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Cost-effective accurate estimates of adult chum salmon, *Oncorhynchus keta,* abundance in a Japanese river using a radio-controlled helicopter

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Abstract

This paper describes an attempt in 2008 to establish an aerial census of adult chum salmon using a small radio-controlled (RC) helicopter. The Moheji River, located in southern Hokkaido, was chosen because all the salmon in a stretch of the river between a weir and the estuary are seine-netted every morning for artificial propagation. Aerial photographs of the river were taken from a RC helicopter equipped with a digital single-lens reflex camera and polarized filter. To quantify salmon density within the census area, the number of salmon per aerial photograph was counted using image-processing software. Salmon could be clearly identified in photographs taken from an altitude of ~30 m. Salmon numbers estimated by aerial census and seine-netting were significantly related. The results indicate that a small RC helicopter can be used to generate adult salmon abundance data in Japanese rivers.

Keywords: Chum salmon; Aerial census; Radio-controlled helicopter; Salmon escapement; Salmon abundance

Highlights

- Chum salmon were identified in photographs taken from a radio-controlled helicopter
- Spawning redds were also distinguishable in aerial photographs
- Counts are significantly positively correlated with independent abundance estimates
- This census is a cost-effective method for abundance estimation of salmon in rivers

1. Introduction

From the point of view of both species and genetic diversity, it is important to conserve and protect wild Pacific salmon (*Oncorhynchus* spp.) in Japan, although the fishery for chum salmon (*O. keta*) is dependent on artificial propagation (Morita et al., 2006, Saito and Nagasawa, 2009, Nagata et al., 2011). It is difficult to estimate wild adult salmon numbers in rivers and streams, except at weirs or ladders with specific equipment (e.g. counters or cameras) or where salmon are captured for artificial propagation. A number of methods are used to estimate abundance in adult salmonids, including visual survey at ground-level (Irvine et al., 1992, Hilborn et al., 1999), mark–recapture (Krebs, 1989) and hydroacoustic sonar (Eggers et al., 1995, Ransom et al., 1998). Aerial surveying is an essential tool in Pacific salmon management and is best suited to broad, shallow, clear-water systems (Jones et al., 2007). In North America, there have been a number of studies on the observation and/or estimation of adult salmon abundance by aerial survey using manned fixed-wing aircrafts or helicopters (Eicher, 1953, Bevan, 1961, Visser et al., 2002, Hedger et al., 2006). However, in Japan, the use of light aircraft/helicopters is rare and expensive (a single charter flight of a helicopter is approximately US$12,600 per hour). Furthermore, many Japanese rivers are small (i.e. stream) and are adjacent to residential areas. The acquisition of the high-resolution images, necessary to the visualization of adult salmon abundance in Japanese rivers, is made difficult due to the dark body color of mature chum salmon and similar coloring of the river bed. In agriculture science, farmland is regularly surveyed using high-resolution images captured by low-altitude, unmanned radio-controlled (RC) helicopters (Swain et al. 2010). However, to the best of our knowledge, there are no reports of aerial surveying by RC helicopter being applied to the estimation of adult salmon abundance or the biomass of other fish species. The present study reports an aerial census of adult chum salmon using a small RC helicopter system in the Moheji River, located in southern Hokkaido, in 2008.

2. Materials and methods

2.1. Study area

The Moheji River is located in southern Hokkaido (estuary location: 41°45′58″N, 140°36′32″E; river width: 20–25 m; Fig. 1). In this river, a chum salmon hatchery program is organized by the Oshima Salmon Propagation Association. A weir, constructed 600 m upstream from the estuary, allows adult salmon to be seine-netted every morning during salmon spawning season. In the studied river, water depths ranged from 50 to 100 cm.

2.2. Aerial census system

The system comprised a 26-cc two-stroke gasoline-engine RC helicopter (Voyager GSR260; Japan Remote Control, Osaka, Japan; length 1570 mm, height 750 mm, equipped weight 8 kg, main rotor ø1770 mm) with a radio-controlled 2-axis gimbal plus anti-vibration device (A810; Fun Tech, Kimitsu, Japan) attached to the main platform (SCRH, salmon census radio-controlled helicopter; Fig. 2). An Advanced Photo System (APS) C-sized digital single-lens reflex (SLR) camera (EOS Kiss X; Canon, Tokyo, Japan) was used for high-resolution image photography. A 17-mm focal length (for 35-mm film frame) wide-angle lens (Model A05 SP AF 17-35mm; Tamuron, Saitama, Japan) with a polarized filter (Wide band C-PL [W]; Kenko, Tokyo, Japan) allowed imaging of a large, anti-reflection area of the river surface (Fig. 2B). Furthermore, a CCD camera (MacromaX MVC-10; GOKO camera, Kawasaki, Japan) equipped with a wireless transmitter (RC12; International Electric Parts, Minokamo, Japan) was attached to the SLR camera to transmit live image to the ground station. A schematic of the aerial census system for adult salmon in the river using the small RC helicopter is illustrated in Fig. 3. The system comprised the SCRH, the flight control unit or "Pilot", and the camera control unit or "Shooter". Communication with both the "Pilot" and "Shooter" was via two-way radio (HX632D; Standard, Tokyo, Japan). The "Pilot", or flight control unit, was a hand-held device, which meant that the operator could move along the riverbank and control the SCRH from the ground. The “Shooter”, on the other hand, required a small electric generator (EF900iS; Yamaha Motor Power Products, Kakegawa, Japan; weight 13 kg) to operate the monitor, which meant that its position was fixed on the riverbank.

2.3. Aerial census procedure

The “Pilot” operated the SCRH and the “Shooter” operated the photographic device (e.g. the camera angle and shutter control), which was confirmed via a live image of the river surface on the monitor. The combination of SLR camera and wide-angle lens gave an angle of view equivalent to a 28-mm focal length wide-angle lens in 35 mm film format (horizontal angle: ~66º). Flight altitude (i.e. height above the water surface) was calculated from the viewing angle of the camera and 1-m rulers aerial-photographed on the riverbank (Fig. 4). Rulers were placed on the riverbank at intervals of ~50 m. Eight aerial surveys were performed in the Moheji River during the autumn of 2008. Quantitative analyses of individual chum salmon in the photographic areas were computed via the standard protocol of the image-processing program ImageJ 1.36b (The National Institutes of Health, Bethesda, MD, USA) using digital aerial images as follows: (i) RGB color splitting, (ii) adjusting contrast, (iii) thresholding of binary images, and (iv) detection and counting of salmon silhouettes. Catch numbers from seine-netting of chum salmon in the Moheji River were provided by the Oshima Salmon Propagation Association immediately after each aerial survey.

2.4. Statistical analysis

The relationships between the seine-netting catch numbers (abundance) and the aerial counts of chum salmon were analyzed using reduced major axis (RMA) regression (Sokal and Rohlf, 2011). This approach reduces the bias due to sampling error by taking into account error in the x as well as the y variable.

3. Results

3.1. Detection of salmon silhouette

In aerial surveys at low attitude (~7 m), the body of adult chum salmon could be clearly identified via the polarization filter attached to the SCRH (Fig. 5A). Although salmon avoided the shadow of the SCRH, the noise and vibrations of the SCRH had no effect on salmon behavior. In addition, the flight of the SCRH had no effect on seabirds on the surface of the river (Fig. 5B). Spawning redds, formed in the bottom of the river, were also clearly distinguishable from altitudes of ~25 m (Fig. 5C). Typical aerial photographs of chum salmon taken from the SCRH at altitudes of ~32 m in the Moheji River are shown in Fig. 6A. The spindle-shaped salmon silhouettes are clearly visible on the riverbed. When the raw color images were split into the three primary colors (red, green and blue) using an image-processing program, images of the red element could clearly distinguish the salmon silhouettes from the riverbed (Fig. 6). Extraction of the red element from the raw digital image was more effective than thresholding in visualizing and counting salmon silhouettes.

3.2. Evaluation of the aerial census by SCRH

Aerial counts for each area and catch numbers are shown in Table 1. The peak period of salmon escapement was the last two weeks in November (data not shown). The standardized number of chum salmon counted by SCRH was significantly positively correlated to the standardized number of salmon seine-netted between the weir and the estuary (r^2=0.933, F=83.53, p<0.0001; Fig. 7).

4. Discussion

The present study indicates that photography from an attitude of ~30 m is suitable for aerial surveying adult salmon abundance in the Moheji River. In previous aerial surveys of salmon abundance in rivers, images of the spawning ground were taken using manned fixed-wing aircraft or helicopters from high altitudes (100–200 m) over broad areas (Eicher, 1953, Neilson and Green, 1981, Hedger et al., 2006). The number of spawning redds, in particular, has been counted by aerial survey from high altitude (160–750 m) (Heggberget et al., 1986, Geist et al., 2000, Visser et al., 2002). On the other hand, Bevan (1961) reported that accurate analysis of aerial photographs taken from an attitude of 33 m was suitable for fish counting. Many researcher workers have adopted these flight conditions (West and Goode, 1987, Jones et al., 1998). Owing to the proximity of residential areas, low altitude flights of the manned aircrafts are not advisable. In fact, the minimum en route altitude for manned aircrafts is prescribed to an altitude of 150 m by the "Ordinance for Enforcement of the Civil Aeronautics Act" in Japan. It is technically difficult to obtain high-resolution images from high altitudes due, among other factor, to the influence of mechanical vibration. Our aerial survey using SCRH could distinguish spawning redds as clearly as manned aircraft (Heggberget et al., 1986, Geist et al., 2000, Visser, 2002); thus, SCRH may be applicable to spawning redds in hostile environments where foot surveys cannot be used. Although the chum salmon were camouflaged by their nuptial coloration, extraction of the red elements from the raw aerial images meant that the salmon silhouette could be clearly distinguished from the riverbed. This extraction process may be more effective when applied to sockeye salmon (*O. nerka*) whose nuptial coloration is vivid red.

In the RMA regression, the numbers of salmon counted by SCRH were significantly positively correlated with the actual numbers in the Moheji River. This indicates that salmon abundance could be estimated by SCRH if conditions are suitable. However, all aerial count data were consistently low compared with the actual abundance data from seine-netting. There are several reasons for this bias, including the time lag between the aerial survey and seine-netting. A small number of spawning salmon may have entered into the river during the short time-interval between the aerial survey and seine-netting (see Table 1). Another possible reason is that the aerial survey area was restricted compared to the seine-netting area. In the present system, the "Shooter" was fixed on the riverside, and although the "Pilot" operator could move along the riverbank controlling the SCRH from the ground, the radio-controllable range was restricted to a few hundred meters. Future developments should include a continuous recording method (e.g. Hi-Vision video camera) operated from the "Pilot", without the need for the "Shooter", or a portable "Shooter".

The area-under-the-curve (AUC) method has been previously applied in manned aerial surveys to estimate adult salmon abundance during the spawning season (Hill, 1997, Parken et al., 2003, Holt and Cox, 2008). From 1960 to the present, Alaska Department of Fish and Game (ADFG) has used peak aerial survey estimates as an index of escapement of Pacific salmon in southeastern Alaska (Baker et al., 1996). The combination of periodic aerial surveying by SCRH during the spawning season and the AUC method could be effective in estimating total adult salmon abundance in small Japanese rivers. Regular aerial surveying by SCRH is essential for the sustainable management of salmon in Japan where manned aerial surveys are not possible and costly. The importance of the wild, naturally spawning salmon populations in the North Pacific region should not be underestimated. In northern Japan, populations of naturally spawning salmon have been recently investigated by foot survey (Miyakoshi et al., 2011), but aerial surveying would certainly contribute to an expansion of the survey areas and our knowledge of salmon stocks.

A comparison of unmanned radio-controlled helicopter, manned helicopter and fixed wing aircraft for aerial salmon surveying applicable to Japanese rivers is summarized in Table 2. In northern Japan, airports with a company that can outsource flights for salmon aerial surveys are limited numerically (e.g. two airports in the Hokkaido area), and the time of a one-way flight from the airport to a survey site is usually one hour or more. Therefore, the use of manned helicopters or fixed wing aircrafts would be far more expensive than SCRH, although both manned aero-vehicles can survey a larger area in a shorter time. In addition, the purchase of a completely equipped SCRH system by a laboratory and its repeated practical use would be more economically beneficial.

As regard safety, the crash of a small RC helicopter would rarely involve personal injury or physical damage to structures on the ground compared with a manned aircraft. However, while RC helicopters are not subject to the same regular safety inspections as manned aircraft, safety should be the main priority during salmon aerial survey using a small RC helicopter. Similar suitable environments (no-covering, broad, shallow and clear-water systems), as with a manned airplane (Jones et al., 2007), are required for aerial surveying by the SCRH. As mentioned above, the RC helicopter is unsuitable for surveying over a wide range due to the short maximum flight time and the restricted radio-controllable range. A flat area (~5 m in diameter) for takeoff and landing is required near the survey site, which means the SCRH cannot be used in rocky areas or areas of overgrown vegetation. Recent technological advances have led to the development of photographic systems in autonomous aircraft such as the unmanned aerial vehicles (UAV) equipped with a global positioning system (GPS). However, at present, the cost is prohibitive for practical use.

In summary, an experimental aerial census of adult chum salmon using the SCRH in a Japanese river has indicated that the aerial count was significantly correlated to the numbers evaluated by seine-netting in the stretch of river between the weir and the estuary. SCRH has the potential to become a new platform for the monitoring of salmon stocks and the estimation of adult salmon abundance in Japanese rivers, and applicable to the sustainable fisheries management of anadromous salmonid fish worldwide.

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and setting-up the SCRH, and Mr. Tadashi Usuki, of the R.C. Lobby, for training of the RC helicopter operators.

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Table 1 Aerial count and catch numbers of adult chum salmon in the Moheji River in autumn 2008.

Aerial count date	Aerial count no.	Catch date[a]	Catch no.
02 Oct 2008 (pm)	15	03 Oct 2008 (am)	34
07 Oct 2008 (pm)	1	08 Oct 2008 (am)	18
16 Oct 2008 (pm)	13	17 Oct 2008 (am)	4
28 Oct 2008 (pm)	14	29 Oct 2008 (am)	85
06 Nov 2008 (am)	65	06 Nov 2008 (am)	210
12 Nov 2008 (am)	245	12 Nov 2008 (am)	440
24 Nov 2008 (am)	222	24 Nov 2008 (am)	342
03 Dec 2008 (am)	130	03 Dec 2008 (am)	215

[a] Date when this number of adult salmon were caught by seine-netting in the survey area.

Table 2 Comparison among unmanned radio-controlled helicopter, manned helicopter and fixed wing aircraft for aerial salmon surveying of Japanese rivers and streams.

	Radio-controlled helicopter	Helicopter	Fixed wing aircraft
Represented model	Japan Remote Control, GSR260 [a]	Eurocopter, AS350 B2 [b]	Cessna, Skyhawk model 172R [c]
Length	1.57 m	12.94 m	8.28 m
Weight	8 kg	>1500 kg	>800 kg
Maximum cruising range	<150 m [d]	666 km	1080 km
Maximum flight time	<45 min	>3 h	>6 h
Lower altitude flight	Easy	Difficult [e]	Difficult [e]
License for flight	Unnecessary	Necessary	Necessary
Equipment price	JP¥2,000,000 [f] (US$26,000)	>JP¥220,000,000 (>US$2,800,000)	>JP¥22,000,000 (>US$280,000)
Charter charge (unit price)	> JP¥147,000 [g] (> US$1,900) per single site	> JP¥330,000 [h] (> US$4,200) per hour	> JP¥110,000 [h] (> US$1,400) per hour
Price of survey at Moheji River	> JP¥147,000 [g] (> US$1,900)	> JP¥990,000 [h] (> US$12,600)	> JP¥330,000 [h] (> US$4,200)

[a] Present study.

[b] Eurocopter; http://www.eurocopter.com

[c] Cessna Aircraft Company; http://www.cessna.com

[d] Case in which the pilot does not move. If a pilot is movable along a river from the ground, a long-distance flight is possible.

[e] The minimum en route altitude is prescribed to an altitude of 150 m by the Ordinance for Civil Aeronautics Act in Japan.

[f] All the prices of this table use the exchange rate as of November 2011.

[g] Some aerial-photographing company (e.g. Toho Kai-Hatsu Co. Ltd.; http://kktoho.com/) include the photography technical fee. In the present study, we used the aerial census equipment of our laboratory and operated them personally.

[h] Some aviation companies (e.g. Hokkaido Aviation Co., Ltd.; http://www.hokkaido-koku.co.jp) apply a flight charge only.

Figure captions

Fig. 1 Map of the study area on the Moheji River, Hokkaido, Japan, where aerial photographs were taken of chum salmon escapement in Autumn 2008.

Fig. 2 Aerial census equipment used for estimation of adult chum salmon abundance in the Moheji River. (A) Side view of the salmon census radio-controlled helicopter (SCRH). (B) Front view of SCRH. (C) Photographing mechanism, including the radio-controlled 2-axis gimbal, the digital single-lens reflex camera equipped with 17-mm focal length (for 35-mm film frame) wide-angle lens and polarized filter, the CCD camera for live imaging, and the image radio-transmitter. (D) All equipment needed for operation of the aerial census system.

Fig. 3 Operational procedure of the aerial census system. SCRH, salmon census radio-controlled helicopter

Fig. 4 Altitude estimation from the SCRH to the river surface using the equation $H=W/(2\cdot\tan\theta)$ $\theta=33°$ and 1-m rulers. Shaded zone is photography area. APS, advanced photo system (APS-C size: 22.2 × 14.8 mm); SLR, single-lens reflex camera.

Fig. 5 Aerial photographs of chum salmon taken from the SCRH at altitudes of ~7 m (A) and ~25 m (B and C). White dots in B are seabirds on the water surface. Asterisks in C indicate spawning redds.

Fig. 6 Aerial photographs of chum salmon taken from the SCRH at an altitude of approximately 32 m in the Moheji River in November 2008 (A). (B) Raw photograph before image analysis from square in A. (C) After image-processing via Image J 1.36b software.

Fig. 7 Relationships between the standardized aerial count number and the standardized seine-netting catch number of chum salmon in the Moheji River in autumn 2008 ($y=0.966x-0.00000018$; $n=8$, $r^2=0.933$, $F=83.53$, $p<0.0001$).

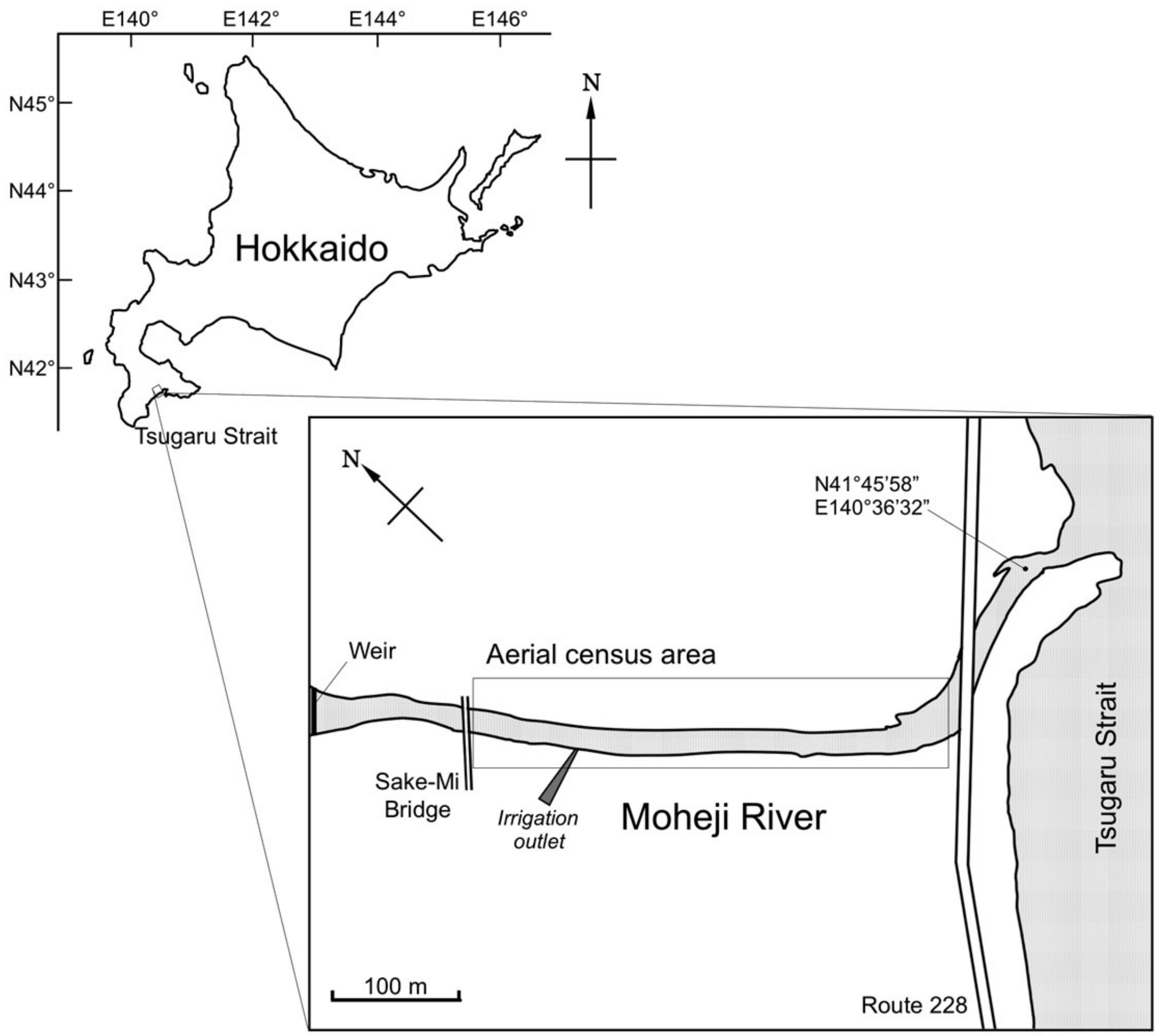

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Figure 1

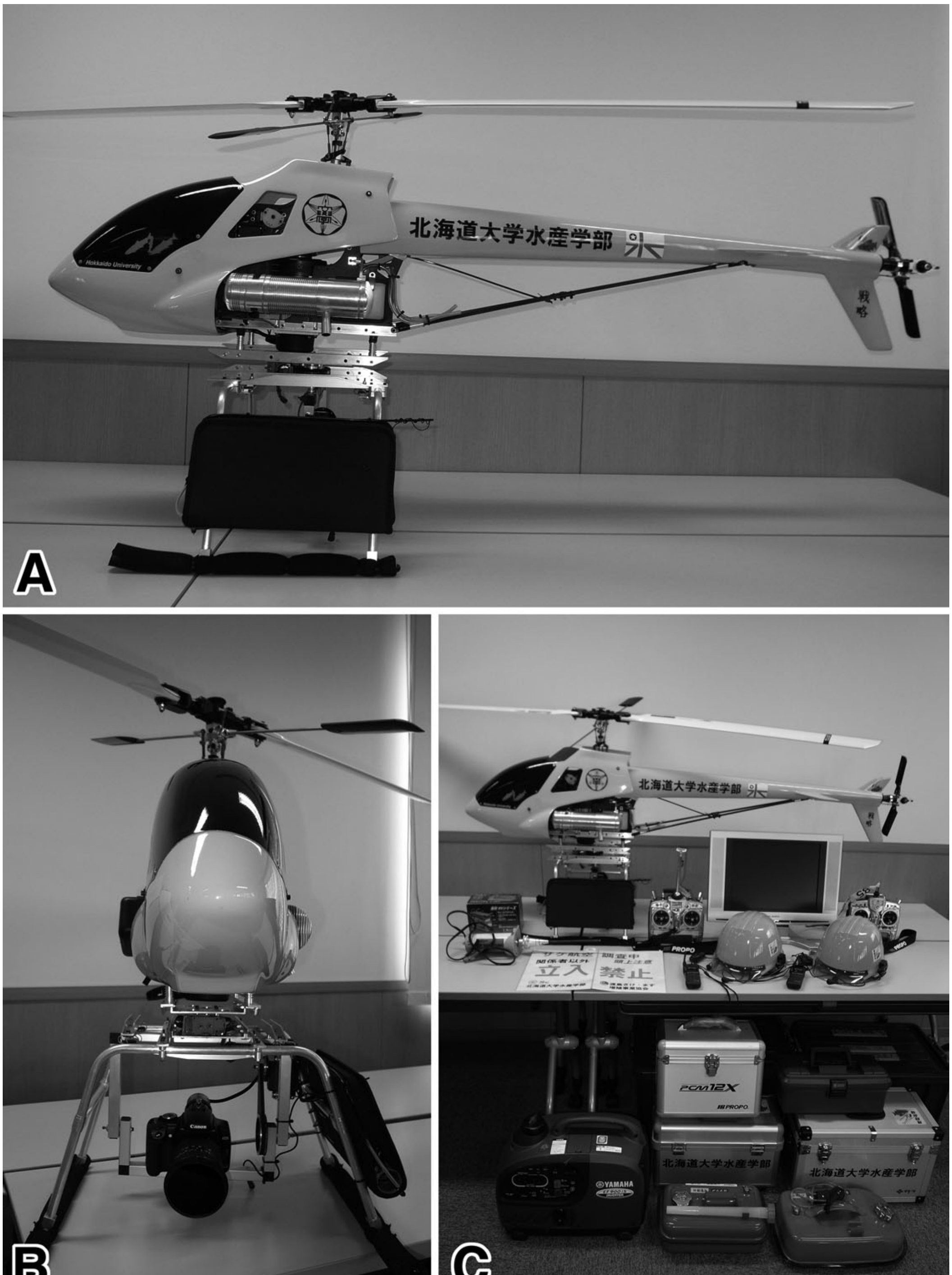

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Figure 2

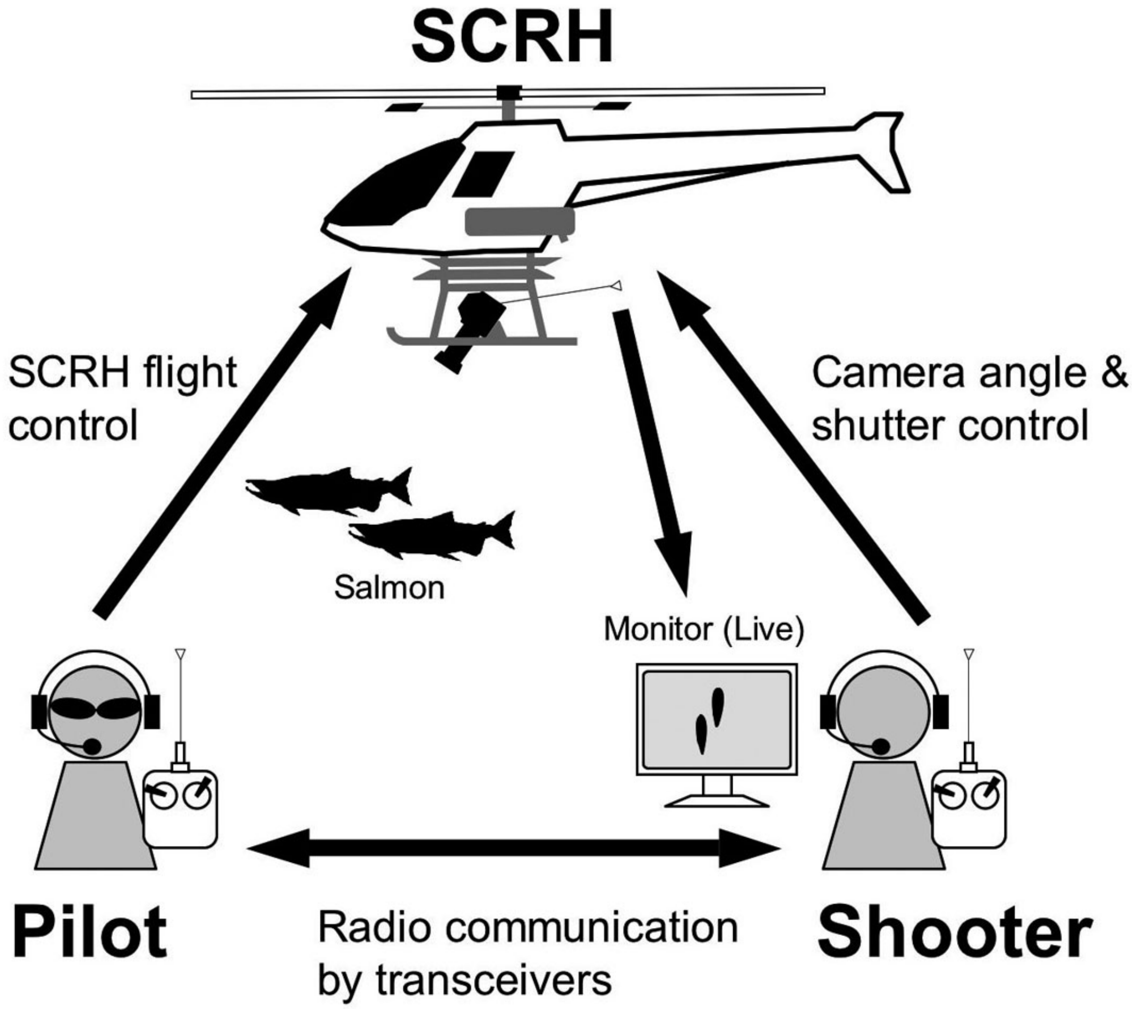

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Figure 3

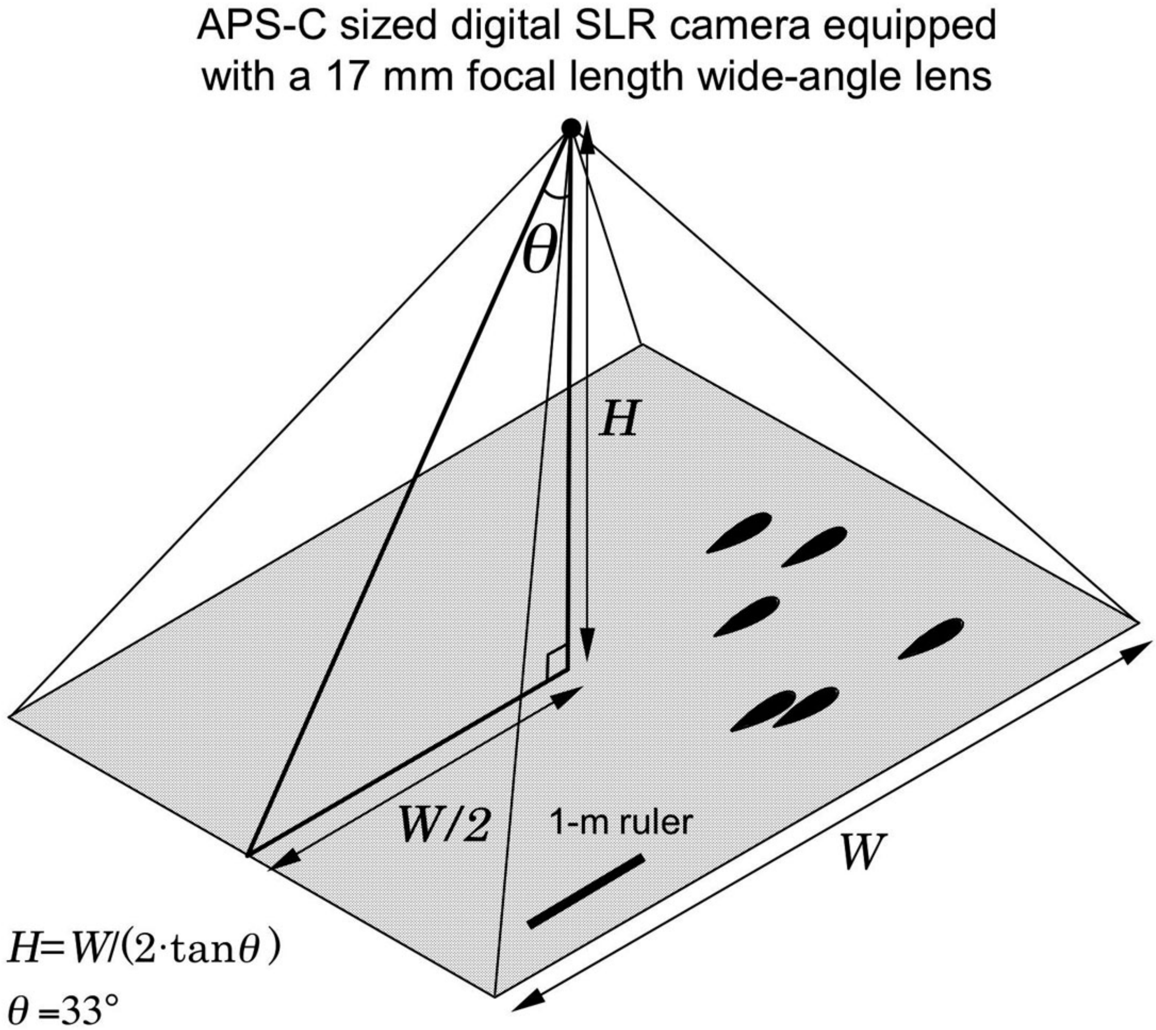

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Figure 4

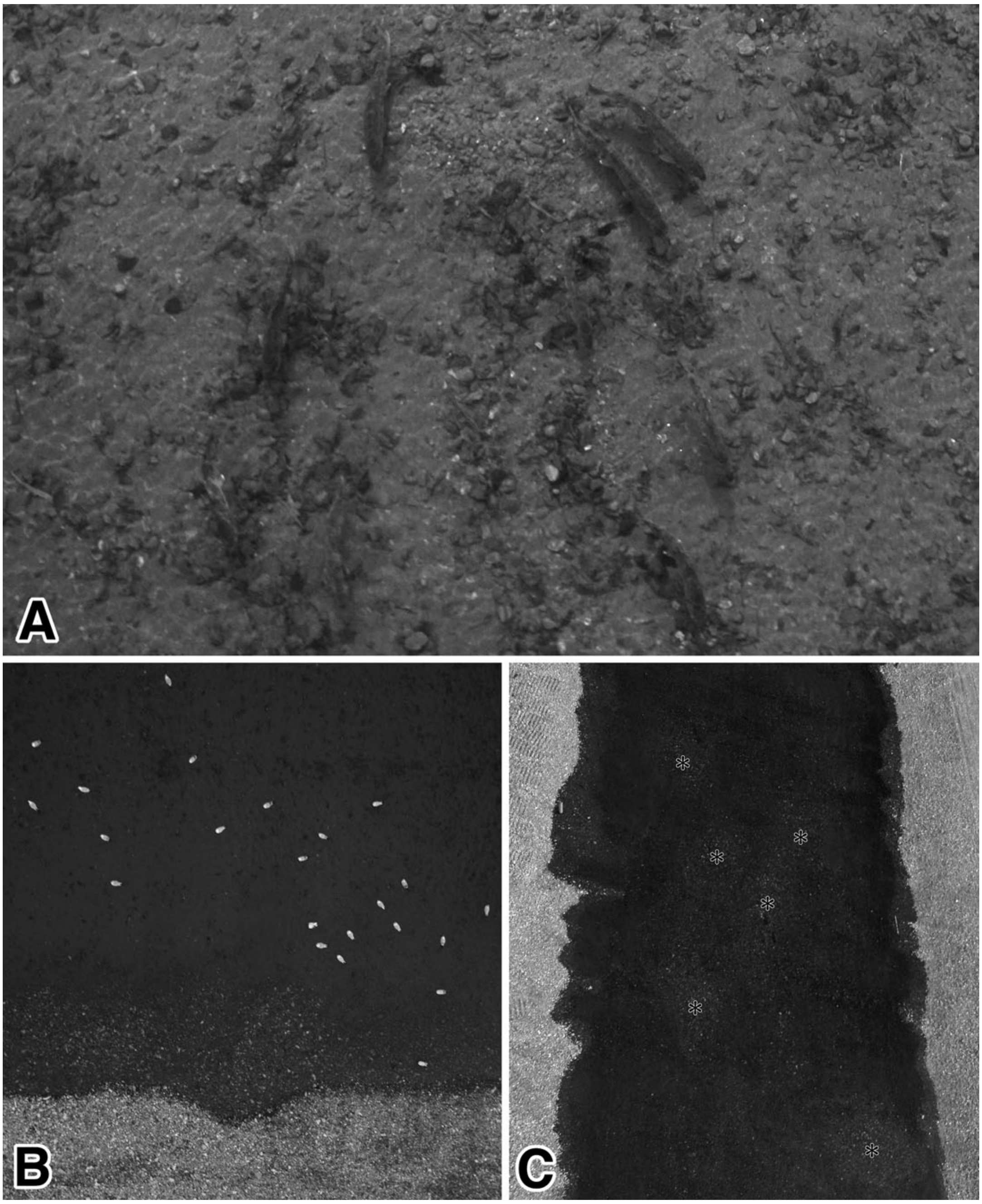

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Figure 5**

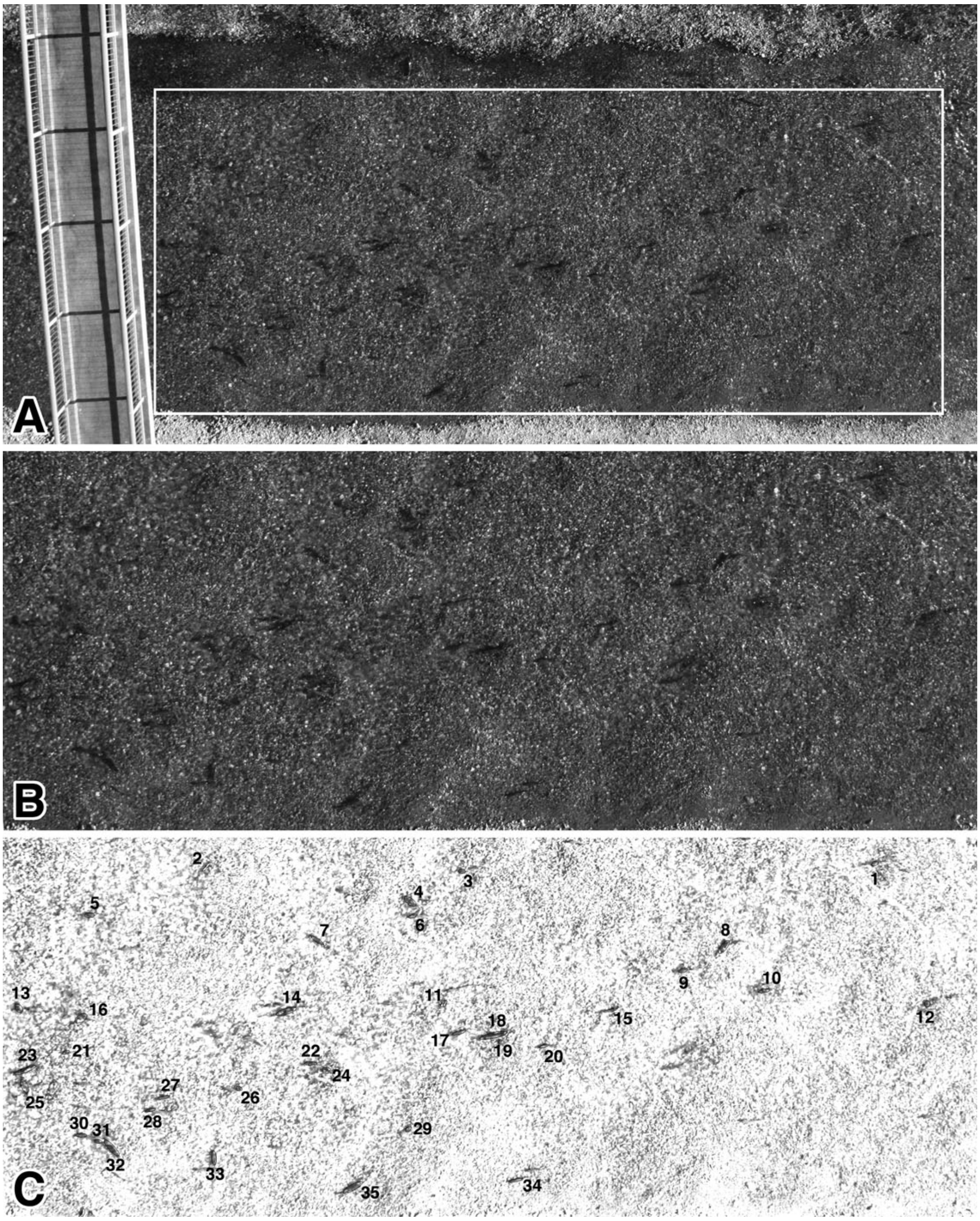

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Figure 6

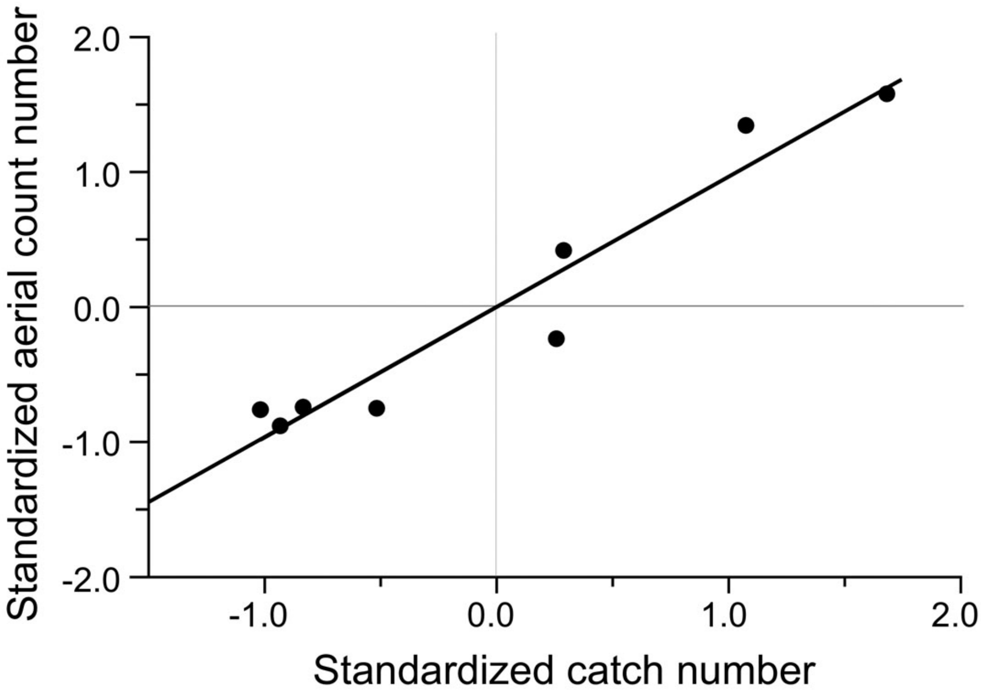

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Figure 7