. Methods may be fairly simple (e.g., snorkeling) or require considerable investment in training and equipment (e.g., scuba). Herein we use the term diver for any person who is immersed in water, whether that person is using snorkel, scuba, or hookah gear. The physical presence of divers in the water allows considerable versatility; divers can readily detect and quickly respond to changing conditions such as absence of target fish in the focal area. In contrast, conventional sampling often does not reveal absence of fish or problems with gear deployment until after the sampling is completed. Divers may also manipulate sampling site markers, collect or tag animals, or inventory habitat. This versatility is moderated by exposure to environmental hazards such as cold water, currents, and dangerous organisms. Moreover, underwater observation requires training, additional personnel to ensure safety and efficiency in the field, and method validation (section 17.4), all of which add to total costs.

17.2.1.1 Snorkel

Snorkeling requires the least equipment of all underwater observation techniques and is one of the simplest ways to observe organisms under water (Figure 17.1). Minimum equipment needs are a mask and snorkel; other equipment may be needed depending on the environment to be investigated. In nearly all waters, some form of thermal protection is required. The high thermal capacity of water drains heat from the human body; even in 25°C water, a person submerged for less than 1 h can begin shivering. A neutrally buoyant Lycra suit will keep a diver comfortable down to about 15°C, neoprene wet suits 2–7 mm thick are useful to about 7°C, and a dry suit is necessary in colder water or for extended time. Wet suits, as the name implies, allow water to seep between the diver and the suit to be warmed by the diver's body. Most dry suits have attached socks or boots and snug latex seals at the wrists and neck to prevent leakage. Under extremely cold conditions or for cold-sensitive individuals, insulating undergarments may be worn and a sealed hood and gloves can be attached to the dry suit.

Snorkeling is effective in a variety of environments. Small streams and rivers are normally well suited for snorkel observations provided underwater visibility is adequate. Small ponds and impoundments also are typically good environments for snorkeling, particularly in the littoral zone.

Figure 17.1 Snorkeler surveying a small montane stream (photo courtesy of U.S. Forest Service Rocky Mountain Research Station).

Snorkeling is especially suitable for remote locations where transport of other sampling gears may be difficult. Snorkeling is depth limited and, for certain types of observations, time limited; only exceptionally fit and conditioned persons can repeatedly surface dive to depths of 10 or more meters or remain at depth for more than 30–90 s. Consequently, snorkeling has limited application in deep areas of lakes, ponds, rivers, and marine environments.

Study objectives and environments dictate snorkeling techniques. For example, divers typically enter streams either upstream or downstream from the area to be sampled. A short resting period allows divers to become acclimated and allows any organisms disturbed by the divers' initial approach to resume normal behavior. Divers in deep pools typically proceed in a downstream direction by floating, whereas in shallow water, divers move upstream by crawling or pulling themselves along the bottom. Snorkelers in lentic or marine environments use swim fins to propel themselves through the water.

The type and consistency of data collected by snorkeling is highly dependent on light conditions and the time of day (Spyker and Van Den Berghe 1995). Investigators usually establish protocols for daytime sampling that specify certain hours with optimum light conditions (e.g., 1000–1700 hours). Observations conducted at night or during twilight hours require handheld or fixed-position underwater lights or chemical glow sticks. Disturbance or displacement can be minimized by not shining light directly on the animals, by directing lights to the underside of the water surface (Contor 1989), or by using color filters (Riehle and Griffith 1993). Differences in fish behavior during different times of the day or year may also affect detectability (Campbell and Neuner 1985; Rodgers et al. 1992; Spyker and Van Den Berghe 1995), as do differences in ability, training, and experience among snorkelers. Investigators need to recognize and account for variability among observers, especially when multiple divers are required to survey a large river or lake.

17.2.1.2 Scuba

More specialized equipment is necessary for scuba diving than for snorkeling. Divers wear tanks filled with compressed air, which is delivered by a mouthpiece that regulates airflow. Depth and pressure gauges, a buoyancy compensator, watch, and weight belt are also required, in addition to mask, fins, and a wet or dry suit (Figure 17.2). Scuba divers can remain submerged for much longer periods of time than snorkelers, but general sampling protocols for the two techniques are similar. Scuba is advantageous in large rivers, lakes, ponds, and many marine environments where organisms reside at greater depths than snorkelers can access. Lighting and visibility are important for successful observations using scuba diving. Scuba divers are able to occupy depths where light penetration may be limited, requiring underwater lights even in daytime. Scuba diving is noisier than snorkeling, and the bubble trails emitted by divers may disturb fish or other aquatic organisms.

Dive time is limited by the amount of air in a scuba tank. A standard 2.26-m^3 scuba tank carries sufficient air for a typical diver to breathe for about 1 h at a depth of 15 m; experienced divers tend to use air more slowly than do novices. Absorption of nitrogen into the bloodstream limits the duration of dives deeper than 15 m. At moderate levels of nitrogen absorption, divers may experience a slightly narcotic effect and decreased mental acuity. If excessive nitrogen is absorbed, it will move out of solution as the diver ascends, resulting in bubbles in the bloodstream—a painful, potentially debilitating condition commonly known as the bends. For symptomatic or undecompressed individuals, treatment involves placing the diver in a pressurized (hyperbaric) chamber to allow reabsorption of the nitrogen, then releasing the pressure slowly, over a period of hours to days, to allow the nitrogen to be safely purged. Prevention requires limiting the amount of nitrogen that is absorbed by carefully following decompres-

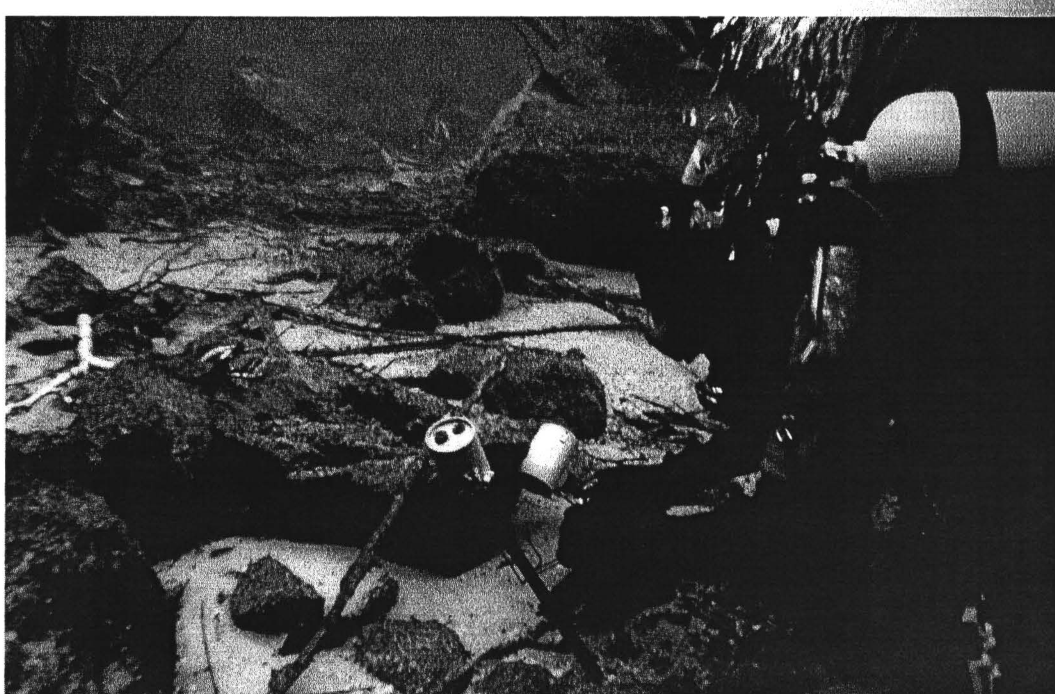

Figure 17.2 Scuba diver wearing a dry suit and using an underwater camera (photo by R. F. Thurow).

sion charts or making decompression stops of 10 or more minutes each at intervals on the way to the surface to allow the body to slowly purge nitrogen from the bloodstream. Divers must therefore understand decompression charts (Table 17.1). For example, divers breathing air (in contrast to breathing a specialized gas mix) have less than 15 min of working time at a depth of 33 m before they must ascend. The practical working depth limit for most divers breathing air from a standard tank is less than 25 m. Divers can, however, employ so-called saturation diving techniques that allow them to work indefinitely at greater depths, with the tradeoff that they must spend time in a hyperbaric chamber afterward. Divers may spend weeks in an underwater habitat (similar to a stationary submarine [http://aquarius.uncw.edu/]), with periodic dives out of the habitat; a single, though lengthy, decompression period is required only when they return to the surface.

Longer dive times or deeper depths or both also can be achieved by using nitrox (air enriched with oxygen) or heliox (helium plus oxygen) breathing mixtures, but these require specialized equipment and training. Nitrox mixtures increase dive time because less nitrogen is available to be absorbed into the bloodstream; however, depth is still limited by toxicity of oxygen at high partial pressures (Table 17.1). In heliox mixtures, helium is used in place of nitrogen to access depths of 60 m to more than 90 m, but oxygen is not enriched. Divers breathing heliox are protected from nitrogen narcosis, but decompression is still required to remove excess blood gas. Trimix, containing oxygen, helium, and nitrogen, is used for very deep dives to avoid physiological effects of breathing helium at high partial pressures.

Rebreathers employ chemical "scrubbers" to remove excess carbon dioxide from exhalations and recycle the remaining carbon dioxide with oxygen from an accessory tank for inhalations. The use of concentrated oxygen increases dive time relative to breathing pressurized atmospheric air, but more importantly, no bubbles are produced, thereby eliminating turbulence and noise caused by exhalations. This has advantages for diver radio communication, which is significantly degraded by the background noise of bubbles, and for studies of fish behavior, particularly those relating to sound production by fish (Lobel 2001).

Hazards of diving vary from minor, such as disorientation in murky water or currents, to life-threatening, such as entrapment in an underwater structure, uncontrolled ascent or descent, or running out of air (section 17.3.2.1).

Table 17.1 Comparison of safe dive times (in minutes) for various gas mixture and depth combinations (NAUI 2000).

	Gas mixture		
Depth (m)	Air	Nitrox (32% O_2)	Nitrox (36% O_2)
12	130	310	250
15	80	200	200
18	55	100	100
21	45	60	60
24	35	50	60
27	25	40	50
30	22	30	40
32	15	25	30

Blue-water diving. One of the most challenging types of underwater work is "blue diving," which is performed off shore at depths where the substrate is not visible. The absence of structure can be highly disorienting; only a direct view of the surface or the knowledge that bubbles must go up offer any hint of direction. The immediate hazard is the lack of perception of depth; without constant monitoring of a depth gauge, it is relatively easy for a diver to inadvertently sink to depths that will require decompression stops during resurfacing or descend to lethal depths. Consequently, blue diving often uses an array of lines with buoys, weights, and cross lines. Divers can be linked to the array with a clipped-in safety line, similar to crews working on a sailboat. The array of lines frames the work area and gives perspective for observations of fish or other subjects of interest. However, any structure in open water is an attractant to fish and may bias estimates of abundance and density.

Ice diving. Special hot-water or other liquid-filled suits are available for truly extreme cold conditions such as under ice or in polar regions. For infrequent, short-duration dives, a dry suit may suffice, as the specialty suits severely limit a diver's mobility and freedom and are expensive to purchase, use, and maintain. When under ice, divers must use tether lines to connect them to their exit hole.

17.2.1.3 Hookah (Surface-Supplied Air)

Hookah diving entails air delivery to a diver by an umbilical hose from an air compressor or compressed air bottles on land, or mounted on a boat or on a floating inner tube, which allows maximum mobility (Figure 17.3). Air pressures from a hookah system are much lower than with

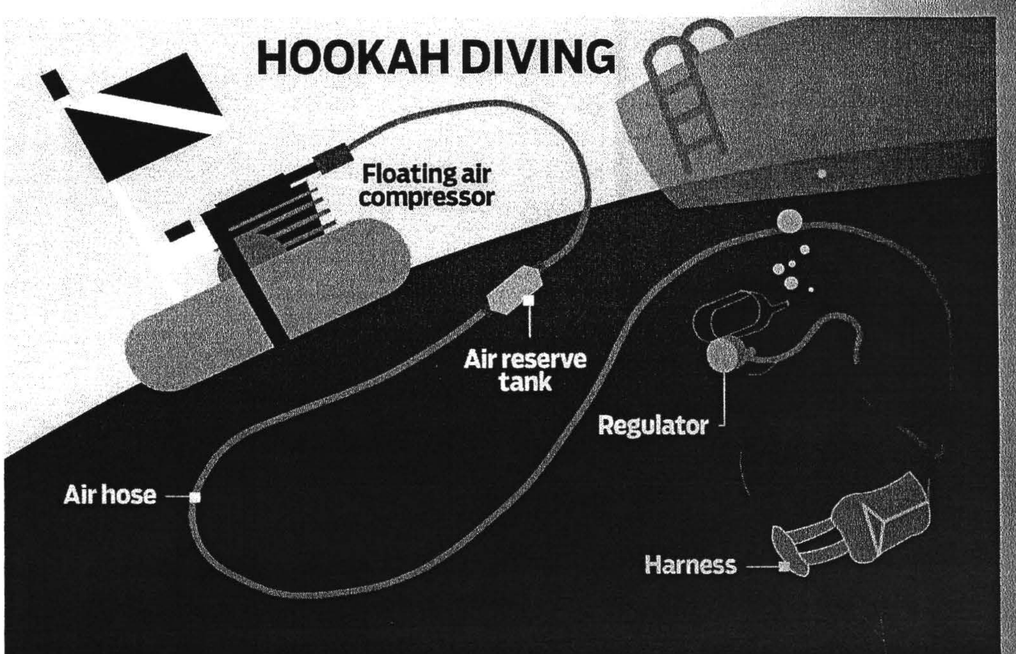

Figure 17.3 A hookah diving rig (graphic by D. Williams; reprinted with permission from the Tampa Tribune, Tampa, Florida).

scuba, about 2–3.5 atmospheres, and require a different air regulator; dive depth is therefore limited to 30 m. The major advantage of hookah diving is that air supply is essentially unlimited; dive duration is a function of the endurance and efficiency of the diver. Voice communication with surface support is also simplified by running a telephone cable along the air supply hose. Although unencumbered by a heavy, awkward air tank, a diver's mobility and range are limited by the umbilical hose. Most dive manuals recommend a minimum crew of three, including the diver, surface tender, and a fully equipped rescue diver, for any hookah diving operations that will exceed a depth of 10 m.

Hookah diving may be impractical in small streams or small, shallow rivers that can be sampled by snorkeling. Hookah diving is most useful in medium to large rivers and shallow lakes and ponds where divers must remain submerged for relatively long intervals and where few obstructions are present that could cause umbilical fouling. Hookah diving is popular for collecting aquatic organisms (Ahlstedt and McDonough 1993), ship and oil rig maintenance, and suction dredging. Commercial mussel divers typically use hookah rigs, which allow them to remain underwater for long periods relatively unburdened by cumbersome equipment.

17.2.1.4 Data Recording

Direct underwater observation requires special considerations for record keeping. Fish counts and other data can be recorded directly by the diver or communicated to an assistant. Waterproof slates and cuffs are popular data recording devices. Erasable slates are made from thin sheets of opaque acrylic (Jacobson 1994) or plastic laminate board (Gardiner 1984). A permanent marker can be used to create lines or a grid on the slate. A pencil can be secured to the slate by inserting it into the free end of a short (30 cm) piece of surgical tubing tied to a hole in the slate. The slate can be carried or attached to the diver; some divers carry slates or small clipboards in specially designed pockets or in the partially unzipped top of their wetsuits. The diver records information on the slate and then transfers it to a paper copy or to an assistant.

Many divers prefer to record data on a waterproof cuff made of white PVC pipe because a slate may be awkward, particularly when a diver must use both hands. A cuff leaves a diver's hands free, thereby reducing the possibility of losing valuable data. Cuffs are manufactured from thin-walled, 10-cm diameter pipe; the length of the cuff is adjusted to fit the diver's forearm. Thurow (1994) illustrated how to modify this basic design by cutting a length of pipe in half length-wise and drilling a hole at the corner of each half. Surgical tubing threaded through each pair of holes secured the pipe to the diver's arm. Pencils were attached to the ends of the surgical tubing. One drawback to slates and cuffs is that the writing surface is limited and the diver must frequently stop and transfer data to other media.

An underwater scroll is another alternative for recording data (Ogden 1977). A scroll consists of a long strip of translucent, matte-surface, polyester drafting film that is fed between two rollers across a flat sheet of stiff plastic. A scroll eliminates the need for single sheets and provides a large, continuous writing surface. Tabular data forms, maps, or photographs can be attached to the flat plastic surface, and data can be recorded on the film. After completing data entries, the film is advanced to provide a clean writing surface. Scrolls can be awkward to operate, particularly by a diver wearing gloves or mitts.

Waterproof paper can be used to record data underwater (Graham 1992). Data forms can be copied and attached to a clipboard to provide a hard writing surface. Large rubber bands fix the paper to the clipboard to prevent it from moving freely. Taxonomic keys or sample protocols also can be copied on waterproof paper and attached or laminated to the clipboard. Data are recorded on the field forms and later transcribed to other media. The clipboard has similar disadvantages to the waterproof slate, and turning pages with gloves is particularly difficult. Waterproof paper has a tendency to smear, so caution must be used when recording and transcribing data.

Alternatives to writing data include sign language (Lee 1967) and verbal communication to transfer information to an assistant on the surface. The assistant records the data and the diver is free to continue the survey. The assistant provides the diver with information on survey boundaries, sample protocols, and potential hazards. Data can also be recorded on electronic voice recorders. For scuba, diver-to-diver and diver-to-surface radio communication also is possible with radios built into specialized, usually full-face, masks so that divers do not have regulators in their mouths. Radio communication is limited by the noise of diver exhalations; generally, divers must speak in one-breath intervals. Holding one's breath must be avoided because it alters buoyancy and also increases the risk of an embolism while ascending.

Diver-held cameras provide a permanent record of visual data. Still or video images can be reviewed to verify or gather additional data or fed into image analysis software to obtain more detailed information. This is particularly useful when censusing multiple species, as unique search images can be developed for each species. Still or video images are valuable for training observers and calibrating inter-observer variation. Digital cameras are available that will record at light levels down to 0.0003 lx, though more light is needed for color images and image resolution degrades considerably at low light levels. Color attenuates quickly with depth, and short wavelengths (reds) usually disappear within 10 m. To identify species, sex, or life stage of many fishes, use of camera lights is necessary to reveal colors and markings. Suspended particles such as plankton or sediments add substantial "noise" and interfere with the ability to detect fish during playback of videotapes. In addition, cameras set on autofocus will tend to focus on the nearest plankton particle rather than the 2-m shark in the near distance. At low light levels, such as in deep or cloudy water, fish can often be more easily observed by pointing the camera directly upward to silhouette fish against the pale water surface. Disadvantages of all recording devices are the expense of the equipment, need for specialized training, and potential for loss of data caused by equipment malfunction.

17.2.2 Above-Surface Techniques and Equipment

A variety of terrestrial and water-surface-based approaches are useful for directly observing fish. These include observations of various life stages ranging from young-of-the-year to adults as well as observations of surrogate structures such as spawning nests. Observers may apply several approaches to collect these data including surveys from streambanks, counting towers, boats, rafts, or aircraft or through counting windows at dams or fishways.

17.2.2.1 Observations from Streambanks

Visual counts from streambanks are a preferred method for assessing fish populations when shallow water depths preclude underwater observation or when alternative capture methods that generate mortality need to be avoided (Bozek and Rahel 1991). Visual counts from streambanks may also be combined with underwater survey methods (Moore and Gregory 1988; Bonneau et al. 1995). Redd counts (section 17.2.2.4) are often conducted from streambanks.

Counts from streambanks are relatively simple to perform and require only a modest amount of equipment. One or more observers walk or crawl along the streambank, taking care to avoid frightening fish. When counts are made from both streambanks, observers should position themselves opposite one another and move at the same rate along the stream on opposite banks. When multiple observers or a bank observer and snorkeler are collaborating in counts, communication is essential to ensure that all fish seen are tallied only once.

Observers typically wear polarized sunglasses to avoid glare on the water surface. In cases where glare or turbulence reduces visibility, clear-bottom plastic buckets or viewing tubes may facilitate viewing (Mason et al. 1991). Bozek and Rahel (1991) towed a clear plastic sled across turbulent, small Wyoming streams to count Colorado River cutthroat trout fry. With a little ingenuity, an enterprising observer can fabricate a wide variety of simple devices to counter the effects of glare and turbulence. Viewing tubes can also be used from shore or small boats to locate fish and survey underwater habitats (Mason et al. 1991).

Many of the same considerations that affect accuracy and precision of other types of direct observations also influence counts from streambanks, including water clarity, water depth, cover type and abundance, fish fright response, cryptic coloration of fish, and glare on the water surface (Bozek and Rahel 1991). Depending on conditions, counts from streambanks may be superior to alternative methods such as electrofishing (Bonneau et al. 1995; but see Fraley and Shepard 1989), but it is essential to validate counts from streambanks to assess how well the technique approximates actual abundances.

17.2.2.2 Counting Towers

When conditions permit, fish can be viewed and counted by observers located in towers or from any elevated position offering an unobstructed view of a clearly defined sample field (Woody 2007; Figure 17.4). The equipment required is relatively simple to assemble and operate, often consisting of no more than a wooden or aluminum frame topped by a platform and accessed by a ladder, a bank-side tree, or even a bridge. Observers in the Pacific Northwest take advantage of the tendency of salmon species to migrate along specific routes to count migrating adult salmon. Tower counts are used to estimate reproductive population abundance and escapement, to accumulate data for forecasts of future returns, and to help set harvest rates. Fish counts from towers are influenced by tower location within a watershed, water transparency, weather, stream channel characteristics such as substrate color and channel shape, and observer variability. Towers typically are constructed well upstream of tidally influenced reaches to decrease the likelihood of counting fish that are not consistently moving upstream. The choice of specific location is guided by field reconnaissance of fish migratory patterns. In general, shallow (<3 m), relatively fast-water sites are preferred locations both for enhanced visibility and because fish are less likely to linger there than in deeper, slower-velocity areas. Light-colored substrates also are preferred, and white panels placed on the streambed enhance contrast. Tower position can be adjusted to reduce glare, but other prevailing conditions such as wind, rain, and turbidity are largely uncontrollable. Towers could be staffed continuously to obtain an absolute count of all migrating fish, but continuous counts are both unnecessary and impractical; accurate, reliable estimates can be obtained by sampling less frequently. One major issue is observer fatigue and boredom, caused by either too many fish passing or, conversely, few or none. Counting error can be minimized by stipulating frequent breaks and relatively short counting intervals, typically no more than 20 min at a stretch. Nonrandom, systematic sample intervals of 10–20 min per hour over 24-h sample periods yielded relatively low error compared with counts obtained from longer intervals (Woody 2007). Sample counts are expanded by an appropriate factor to obtain estimates for the entire sample period. Counts must periodically be calibrated, preferably by an alternate method.

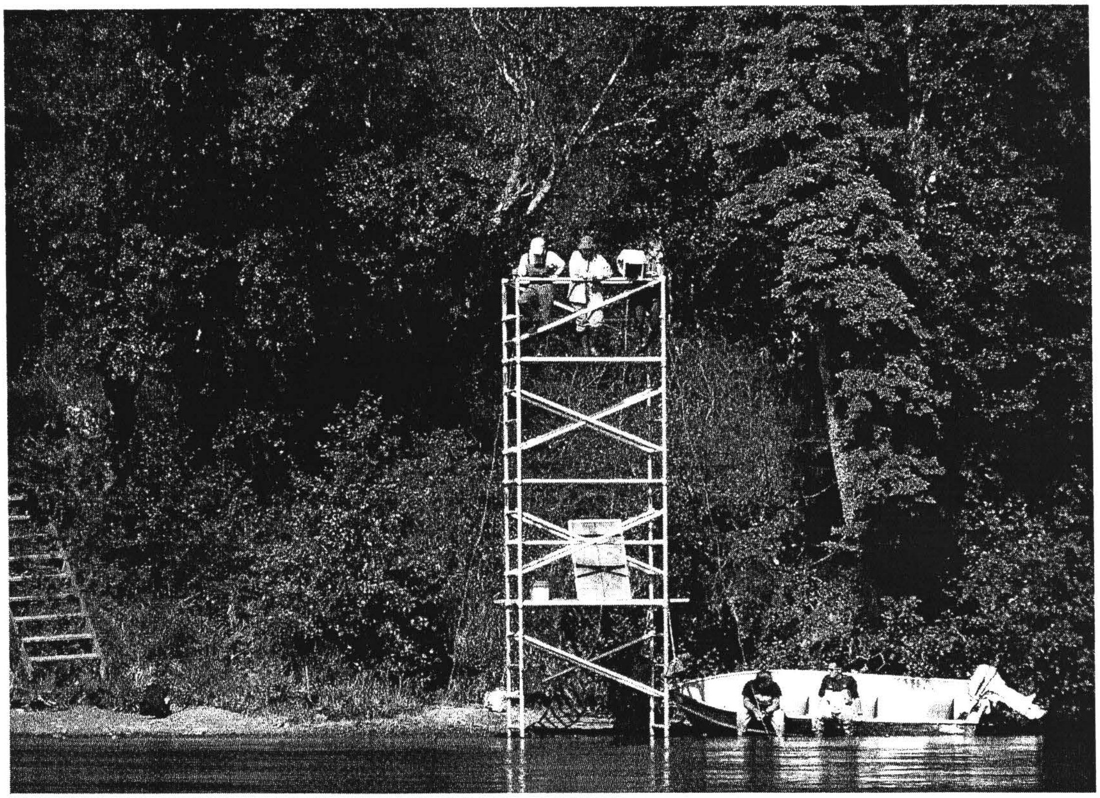

Figure 17.4 Tower for counting migrating Pacific salmon in the Wood River, Alaska, operated by the Alaska Department of Fish and Game (photo by M. Adkison, University of Alaska Fairbanks, with permission).

17.2.2.3 Counting Windows

Many fish ladders in dams and other structures are equipped with underwater viewing chambers in which observers count fish as they ascend ladders. Fish can also be observed from the surface above a dam or weir. Temporary installation of constriction weirs is valuable for reducing the area through which fish pass, although this approach may reduce accuracy of counts if large numbers of fish are traveling together. Observations must be made over an entire 24-h period to determine the periods of highest fish movement; after this determination is made, counts can be stratified to concentrate observations when counts will be highest. Use of videography, including time-lapse recording, reduces the number of observers that must be present to make replicate counts and increases the number of stations that can be observed simultaneously. This method overcomes the problem of observer saturation, which occurs when too many fish pass a viewing point for an observer to count in real time. At low fish densities, Newcomb and Coon (2001) required only 3 h to review 8 h of recorded video. They also reported that counts from surface observation and time-lapse videography were much lower than mark–recapture estimates, probably because of violations of mark–recapture assumptions (Chapter 11).

17.2.2.4 Aerial Surveys

Fish counts. Aerial surveys have been used for decades to monitor fish populations, particularly aggregations of relatively large, conspicuous species such as salmons (Bevan 1961). Commonly, a series of helicopter or fixed-wing flights is made at intervals throughout the spawning period (Neilson and Geen 1981). One or more observers wearing polarized sunglasses counts adult salmon, either directly on spawning grounds or in deeper staging areas. In many cases, an area-under-the-curve (AUC) estimate of total salmon escapement (the number of spawners that have escaped harvest) can be computed from sequential aerial counts of fish combined with estimates of the residence times of spawners (Neilson and Geen 1981). The point estimates of fish abundance are connected to form an escapement curve. The integrated area under the curve yields the number of spawners only if the residence time is one day. If the residence time varies, then the total number of spawner-days is divided by the mean residence time to generate the escapement estimate (i.e., escapement = AUC/residence time).

Three sources of error affect the precision of escapement estimates generated by the AUC method: (1) measurement error associated with the counts, (2) imprecision of curve shape if fewer than daily counts are used to define the curve, and (3) measurement error associated with estimation of residence time (Hill 1997). Measurement error of counts is affected by water clarity, observer experience, weather, fish abundance, aircraft type, and pilot experience (Neilson and Geen 1981) as well as water depth (Hill 1997) and canopy type and density (Thurow and McGrath 2010). Counts are most likely to be biased low because some fish will not be detected. Estimates of residence time may also be biased as a result of a difference in residence times of males and females (Hill 1997). Simulation modeling showed that confidence in estimates increased as the frequency of survey flights increased, especially when residence times were short (Hill 1997). Such models can help managers optimize the frequency of aerial flights by comparing the benefits of frequent flights (increased precision in estimates) with the costs of those flights.

Counts of surrogate structures or redds. Under certain conditions, counts of live fish may be more difficult or less desirable than counts of surrogate structures. For example, counts of spawning nests or redds can be used as an indicator of fish presence and relative abundance (Burner 1951; Dauble and Watson 1997; Moser et al. 2007). Redd counts can be correlated with adult escapements (Hay 1987) as well as juvenile abundances (Beland 1996). Moreover, the distribution of redds across a landscape may also serve as a useful proxy for understanding important biological or physical processes (Montgomery et al. 1999; Isaak and Thurow 2006). The Idaho Department of Fish and Game has conducted annual counts of spring and summer Chinook salmon redds during the peak spawning period in selected index areas of Idaho since 1957 (Hassemer 1993). Cumulative redd counts or counts that are completed near the termination of the spawning period provide an index of total Chinook salmon abundance. Redd counts are preferable to adult Chinook salmon counts in Idaho because adults are not readily visible within most of the areas monitored.

Redds are counted by one or more observers wearing polarized sunglasses, either from the ground or during low-elevation helicopter (Figure 17.5) or fixed-wing flights. When feasible, it is desirable for surveys to be conducted by the same observer to avoid introducing inter-observer bias (Dunham et al. 2001). Ground and aerial surveys are typically conducted between 0900 and 1800 hours to take advantage of direct overhead light. Ground-based redd surveys are completed by observers walking streambanks where tree canopy precludes aerial observation, where traditional counts were ground-based, or when funds are unavailable for aerial surveys. Observers are trained to watch for live fish that are staging or spawning and to avoid disturbing them. Streams

Figure 17.5 Aerial view of a Chinook salmon redd, in the ellipse to the right of the helicopter shadow (photo by R. F. Thurow).

are crossed only when necessary to avoid walking near redds. Redds are identified by their characteristic morphology, which includes a depression or "pit" at the upstream edge and a mound of gravel or "tailspill" at the downstream edge (Burner 1951). Locations of redds are georeferenced using the Global Positioning System (GPS) or marked on a detailed topographic map. Redds of the target species are readily differentiated from those of other species in locations where little overlap exists in spawning timing among species or if species or redds differ substantially in size (e.g., Chinook salmon and bull trout; Isaak and Thurow 2006). An exception may occur in systems where multiple species of similar size have overlapping spawning locations and times (e.g., Chinook, coho, pink, chum, and sockeye salmons in coastal rivers). Where multiple species spawn simultaneously, repetitive redd surveys conducted at short time intervals may enable observers to identify spawning fish and their redds by individual species.

Aerial redd surveys are effective for surveying large areas in a relatively short time. In central Idaho, biologists survey about 800 km of potential spawning areas in 5–6 person-days (Thurow 2000). Ground surveys of the same area would require perhaps 80 person-days for the actual surveys and additional days to access remote sites. Surveys from a helicopter can provide optimal visibility because an experienced pilot is capable of maintaining airspeeds of 20–40 km/h and altitudes of 15–50 m, depending on the surrounding terrain.

A variety of redd-specific (e.g., age, size, and density), stream-reach-specific (e.g., stream shading, habitat complexity, turbidity, and depth), and observer-specific (e.g., experience of the observer or pilot) errors of estimation may result in redd count errors (Thurow and McGrath 2010). Quantification of these errors and validation of counting methods is a critical aspect of redd counts (section 17.4.2).

Habitat surveys. Aerial surveys are also valuable for locating and quantifying habitats such as macrophyte beds or reef structures (Chapters 4 and 10). Calm water and low turbidity are critical for good visibility.

17.2.3 Remote Observation Techniques and Equipment

Remote observation involves use of underwater cameras to replace direct human observation. Cameras may be stationary or mounted in vehicles of varying mobility and complexity. These methods allow observation in areas otherwise inaccessible to surface observation or divers or where prolonged periods of observation are impractical with other methods. Fish behavior is generally unaffected by the camera, provided no noise is produced. Use of baited cameras has been particularly valuable for detecting and enumerating cryptic species; however, taxonomic biases are induced by use of bait, and species richness is more reliably sampled than species abundance (Stobart et al. 2007; Stoner et al. 2008). Visual data are recorded for later examination and enumeration of fish or habitat (section 17.2.1.4).

17.2.3.1 Cameras

Remote-sensing methods allow specialized underwater sampling where conditions such as extreme cold or excessive depths preclude or inhibit direct observation. Underwater cameras are popular for conducting surveys. Waterproof cameras (still or video) may be placed in blinds (camouflaged areas in a fixed location) and remotely operated to take pictures at predetermined frequencies. Remote cameras and lighting systems allow investigators to obtain information on populations of organisms at any time of the day or night. They can be set to operate continuously or at predetermined intervals. More sophisticated systems have triggering mechanisms that are activated by movements such as the passing of a school of fish, making these cameras particularly useful for monitoring migrations.

Remote cameras have several disadvantages. Cameras, light sources, underwater housings, and remote sensing equipment are expensive to purchase and maintain. Divers are generally required to install and periodically to service equipment. Remote cameras are also limited by the same conditions affecting underwater observers: low-light or turbid water may render cameras ineffective or result in poor sampling efficiency. To obtain the best results, we recommend that remote cameras be used in combination with other methods.

Digital underwater cameras, either waterproof or with a small housing, have become widely available and are relatively inexpensive. Inexpensive cameras are generally limited to depths of less than 10 m. Systems tailored for underwater work allow the addition of various lighting options. Further details on uses of still cameras are covered in section 17.2.1.4.

17.2.3.2 Mobile Submersibles

Another alternative to "being there" is the use of mobile submersibles. Technology has advanced since Beebe's bathysphere (essentially an occupied lead balloon on a rope), and the number of institutions with submersibles is increasing. Unfortunately, increases in cost, infrastructure, support requirements, and specialized training have been exponential and prohibitive for most researchers. However, institutions such as the National Undersea Research Program (www.nurp.noaa.gov/index.htm) provide equipment and personnel for high-profile projects that require submersibles (Donaldson and Tusting 1997).

The three general types of submersibles are ROVs, autonomous underwater vehicles (AUVs), and deep submersible vehicles (DSVs); the latter have pilots on board. Remotely operated vehicles have umbilical cables for power and digital communication with surface vessels; their movements are controlled by a pilot at the surface. Autonomous underwater vehicles carry their own power and a preprogrammed dive mission, though instructions may be transmitted to the vehicle from the support ship. Most fisheries work, except some deep oceanic research, is confined to the use of ROVs, primarily because of the cost of AUVs and DSVs; however, lower-cost and smaller AUVs are being developed (Alvarez et al. 2009). Therefore, our focus is on ROVs with the understanding that additional capabilities and range are possible with the more sophisticated technology of AUVs and DSVs.

The simplest underwater video system is a camera at the end of a 30–60 m cable (a "scope on a rope"). These have become popular in recent years with anglers who hope to view their intended catch; advances in digital technology have reduced the size from the early "cannonballs" to cameras that are barely larger than the diameter of their 1.25-cm cable. A basic underwater camera can be purchased for US$100–200, exclusive of a surface monitor and recorder. These cameras can be used for stationary observation or mounted on a sled and towed behind a boat for transect or area surveys (Sanchez et al. 2009). A lightweight frame made of PVC or aluminum conduit can be used to set a camera at a fixed height above the substrate or to tilt the camera angle. Mueller et al. (2006) fixed a camera to an extendable pole to make observations under the ice.

Remotely operated vehicles. A true ROV is a video camera mounted in a frame that has thrusters and controls to propel the camera forward, backward, up, and down and to rotate the frame (Figure 17.6). The thrusters must have sufficient power to propel both the camera vehicle and the umbilical cable. In shallow water, or if the vehicle is traveling less than about 30 m, the ROV can be quite small (Figure 17.7) and inexpensive. Some simple devices can be constructed inexpensively. For work at greater depths, or if lights or sampling equipment are needed, the vehicle and thrusters must be larger and more powerful, resulting in higher cost to purchase and operate. For most large lake or ocean work, a support vessel is needed that has a davit (mechanical arm with a winch) or trawl frame to lower and retrieve the ROV and space for the monitor and associated video recording equipment. In addition to these basics, ROVs can be fitted with a variety of optional equipment and offer the advantage of essentially unlimited underwater time. Lights allow night work, still and video cameras can both be mounted on the vehicle, grabber arms can be used to manipulate objects, and suction samplers and electroshocking units can be used to capture organisms. Distances to target substrates or organisms in the field of view can be estimated with twin laser beams set on the sides of the ROV at a known angle from each other; the distance between the laser spots on the target allows calculation of distance to the camera (Davis and Tusting 1991).

The advantages of ROVs are offset by their cost, including a large support vessel, crew, an experienced pilot to operate the ROV, and a technician to troubleshoot the electronics. In addition, ROVs are limited by their umbilical cables. Towing the cable limits the speed and maneuverability of the vehicle, and the potential for snagging or tangling the cable is a constant threat. Additional problems are created near soft substrates where the down-thrusting rotor can stir up sediment clouds and blind the camera. Several of these problems have been partially solved with

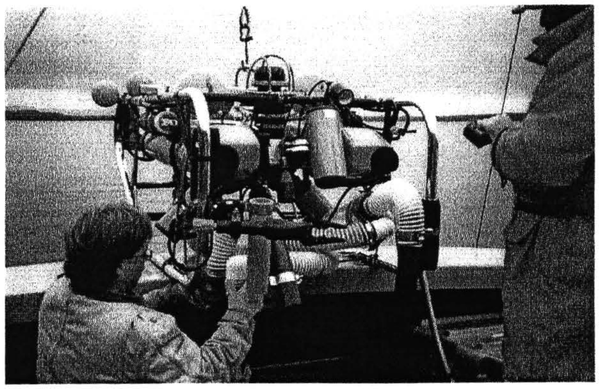

Figure 17.6 Remotely operated vehicle (ROV) used by the National Undersea Research Program and equipped with a suction sampler for collecting fish eggs (photo by J. E. Marsden).

mini-ROVs, which can be built in a shop for less than $1,000. Mini-ROVs are the size of a small suitcase, are lightweight, and have a small umbilical cable. Designs have been developed by high school and college engineering "challenge" projects, and several designs are available on the Internet. The SeaFox is one of the more widely used examples (www.eng.newcastle.edu.au/eecs/fyweb/Archives/2004/c2004223/index.html).

Submersibles with pilots. A submersible with a pilot on board, or DSV, is basically an ROV or AUV with the brains on the inside. Although capable of independent operation, submersibles may be tethered to a surface vessel to provide an extra measure of safety and direct communication. Requirements for life support (e.g., oxygen and power to provide heat) restrict their operating time; however, a piloted submersible can respond quickly, and crews enjoy higher visibility than when using an ROV. Typically, DSVs have a hemispherical window for observation and are equipped with mobile cameras. Deep submersible vehicles are supported by a mother ship, gener-

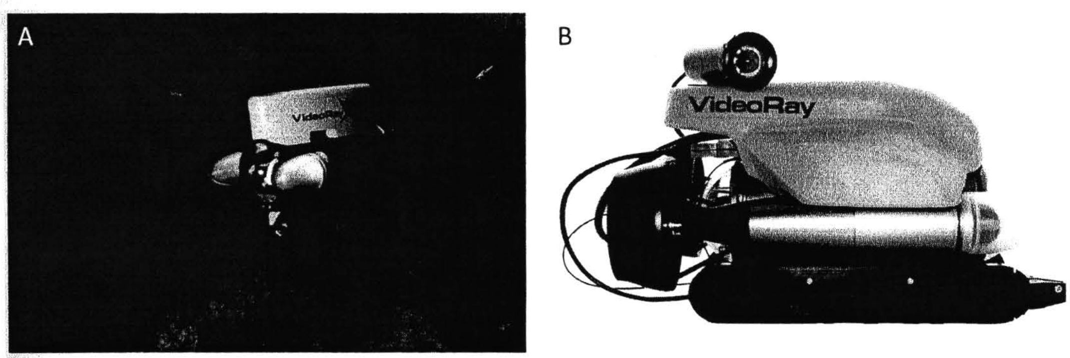

Figure 17.7 Two small, remotely operated vehicles (ROVs): **(A)** this unit is slightly larger than a shoebox, weighs 4.5 kg, and is depth rated to 150 m; **(B)** this larger unit has a grabber arm and externally mounted second camera and is depth rated to 300 m (photos courtesy of VideoRay LLC, Phoenixville, Pennsylvania, with permission).

ally carry a pilot and two crew members, and are capable of dives to nearly 6,500 m (CUVNN 1996; Table 17.2).

17.3 METHOD SELECTION CONSIDERATIONS

17.3.1 Definition of Objectives

Although myriad advantages provide compelling reasons for choosing direct observation methods, the first and most important step in any investigation is to define its goals and objectives clearly or, simply put, to ask the right questions. The investigator then considers which biological indicators are most appropriate to meet study objectives. Ultimately, the investigator determines whether direct observation methods are appropriate and feasible to measure or estimate the desired biological indicators.

17.3.2 Limitations of Direct Observation Methods

Direct observation methods have a place in the repertoire of nearly all fisheries professionals, yet they are not without unique limitations. The application of direct observation techniques may be compromised by safety considerations, the need for specialized training and equipment, limitations imposed by habitats, or the inability to collect data from individual organisms.

17.3.2.1 Safety

Each direct observation method has its own unique set of hazards that needs to be assessed and addressed prior to employing the method (Box 17.1). Hazards include but are not restricted to fast-moving water, cold water temperatures, poor visibility, physical obstructions, contaminants, challenging terrain and weather conditions, and dangerous organisms. The potential hazards of a site should always be assessed before beginning a survey. Training to recognize and treat the symptoms of hypothermia is especially critical for underwater observation (Dolloff et al. 1996). Hazards of scuba diving vary from minor disorientation in murky water or currents to life-threatening concerns such as entrapment in underwater structures, uncontrolled ascent or descent, or lack of air. Familiarity and comfort with personal equipment, working conditions, and any specialized gear are essential for diver safety. Divers must never dive alone; at a minimum, a support diver should be on the surface or streambank whenever a diver is working underwater. Many agencies and institutions require two divers in the water and one support diver on the surface for all diving operations. In lentic waters, a "diver down" flag on a boat or buoy, consisting of a broad white diagonal stripe on a red background, signals the presence of divers; boaters must make a reasonable effort to maintain a distance of at least 30 m from the flag. However, many boaters do not know or respect the meaning of this flag and may approach out of curiosity or deliberate harassment. The "alpha" signal flag, a swallow-tailed flag separated vertically into white and blue halves, indicates "I have a diver down; keep well clear at slow speed" under the International Code of Signals but is not recognized by many boaters. Divers should be familiar with local, state, or national regulations.

17.3.2.2 Specialized Training and Equipment

As with any specialized method, technical skills and appropriate equipment must be acquired. Training is essential for successful application of direct observation surveys. An initial investment in crew training will help ensure observer safety and collection of accurate information. Training should address safety, equipment, observation techniques, and data collection and recording

Table 17.2 Comparison of underwater vehicle capabilities (CUVNN 1996).

Parameter	Underwater vehicle: Deep submersible vehicles (DSVs)	Remotely operated vehicles (ROVs)	Autonomous underwater vehicles (AUVs)
Definition	Untethered, human-occupied, free-swimming, undersea vehicle	Tethered, self-propelled vehicle with direct real-time control	Untethered undersea vehicle; may be totally preprogrammed and equipped with decision aids to operate autonomously or operation may be monitored and revised by control instructions transmitted by a data link
Depth	Most DSVs dive to 1,000 m; few to 3,000 m; very few to 6,000 m; and one to 6,500 m	Most ROVs dive to 500 m; many to 2,000 m; few to 3,000 m; few to 6,000 m; and one to 11,000 m	Several AUVs dive to 1,000 m; few to 3,000 m; and very few to 6,000 m
Endurance time	Normally 8 h, 24 to 74 h maximum	Indefinite, depending on reliability and operator endurance	6 to 48 h of propulsion; may sit on bottom for extended periods
Range	<50 km	Distance from host ship limited by tether	350 km demonstrated; near-term potential 1,500 km, depending on energy source
Payload	45 to 450 kg (1 to 3 people); adaptable to tools and sensors	45 to 1,590 kg; adaptable to tools and sensors	11 to 45 kg; adaptable to measuring equipment, tools, and sensors
Support ship	Most DSVs require support by a large ship; ship size varies with DSV size	Dependent on ROV size and mission requirements	Medium—dependent on AUV size and mission requirements
Navigation systems	Relative to seafloor or surface vessel	Relative to surface or seafloor	Seafloor and inertial navigation
Strengths	Direct human observation and manipulation; real-time feedback to operator	Real-time feedback to operator; long endurance capability; low cost per operating hour	Potential for automated operations; ability to operate with or without human command and without tether; minimum surface support
Limitations	Large size, weight, and cost because of operator requirements; limited mission time; potential operator hazards	Tether cable potentially limits maneuverability and range	Energy supply; bandwidth of data link; capacity of internal recorders; limited work function complexity

Box 17.1 Safety Checklist for Divers and Snorkelers

1. Be in good physical condition as certified by a physician within the last 12 months.
2. Never work in water alone; diving teams consist of a minimum of two persons. Divers and snorkelers must *always* be accompanied by observers on the bank or in a boat to assist in case of an accident.
3. Certify crews in cardiopulmonary resuscitation (CPR) and basic first aid (Chapter 3). Be sure that crews can recognize and treat hypothermia.
4. Carry a first-aid kit at all times including a device for extracting venom and medication to prevent anaphylactic shock (resulting from insect stings and some snake bites) as prescribed or recommended by a physician.
5. Be certain that persons not in the field know the work location and schedule. Carry two-way radios or cellular or satellite telephones for rapid communication with emergency personnel. Carry telephone numbers and addresses of nearest medical facilities, fire or rescue stations, and police departments.
6. For scuba, consult and follow diver decompression tables and carry telephone numbers for the closest decompression chamber.
7. Develop and follow a safety plan for all underwater operations. Address the following as appropriate:
   a. water temperature and maximum time of submersion;
   b. escape routes and rescue protocols for potentially dangerous situations;
   c. equipment requirements and condition; and
   d. potential risks of the environment and recommended prevention and treatment.

(Thurow 1994). In some cases, more formal training and certification may be required, such as the diver certification programs sponsored by the National Association of Underwater Instructors and the Professional Association of Diving Instructors. Equipment needs are specific to the body of water and type of study; basic snorkel, scuba, and safety equipment is listed in Box 17.2.

17.3.2.3 Environmental Requirements

Although direct observation methods can be used to gather a wealth of vital information, observations are limited for all methods by local environmental conditions such as water clarity, currents, waves, substrate complexity, and water depth.

Water transparency. All types of direct observation are influenced by visibility. Visibility is affected by turbidity, which is the amount of suspended matter, and to a lesser extent by color, which is influenced by dissolved organic and inorganic matter. Suspended matter includes both living and dead plankton and other organic material and small mineral or inorganic fragments. Bubbles from scuba and water turbulence may also affect visibility. In many streams, rivers, lakes, estuaries, and ocean environments, it may be impossible to conduct observations because of episodic or perpetually high turbidity. Poor visibility can result from a variety of natural and human causes. Soil erosion from nearshore areas is among the most common long-term causes of poor

Box 17.2 Equipment Checklist for Fish or Habitat Surveys Using Underwater Visual Techniques

Essential equipment is marked with an asterisk; other equipment needs depend on local dive conditions and survey objectives.

Basic snorkel equipment (section 17.2.1.1)
*Mask and snorkel
*Wading boots or swim fins
Wet or dry suit
Neoprene hood, gloves, and booties
Knee pads
Weight belt
Knife
Dive watch
Underwater data recorder (e.g., slate or cuff)
Clipboard and data form
Camera
Hand tally counter
Fish silhouette for measuring visibility
Calibrated thermometer
Flagging
Tape measure
Stadia rod
Underwater dive light and spare batteries
Flashlight or headlamp
First aid kit including swimmer's ear drops
Mask defogger
Neoprene or dry suit repair kit
Drinking water
High energy food

Additional scuba items (section 17.2.1.2)
*Tanks and backpack
*Regulator
*Pressure gauge
*Depth gauge
*Buoyancy compensator vest
*Dive tables or dive computer

Additional hookah items (section 17.2.1.3)
*Air compressor or air bottles
*Umbilical hoses and filters
*Regulator
*Harness
*Full face mask
*Pony bottle and regulator (emergency air)
*Depth gauge
*Weight belt
Communication gear (e.g., microphones)

visibility. Storm waters transport sediments from disturbed land surfaces, resuspend materials in nearshore waters, and cause scouring and resuspension of sediments in flowing water. Under favorable conditions of light, temperature, and nutrient concentrations, biological production can soar, greatly increasing the amount of suspended plankton. In highly productive, eutrophic waters, horizontal visibility often can be less than 1 m; in less fertile oligotrophic areas, divers can recognize fish and habitat up to 75 m away. In lentic waters, areas of low visibility are generally confined to the epilimnion and nearshore regions in proximity to soft sediments. Investigators must use particular care when operating over silt substrates, where incautious movements or disturbances can resuspend sediments, resulting in local "blackout" conditions. On rare occasions, small suspended particles settle in a layer at the top of the hypolimnion of deep lakes because their descent is slowed by the higher density of hypolimnetic waters.

Suspended material is problematic for visual observation and use of lights and cameras because it reduces light penetration and scatters light. Underwater lights and camera flashes reflect particles in the water column, causing glare. Photographers are compelled to use low-lux digital cameras or fast optical film under these conditions. In addition, photographers must be prepared to override the autofocus feature to have a better chance of capturing the object of interest rather than the nearest suspended particle.

Currents and waves. All direct observation methods are affected by water movement. In lotic waters, the direction and speed of water movement is usually predictable; divers and technicians can assess in advance the safety and effort required for a particular dive or equipment deployment with respect to current. However, water flow may vary considerably and sometimes unexpectedly. The presence of current can also be advantageous—currents provide directional cues and sweep dislodged sediments and debris downstream. Currents also can be used by divers to help conserve energy on relatively long transects or during reach-scale sampling. In lakes and oceans, current direction and speed is often unpredictable and highly variable. The illusion of "flat" water can be dangerous; even when the weather is calm, significant underwater currents can be present. A swimmer can generally swim against a 3–4 knot (5.6–7.4 km/h) current, but a scuba diver impeded by tanks and equipment cannot move as fast. The chief danger for divers occurs upon surfacing at an unexpected place or distance from the point of entry. Swimming at the surface back to a boat or shoreline can be severely taxing, especially in wind and waves. Dive plans must account for the possibility of divers drifting; support personnel should constantly watch divers or their bubbles, maintain a lookout for surfacing divers, and stay within a reasonable recovery distance. Surface water movements also must be considered; because of their buoyancy gear, divers are generally safe in open water and even in large waves, but stress or proximity to shore or hard surfaces poses danger. Training is required for safe entry and exit in surf or from boats in heavy weather. Surface waves and currents also limit use of remotely operated vehicles. At the surface, severe weather makes deployment and retrieval of the vehicles challenging; below the surface, most underwater vehicles cannot operate in currents in excess of 3 knots.

Depth. Depth presents varied challenges to divers, remotely operated vehicles, and above-surface observers. Trained snorkelers usually can dive to the deepest recesses of many streams and small rivers, but the greater depths of larger rivers, lakes, and the oceans must be sampled either by divers having access to compressed air or by an underwater vehicle. Lentic and ocean work presents the additional challenge of working in high volume, three-dimensional environments. In the absence of currents, and at distances above the substrate beyond the range of sight, divers can easily become disoriented. Work in large lakes and the ocean also requires deep-diving skills, including familiarity with and use of decompression tables. Dive depth of submersibles is limited by the pressure integrity of the hull and, in the case of tethered vehicles, the length of the umbilical cable.

Biota. Divers should be familiar with potentially dangerous organisms before attempting a survey. Divers in marine environments may encounter a variety of potentially dangerous animals including predators (e.g., sharks and barracudas), large marine mammals, and poisonous fish, reptiles, and invertebrates (U.S. Navy 2008). Divers in freshwater environments also may encounter potentially dangerous organisms such as venomous snakes and insects, large mammals, and poisonous plants and microorganisms, both in the water and along riparian areas of lakes and streams. Diving in thick growths of aquatic vegetation such as freshwater macrophytes or giant kelp can disorient or entangle a diver; often the primary hazard is claustrophobia or panic. All divers and support personnel must be trained to recognize, avoid, and cope with injuries from local dangerous fauna or flora.

17.3.2.4 Limitations in Measuring Biological Characteristics

Direct observation techniques are among the most effective methods for obtaining accurate information on aquatic organisms in their natural surroundings. However, even when conditions are ideal, direct observation alone may be insufficient to address important questions. For example, although sex and reproductive status may be evident for fishes such as salmonids and many cyprinids that are sexually dimorphic or exhibit secondary sexual characteristics, for many species it may be impossible to determine size, sex, age, reproductive status, or genetic identity accurately without capturing and handling organisms. In addition, the computation of many vital fisheries statistics, such as growth and mortality rates as well as production, is not possible without accurate measurements of length, weight, age, and other characteristics. For example, if an investigator's objective is to determine how many smallmouth bass are using newly installed habitat structures, direct observation methods are among the logical choices for sampling. However, if the investigator also needs to know the state of maturity, biomass, and diet of those smallmouth bass, then another method that allows their capture, either in addition to or in place of underwater methods, will be required.

Size estimates of fish by visual observation are confounded by the refraction of light in water; objects appear 25% larger than their actual size. Many species flee, hide, or attack when approached closely by a diver, so size must be estimated from a distance. One approach is to estimate the size of an animal relative to fixed points. The diver then swims to the reference points and measures the distance with a measuring device (Cunjak and Power 1986; Baltz et al. 1987). Alternatively, a scale such as a ruler or marked dive slate may be placed within the field of view of the diver or a camera near where fish are to be observed (e.g., Steinhart et al. 2004). Divers can carry a ruler to use as a reference to compare with fish size (Mueller 2003). Swenson et al. (1988) developed a calibrated bar that attaches to the diver's mask. The diver observes length on the bar and measures distance to the organism to estimate its length. Divers can also practice estimating fish size by viewing wooden dowels or fish silhouettes of known lengths underwater. Accuracy of size estimates improves with training (Griffith 1981). Marked improvements in precision of diver estimates of fish size were achieved with an underwater stereo-video system (Harvey et al. 2002).

17.4 METHOD VALIDATION

No matter how appealing a particular technique may be, prudent investigators will regularly attempt to validate their methods. As is true of all methods, direct visual observation of fish and surrogate structures such as spawning nests or redds yields valid estimates of abundance and distribution only when estimators are unbiased (i.e., data are both precise and accurate; Griffith et al. 1984; Thurow et al. 2006). Ensuring that an estimator is unbiased requires evaluation of potential violations of assumptions and comparison of estimated abundances to actual abundances (Peterson et al. 2004). If estimators are biased, reliable estimates of fish abundance can still be obtained by applying unbiased estimates of capture efficiency (Buttiker 1992; Bayley and Dowling 1993). Although the type or nature of validation depends on the sampling protocol, without method validation bias in data will be unknown and conclusions or management recommendations will be suspect.

Validation can be simple or involved, but it should be a routine practice for all investigators. Validation typically has three components: (1) an unbiased estimate of the "truth" (for example, the actual number of fish or surrogate structures such as redds in a sample site); (2) an estimate of the sampling efficiency of the method compared to the truth; and (3) use of the sampling efficiency estimate to adjust the data. Depending on the initial methods employed, validation also provides opportunities to exercise ingenuity and creativity in documenting data quality. Fisheries biologists use three basic approaches to obtain an unbiased estimate of the actual number of fish in a site (Peterson et al. 2004): (1) stocking a known number of fish into a site (Rodgers et al. 1992); (2) using a dual-gear procedure, often with one gear being lethal (Bayley and Austen 2002); or (3) mark–recapture methods that involve collecting, marking, returning, and recovering fish within a site (Riley et al. 1993).

17.4.1 Snorkel Count Validation

Validation of visual observation methods is particularly important for species that behave and use habitat in a way that causes them to be difficult to sample. For example, bull trout occupy complex habitat (Goetz 1994; Jakober et al. 2000; Dunham et al. 2003) and exhibit cryptic behavior (Pratt 1984; Thurow and Schill 1996; Thurow 1997), especially at low temperatures. Consequently, direct underwater observation by snorkeling may fail to detect bull trout or underestimate their actual abundance (Thurow and Schill 1996).

Underwater observation methods have been widely used for several decades to census stream-dwelling fishes, but their accuracy has been difficult to assess because actual population densities are usually unknown (Hillman et al. 1992). Diver counts should be calibrated with abundance estimates derived by other methods because the accuracy of diver estimates varies among aquatic environments (Hankin and Reeves 1988; Rodgers et al. 1992). Accuracy has been assessed by comparing diver counts with abundance estimates derived by electrofishing (Griffith 1981; Hankin and Reeves 1988), seining (Goldstein 1978), and piscicides (Northcote and Wilkie 1963; Dibble 1991; Hillman et al. 1992). Combining diver counts with mark–recapture estimates can be used to calibrate diver counts in remote streams (Slaney and Martin 1987; Zubik and Fraley 1988).

Thurow et al. (2006) used multiple-pass electrofishing catch data, adjusted for capture efficiency, to estimate true or baseline fish abundance to compare with day and night snorkel counts of bull trout (Box 17.3). The ability to detect and count fish accurately under water was influenced by fish size, species, time of day, and stream habitat characteristics. Thurow et al. (2006) cautioned that although snorkeling is versatile and has many advantages over other sampling methods, use of raw snorkel counts unadjusted for the effects of these biases will result in biased conclusions.

17.4.2 Redd Count Validation

Redd counts in index areas are commonly used to monitor annual trends in fish populations for which total adult escapements are unknown. A key assumption of redd counts is that they are representative of the actual number of redds (Dunham et al. 2001). Unfortunately, many redd counts lack measures of bias and precision, and the number of observed redds is treated as if it were the true number; that is, the total number of redds is assumed to be known without error. However, sampling error is common in redd counts (Rieman and McIntyre 1996; Bonneau and LaBar 1997; Dunham et al. 2001), and counting errors may lead to erroneous interpretations (Rieman and Myers 1997; Maxell 1999). Without a correction for missed redds or erroneously

Box 17.3 Evaluation of Capture Efficiencies

The following procedure was used to evaluate and adjust for bias in snorkel counts made to estimate bull trout abundances at 215 sites in first- to third-order streams. It involves determining snorkeling efficiency by comparing the numbers of fish seen while snorkeling to the actual abundance determined by electrofishing (Thurow et al. 2006). However, because electrofishing catches are also biased, they were first adjusted using capture rates of marked fish (Peterson et al. 2004).

Step 1

Conduct a snorkel count and record sizes of fish observed; C_i is the number of fish of size i observed. For example, if 4 bull trout 100 to 199 mm long are observed, $C_{100-199} = 4$.

Step 2

Obtain an unbiased estimate of the actual population abundance at the site. A sample of fish at the site is captured and marked. Multiple electrofishing passes are completed, and the number of marked fish of each size-class that is recaptured is recorded (Peterson et al. 2004). Electrofishing capture efficiency $\hat{\pi}_i$ is calculated as the number of marked fish of a size-class recaptured divided by the total number of marked fish of that size-class released. For example, if 5 fish of size i were captured, marked, and released and 2 of them were recaptured, $\hat{\pi}_i = 2/5 = 0.4$. The adjusted number of fish of size i at the site A_i is calculated as

$$A_i = \frac{N_i}{\hat{\pi}_i},$$

where N_i is the number of individuals of size-class i collected by electrofishing. For example, if $N_i = 6$ and $\hat{\pi}_i = 0.4$, then $A_i = 15$. This is essentially a two-sample Lincoln–Petersen capture–recapture estimate (Chapter 11).

Step 3

Estimate the sampling efficiency of your method. Snorkeling efficiency (SnEff) is estimated by comparing snorkel counts C_i to actual fish abundances A_i rounded down to the nearest whole number:

$$\text{SnEff} = C_i / A_i.$$

For example, if 4 fish are observed while snorkeling and the adjusted abundance estimated by electrofishing is 15, then SnEff = 4/15 = 0.27 = 27%. The exercise is performed at many sites to model the influence of fish size and stream habitat features on snorkeling efficiencies (Thurow et al. 2006).

Step 4

Use your estimate of snorkeling efficiency to adjust data collected at similar sites. Calculate unbiased snorkeling abundance estimates N_i at new sites by dividing snorkel counts (C_i) by the estimated snorkeling efficiency (SnEff). For example, if $C_i = 9$ and the snorkeling efficiency is 27%, then an unbiased estimate of abundance is 9/0.27 = 33.

included redds, the bias must be assumed to be constant across space and time. This assumption is untenable given the wide variety of factors potentially affecting detectability of redds. Inadequately accounting for bias or precision or both may lead to misleading conclusions about population trends (Thompson et al. 1998). Similar to the approach described above for snorkeling, the first step in estimating bias and precision of redd counts is to estimate the actual redd number, commonly by repeating redd counts over short time intervals from the onset of spawning to the end of the spawning period. The resulting cumulative redd count provides an estimate of the total number of redds present (Bonneau and LaBar 1997; Dunham et al. 2001). Next, individual or multiple redd counts are compared with the baseline while assessing the factors that influence errors of omission and commission, and detection efficiency models are created. Errors may be associated with redd age, redd size, redd density, physical characteristics of the redd location (e.g., water depth, clarity, or substrate color and contrast), canopy cover, and observer experience (Thurow and McGrath 2010). Finally, error bounds are placed around raw redd counts or detection efficiency models are applied to adjust counts for errors of omission and commission.

17.5 APPLICATIONS

17.5.1 Precision and Accuracy

The statistical precision (Chapter 2) of estimates of fish abundance and habitat features obtained by visual techniques can be derived by replicating counts. In the simplest case, observers make three counts in the same unit, calculate the mean and variance, and place confidence limits around the mean. Counts may be replicated temporally within the same unit (Colton and Alevizon 1981; Sale and Douglas 1981; Slaney and Martin 1987; Spyker and Van Den Berghe 1995) or spatially across multiple units within a stratum (Hankin and Reeves 1988). Under ideal conditions, replicate counts by trained observers tend to be similar. Hankin and Reeves (1988) replicated diver counts of age-1 steelhead in 30 pools in a small (2–16 m wide) stream. Mean counts ranged from 1 to 60, but 87% of the replicate counts were within 15% of the mean. Stream size does not appear to influence the repeatability of counts by trained divers in all but the largest habitats. Schill and Griffith (1984) made 28 replicate fish counts in 10 reaches of a large (77–99 m wide) stream; 93% of the replicate counts were within 15% of the mean count. Replicate counts form the basis for bounded counts, a method of estimation that accounts for bias associated with direct counts (Box 17.4).

Differences in fish behavior during different times of the day or year influence detectability and hence precision (Campbell and Neuner 1985; Rodgers et al. 1992; Spyker and Van Den Berghe 1995), as do differences in ability, training, and experience among divers. Investigators need to recognize and account for variability among observers when a study design requires multiple divers as, for example, in a large river or lake.

17.5.2 Visual Observation Survey Procedures

17.5.2.1 Direct Enumeration

Direct enumeration is an accurate method of counting aquatic organisms such as stream-dwelling salmonids (Northcote and Wilkie 1963; Slaney and Martin 1987), northern pike in shallow margins of lakes (Turner and Mackay 1985), and fishes associated with structure in ma-

Box 17.4 Bounded Counts

The bounded counts method is appropriate when it is possible but not certain that all fish will be counted in a pass (Regier and Robson 1967). The estimated number of fish present, $\hat{N}$, is calculated using

$$\hat{N} = 2N_m - N_{m-1},$$

where N_m is the largest count and N_{m-1} is the second largest count in a series of passes through the sample unit. Data and seasonal abundance estimates for rainbow trout in New Zealand's Rangitikei River (Hicks and Watson 1985) are presented below.

Table Rainbow trout counted and estimated ($\hat{N}$) by size category.

	Fish by size category			
Pass and estimate	Large	Medium	Small	Total
1	15	35	29	79
2	7	43	41	91
3	14	34	39	87
$\hat{N}$	16	51	43	95

rine habitats (Thresher and Gunn 1986). This method assumes that all organisms in a sample unit have equal probability of being detected and counted. Typically, one or more observers (underwater or above surface) count all organisms in a single pass through a sampling unit (Box 17.5). Precision is evaluated by making multiple passes through individual sampling units (Keast and Harker 1977; Hicks and Watson 1985).

In lentic habitats, small benthic fish can be counted within randomly placed quadrats (Chotkowski and Marsden 1999; Chapter 10). Alternatively, transect lines laid from a boat or by divers can be used to cover large areas or count mobile or large species. One or more observers then swim, float, or walk along the transect lines counting individuals within a set distance perpendicular to either side of the line (Ensign et al. 1995). The width of a transect may be determined by measured limits to visibility or by a measured rule carried by the diver; all fish within the defined area are counted. Replication can be achieved by sequential passes along the transect lines (Ensign et al. 1995). An ROV can be used to enumerate fish in deep water along transect lines that establish distance traveled, and a frame can be mounted in front of the vehicle to define transect width. Alternatively, the ROV may use a GPS to determine start and stop locations, or speed can be used as a surrogate for distance, as with trawling.

Divers and bank observers moving upstream in flowing waters are less likely to startle fish and cause them to flee or change their behavior because most stream-dwelling fish orient into the current. When conditions permit, divers in flowing waters should enter the water downstream from the unit to be sampled and proceed slowly upstream. A diver who moves slowly and avoids sudden movements can nearly touch fish before they are frightened (Heggenes et al. 1990). In

Box 17.5 Fish Surveys Conducted by the REEF Fish Survey Project

The mission of the REEF (Reef Environmental Education Foundation; www.reef.org) Fish Survey Project is to educate and enlist divers in the conservation of marine habitats. The project was developed in 1990 with support from The Nature Conservancy and guidance by the Southeast Fisheries Science Center of the National Marine Fisheries Service. It enlists volunteer scuba divers and snorkelers to collect and report information on marine fish populations. Data are collected using a standardized method, maintained in a publicly accessible database on REEF's Web site, and used by a variety of resource agencies and researchers to assess species distributions and population trends.

To collect data for REEF, volunteers use the roving diver technique, a visual survey method specifically designed for volunteer data. The only materials needed are an underwater slate and pencil and a good reference book on fish identification. Divers swim freely throughout a dive site and record every observed fish species that can be positively identified. The search begins as soon as the diver enters the water. Because the goal is to find as many species as possible, divers are encouraged to look under ledges and up in the water column. Any sea turtles seen during dives are also recorded. At the conclusion of each survey, each observed species is assigned one of four abundance categories based on how many were seen throughout the dive: single (1), few (2 to 10), many (11 to 100), or abundant (>100). Additional data recorded are survey time, depth, temperature, and other environmental information. Data are submitted online at the REEF Web site, reviewed, and made available within weeks.

sampling units that are too deep, swift, or inaccessible to allow a downstream entry, divers may enter the water upstream from the sampling unit and float downstream with the current, remaining as motionless as possible.

In small streams where a diver can see the stream bottom from bank to bank from a single point, the diver typically proceeds upstream, zig-zagging between banks and taking care to conduct a thorough search of the stream margins and all cover components such as undercut banks, substrate interstices, and accumulations of woody debris. Where water depth, turbulence, or clarity limit the ability to see and identify fish accurately, the diver first partitions the unit into two or more distinct lanes and then proceeds up each lane, counting all fish out to the limits of the lane. The diver repeats the procedure for the remaining lanes, taking care to avoid double counting fish encountered in previous lanes.

The number of observers needed to complete a particular survey is determined by the size and complexity of the sampled unit, underwater visibility, type or age of fish or other aquatic organism, and the type of estimate. Shallow habitats such as riffles typically require more observers than pools or other deep habitats. Although water clarity in small streams may allow one diver to see the entire channel width, additional divers may be needed to count concealed or less conspicuous organisms. Multiple observers are usually necessary to obtain accurate fish counts in large rivers and lakes. In relatively homogeneous riverine habitats, sampling units can be divided into equal lanes within which divers move slowly upstream as a group, counting all fish within their assigned lanes. If the unit is too deep, turbulent, or complex, divers can use natural features such as a line of boulders to partition the unit. If it is not feasible to count all fish from bank to bank, divers may count fish within a subunit of the stream channel. The area surveyed can be calculated by multiplying the length of the unit by the width of the sampled subunit. In water too deep or fast to move upstream, two divers can each hold one end of a baton or multiple divers can position themselves along a length of plastic pipe to maintain a uniform counting lane (Schill and Griffith 1984). In all situations, the distance between divers should always be less than the maximum underwater visibility, and divers must start and stop at the same time, remain in their assigned lanes, and move at the same speed. To avoid double-counting fish, divers must not count fish that move between lanes.

Enumeration of highly mobile or pelagic fishes is particularly challenging. Use of diver-held or ROV-mounted video cameras provides a permanent record that can be reviewed multiple times to increase count precision. Spawning aggregations of lake trout have been estimated at several sites in the Great Lakes by counting the number of fish seen per minute by an ROV held motionless on the bottom (Marsden and Janssen 1997). As with diver counts, care must be taken to avoid counting individual fish multiple times as they move in and out of the transect. Differences in size, unique markings, and presence of scars or fin anomalies (Mueller 2003) often can be used to identify individuals and avoid double counts.

Underwater observation is particularly valuable for estimating fish densities in habitats that are not amenable to traditional capture-based methods and for enumerating difficult to sample life stages such as eggs and fry. For example, Pacific herring eggs adhering to giant kelp and other marine vegetation have been successfully censused by divers to derive estimates of spawning stock biomass (Haegele and Schweigert 1985; Schweigert et al. 1990). Similarly, egg masses of yellow perch are difficult to sample by bottom trawl over brush and cobble substrates but can be readily enumerated by divers or ROVs (Robillard and Marsden 2001).

When used appropriately, diver censuses may be of equal accuracy and greater efficiency than those conducted with traditional capture-based methods and have less effect on fish (Mueller 2003). However, as with any sampling method, underwater survey is prone to specific biases. Small, cryptic, or well-camouflaged fishes are less likely to be detected than larger or more conspicuous fish. For example, divers observed 9 species in a reservoir cove whereas 21 species were collected during subsequent rotenone sampling (Dibble 1991). Nevertheless, the investigators were able to establish statistically significant relationships between the relative abundances of certain fishes and micropterine basses observed using the two methods.

17.5.2.2 Expansion Estimates

The expansion method can be used to estimate the total abundance of fish in large rivers, lakes, and marine environments where direct enumeration is not feasible. Habitats are partitioned into relatively homogeneous strata within which all fish are counted and recorded separately. In rivers, for example, individual lanes are established according to criteria such as underwater visibility, distance from banks, or substrate complexity, and divers are randomly assigned lanes along which to count fish (Zubik and Fraley 1988; Box 17.6). Assuming that all fish within a particular stratum (lane or type of lane) have an equal probability of being detected, the total number of fish can be estimated by dividing the number of fish counted in the sampled lanes by the fraction of the stratum that was sampled. Average density, variance, and confidence intervals can be calculated by replicating counts within individual strata and lanes (Slaney and Martin 1987).

Box 17.6 Expansion Estimates

To estimate the number of cutthroat trout greater than 254 mm in total length (TL) in the Flathead River, Zubik and Fraley (1988) divided a 45.1-m-wide, 2.2-km-long section into four lanes. Divers were randomly assigned lanes and instructed to count fish within a 4.0-m-wide visual corridor. Because only 36% of the actual river corridor was sampled, the first step in calculating the number of fish per kilometer was to develop an expansion factor (EF) to extrapolate counts to the entire river section:

$$EF = 45.1 \text{ (mean river width)}/4 \text{ (counting lanes)}/4 \text{ (visual distance)} = 2.82.$$

The mean number of fish seen (44) in three passes was then multiplied by 2.82 to yield an expanded total abundance estimate of 124 fish, or 124/2.2 km = 56 fish/km.

Table Number of cutthroat trout larger than 254 mm (TL) and summary statistics based on 4-m-wide visual corridors.

Pass and statistic	Fish by lane				Total
	1	2	3	4	
1	13	13	8	13	47
2	11	5	11	15	42
3	20	9	5	10	44
Mean	15	9	8	13	44
SE	2.73	2.31	1.73	1.45	1.45

Zubik and Fraley (1988) also calculated confidence intervals about their estimate. The SE of the total was similarly expanded by the EF (1.45 × 2.82 = 4.09) and adjusted to a per kilometer basis (4.09/2.2 = 1.86). The 95% confidence interval was $N \pm t(\text{SE})$ with 2 degrees of freedom or 56 ± 4.303(1.86) = 56 ± 8.

17.5.2.3 Basinwide Estimates

Basinwide sampling uses calibrated diver counts to estimate fish abundances within entire watersheds (Hankin and Reeves 1988). The basic premise of the method is that if a consistent relationship exists between observer counts and the actual numbers of fish, then a calibration ratio can be used to correct for bias associated with diver counts. Basinwide sampling has distinct diver count and independent calibration phases. During the first phase, different habitat types are selected, and divers count fish in a sample of each habitat type. During the second phase, an alternative method (typically electrofishing) is used to estimate the actual numbers of fish in at least 10 habitats of each type sampled by divers. The second phase evaluates the relationship between observer counts and independent estimates of the actual numbers of fish. Means, variances, and total number of fish can be calculated.

Modifications to the original basinwide methodology revised the variance estimator for total numbers of fish and outlined a method to allocate first- and second-phase sampling effort optimally (Dolloff et al. 1993). The optimum allocation procedure minimizes overall sampling variance based on the relative costs of first phase (observer estimated) and second phase (electrofishing) sampling.

17.5.2.4 Mark–Recapture Estimates

Direct observation also can be used with other techniques to derive mark–recapture estimates of abundance (Van Den Avyle 1993). Fish captured by angling or another method can be fin clipped or marked with tags that are visible to divers, bank observers, remote cameras (Helfman 1981; Slaney and Martin 1987; Zubik and Fraley 1988; Vore 1993; Lindholm et al. 2005), or an ROV. Colored tags or marks can be used to mark each size-class of fish differentially (Nielsen 1992). After the marked fish redistribute in the sampling unit, observers can enumerate the numbers of marked and unmarked fish both by species and size-class. A total abundance estimate can be derived by summing the estimates for each size-class.

17.5.2.5 Line Transect Estimates

Most direct observation estimates of fish abundance assume constant probability of detection out to the limits of visibility. In practice, this means that all fish within the field of vision (lane) must be seen with certainty. This approach works well in both terrestrial (Burnham et al. 1980; Seber 1982) and aquatic (Lyons 1987; Bergstedt and Anderson 1990) environments for highly visible or sessile species and has also been used to estimate redd abundances in streams (Mitro and Zale 2000). However, for many other species, detection probability is not constant, and this approach will result in biased abundance estimates. Many benthic organisms are cryptically colored and occupy interstitial spaces or other inconspicuous locations; others rapidly seek cover when disturbed. For such species, an approach that assumes a decreasing probability of detection with increasing distance from a transect line may be more appropriate. Ensign et al. (1995) advised investigators to define lanes of travel with lines oriented parallel to the current and spaced at distances greater than the maximum underwater visibility. Observers identify and count fish on both sides of the line, marking the positions of all target fish with weighted, species-specific, color-coded markers attached to floats. After completing counts, the distance from each marker to the survey line is measured and recorded. The specific model used to estimate density depends on the amount and quality of the available data and the degree to which assumptions about the data can be met. Models that correct for unequal probability of sighting are strongly recommended (Ensign et al. 1995).

17.5.3 Habitat Use Estimates

Direct observation can provide relatively unbiased information on habitat use by species that do not modify their behavior in the presence of divers. For example, many salmonids occupy and defend specific locations in stream channels called focal points that can be identified by direct observation (Fausch and White 1981; Rimmer et al. 1984; Cunjak and Power 1986; Cunjak 1988). These focal points represent locations that confer advantage to fish in securing food and shelter. During habitat use surveys, observers note the species and relative size of undisturbed target fish and place individually identifiable markers (weights with attached floats) on the stream bottom at the focal locations. A suite of macro- and microhabitat features can be measured at the focal points. Investigators can estimate habitat use by comparing habitat characteristics at occupied locations with measurements of available habitat. Direct observation is useful in sampling physically complex habitats such as reefs, which are impractical to sample with standard capture techniques and equipment. Observations of fish behavior are of particular value in understanding the influence of structure, such as natural or artificial reefs, on fish population dynamics (Kudoh et al. 2002; Cunningham and Saul 2004). Direct observation is also useful for documenting changes in habitat, such as damage by fishing gear (Engel and Kvitek 1998; Schwinghamer et al. 1998; Watling and Norse 1998; Freese et al. 1999) or introductions and changes in distributions of exotic plants (Eichler et al. 2001).

17.5.4 Evaluation of Traditional Fishing Gear

Direct visual observation is a valuable tool for assessing efficiency and biases of traditional fisheries sampling methods. Information based on fish collected with passive methods such as gill nets and longlines may be biased by periods of fish inactivity. For example, divers have observed Eurasian perch resting on the bottom at night, where they were unavailable to gill nets and not detectable with hydroacoustic equipment (Imbrock et al. 1996). Distributions of fish also vary diurnally; abundances of 18 species of Mediterranean fishes surveyed across several depth strata varied significantly at different times of day (Spyker and Van Den Berghe 1995).

Factors affecting the efficiency of collecting gear can be assessed by direct observation. Cameras mounted on the headropes of trawls, for example, have increased understanding of how trawls operate under different design constraints and conditions, resulting in advances in trawl design (High 1971; Piasente et al. 2004). Cameras showed that movement of longlines set for tilefish resulted in a broader area fished than that transected by the longline, that starfishes and crabs consumed significant amounts of bait, and that hooks often released from tilefish in burrows (Grimes et al. 1982). The authors recommended shortening soak times to limit bait loss to nontarget organisms.

17.5.5 Collection of Biological Data

Although diving generally is an inefficient method for collecting large or pelagic fishes, notable exceptions exist. Collection of threatened lake sturgeon by divers was more effective (1.5 fish/h) than use of gill nets (0.07 fish/h) or set lines (0.06 fish/h), though diving required more effort than use of passive gear (Hughes et al. 2005). Lethal capture methods used by divers include explosive charges (Everest 1978) and spear guns. Nonlethal capture methods include slurp guns (Morantz et al. 1987), nets (Bonneau et al. 1995), diver-operated electrofishing probes (James et al. 1987), pumps (Flath and Dorr 1984), and suction dredges (Koch 1992). Suction devices and other equipment can be added to ROVs to collect sediments, benthic invertebrates, fish eggs, and benthic fishes (Tusting and Tietze 1995; Marsden and Janssen 1997).

17.6 SUMMARY AND RECOMMENDATIONS

Direct observation techniques are among the most effective means for unobtrusively obtaining accurate information about aquatic organisms in their natural surroundings. Both above-surface and below-surface observation methods have numerous potential applications in fisheries science. Above-surface approaches are applicable for fish behavioral studies, counts of redds or other surrogate structures, fish counts from towers and viewing windows, and aerial or boat-based fish or habitat surveys. Similarly, subsurface methods can be used to observe fish behavior and interactions directly, assess population status and trends, and evaluate habitat condition and use. Subsurface direct observation methods are readily available, affordable, and diverse. Subsurface techniques and equipment needs range from the relatively simple, for example, snorkeling and hookah diving in riverine and shallow-water areas, to more complicated scuba gear for sampling deeper and offshore areas, to highly sophisticated remotely operated or piloted submersibles that can access sites hundreds of meters below the surface in waters too cold or hazardous for divers. Subsurface data recording options include underwater writing slates, waterproof paper, sign language between divers, and verbal transmission of observations by means of radios in specialized face masks. Use of video—taken from the surface or taken subsurface by divers or cameras mounted on underwater vehicles—provides a permanent record of observations that can be viewed by multiple observers to confirm fish identification and to replicate fish abundance counts. Video can also be used to evaluate factors that affect efficiency of traditional fishing gears; for example, a camera mounted on the headrope of a trawl can be used to observe the net opening and fish responses.

Species that are difficult to sample with traditional approaches may be more readily detected and observed while undisturbed in their natural environments, and direct observation methods may be especially effective for sampling such species. Similarly, habitats that are inaccessible to standard collecting gears, such as coral reefs, deep oceans, and waters under ice, and habitats with low conductivity or many obstructions may be more effectively sampled with direct observation methods. Marked organisms can also be "re-sighted" multiple times without handling.

Despite numerous benefits of direct underwater observation, potential limitations must also be considered. Limitations depend in part on study objectives. For example, direct observation may be less suitable than traditional techniques if fish must be captured and handled to determine fish sex, age, size, growth, or reproductive status. Direct observation methods may require specialized training and equipment. Hazards to personnel and equipment must be considered; for example, subsurface methods require an awareness of currents, waves, extreme temperatures, physical obstructions, depth restrictions, and dangerous fauna. Like all sampling methods, direct observation methods require validation to eliminate or account for sampling error and bias. As fisheries professionals continue to test and evaluate direct observation methods, their applications in fisheries science and management will probably increase.

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