

FEATURE ARTICLE



Movements of gray whales between the western and eastern North Pacific

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ABSTRACT: The western North Pacific (WNP) population of gray whales *Eschrichtius robustus* is redlisted by the IUCN as Critically Endangered. As part of a long-term study on whales off Sakhalin Island, Russia, photo-catalog comparisons of gray whales in the western and eastern North Pacific (ENP) were undertaken to assess population mixing. These comparisons involved 2 approaches: (1) a systematic comparison of the WNP 'Sakhalin Catalog' to an ENP 'Pacific Northwest Catalog' that consisted of images from the northwest coast of North America and (2) a non-systematic comparison of the WNP 'Sakhalin Catalog' to an ENP 'Laguna San Ignacio Catalog' that consisted of images from central Baja California, Mexico. The Sakhalin to Pacific Northwest comparison consisted of 181 and 1064 whales, respectively, and resulted in 6 matches (3 males, 2 females, and 1 whale of unknown sex). All sightings of 'Sakhalin whales' in the Pacific Northwest occurred off southern Vancouver Island, British Columbia, Canada. The Sakhalin to Laguna San Ignacio comparison consisted of 181 and 2514 whales, respectively, and resulted in 4 matches (2 males and 2 females). As the Pacific Northwest and Laguna San Ignacio catalogs represent only a small fraction of the total estimated number of individuals in the ENP population (~19 000), it is likely that more WNP/ENP exchange has occurred than was detected by these photo-catalog comparisons. Although these matches provide new records of movements between the WNP and ENP, recent observations of gray whales off Japan and China suggest that not all gray whales identified in the WNP share a common wintering ground.



Once thought to be extinct, an endangered western North Pacific gray whale breaches off Sakhalin Island, Russia.

Image: David W. Weller

KEY WORDS: Gray whale · Pacific Ocean · Movement patterns · Conservation

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INTRODUCTION

Gray whales *Eschrichtius robustus* are presently recognized as 2 populations in the North Pacific Ocean. Recent genetic studies using both mitochondrial and nuclear markers have demonstrated significant differentiation between the western North

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Pacific (WNP) and eastern North Pacific (ENP) populations (LeDuc et al. 2002, Lang 2010, Lang et al. 2011). The ENP population ranges from calving areas off Baja California, Mexico, to feeding areas in the Bering, Beaufort, and Chukchi Seas. The WNP population feeds in the Okhotsk Sea off Sakhalin Island, Russia, and in nearshore waters of the southeastern Kamchatka Peninsula (southwestern Bering Sea). Little is known about the current migratory routes and wintering areas of the WNP population, but historic evidence indicates that the coastal waters of eastern Russia, the Korean Peninsula, and Japan were part of the migratory route and that areas in the South China Sea were used as wintering grounds (see review by Weller et al. 2002).

Both populations were dramatically reduced by commercial whaling during the 19th and 20th centuries (Henderson 1984, Weller et al. 2002, Reeves et al. 2010). The ENP population was removed from the U.S. List of Endangered and Threatened Wildlife in 1994 and is currently estimated to number approximately 19 000 individuals (Laake et al. 2009). At the single species-level unit, gray whales are redlisted by the International Union for Conservation of Nature (IUCN) as being of Least Concern (Reilly et al. 2008). The WNP subpopulation, however, is redlisted by the IUCN as Critically Endangered (Reilly et al. 2008). The most recent assessment of the Sakhalin population, using a Bayesian individual-based stage-structured model, resulted in a median 1+ (non-calf) estimate of 130 individuals (90% Bayesian CI = 120–142) in 2008 (Cooke et al. 2008).

Research on gray whales in the WNP has been ongoing since 1995, predominantly on the primary feeding ground off northeastern Sakhalin Island (Weller et al. 1999, Bradford et al. 2008, Lang et al. 2011), and more recently off southeastern Kamchatka (Vertyanin et al. 2004, Tyurneva et al. 2010, Burdin et al. 2011). These studies monitor gray whales using photo-identification methods, as gray whales are individually identifiable based on unique, permanent pigmentation features (Darling 1984). Such monitoring on the Sakhalin feeding ground has documented (1) pronounced seasonal site fidelity and inter-annual return of known individuals, (2) consistent use of the area by adult females when pregnant, resting (i.e. when not pregnant or lactating), and accompanied by calves, and (3) annual return by many individuals that were first identified there as young-of-the-year (Weller et al. 1999, 2002, Bradford et al. 2008, Bradford 2011).

Whales associated with the Sakhalin feeding area can be absent for all or part of a given feeding season (Bradford et al. 2008), indicating that they probably use other areas during the summer and fall feeding period. Some of the whales identified feeding in the coastal waters off Sakhalin, including reproductive females and calves, have also been documented off the southern and eastern coast of Kamchatka (Tyurneva et al. 2010, Burdin et al. 2011). Further, whales observed off Sakhalin have been sighted off the northern Kuril Islands in the eastern Okhotsk Sea and Bering Island in the western Bering Sea (Weller et al. 2003). Finally, Lang (2010) reported that 2 adult individuals from the WNP, sampled off Sakhalin in 1998 and 2004, matched the microsatellite genotypes, mtDNA haplotypes, and sexes (1 male, 1 female) of 2 whales sampled off Santa Barbara, California, USA (Area 3 in Fig. 1) on 20 and 23 March 1995. The study by Lang (2010) was the first to suggest that some level of interchange might be occurring between the WNP and ENP.

While information regarding the summer feeding areas of gray whales in the WNP has become increasingly available in the past decade, current data from the historic migratory corridor(s) are limited and data from the presumed wintering area(s) are essentially unavailable. There have been only 13 known sightings or strandings in Japanese waters since 1990 (Nambu et al. 2010). Between 2005 and 2007, 4 female gray whales were fatally entrapped in set nets along the Pacific coast of Honshu, Japan. One of these females, entrapped in January 2007, was matched to earlier photographs of it as a calf (with its mother) while on the Sakhalin feeding ground in July and August 2006 (Weller et al. 2008). This match provided the most contemporary link between the summer feeding ground off Sakhalin and a winter location along the coast of Asia.

In an effort to obtain more information about the southern migration route(s) and wintering area(s) of gray whales in the WNP, a satellite telemetry project was undertaken in 2010 by a team of Russian and American scientists (Mate et al. 2011). While the objective of that study was to document gray whale movements in the WNP, the only whale tagged was tracked from the WNP to the ENP. The result of this telemetry study, together with the genetic matches reported by Lang (2010), provided the impetus for WNP/ENP photo-identification catalog comparisons, which we conducted to further assess population mixing.

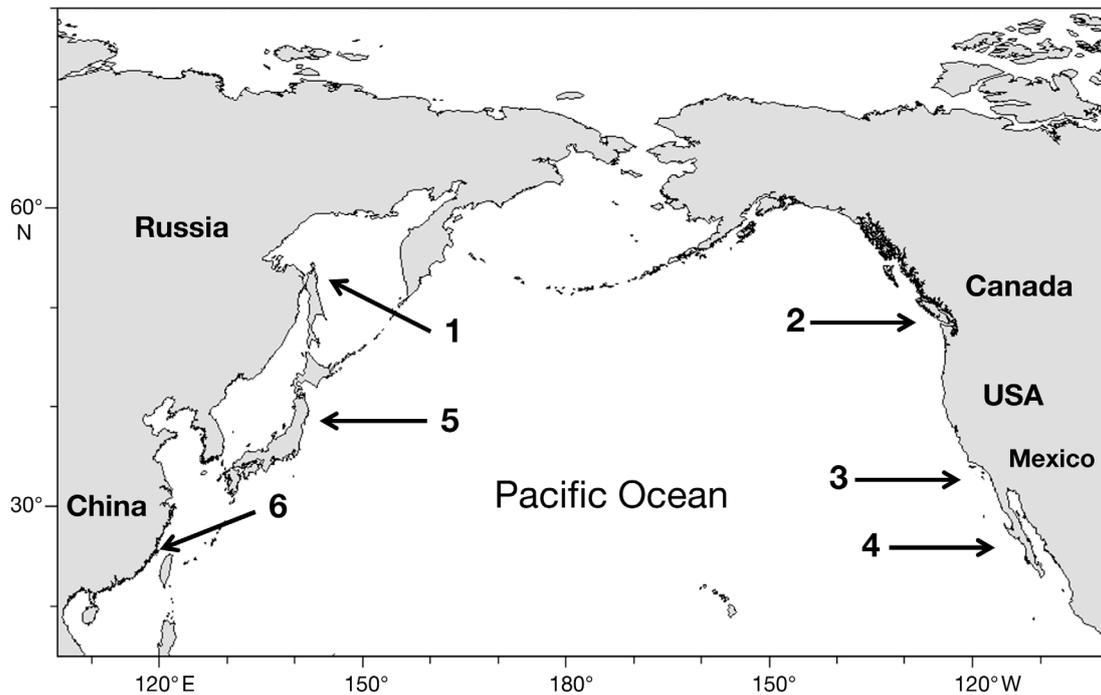


Fig. 1. *Eschrichtius robustus*. North Pacific Ocean, showing: (1) Western North Pacific (WNP) feeding ground off Sakhalin Island, (2) Eastern North Pacific (ENP) region off Vancouver Island where 6 photographic matches to Sakhalin individuals were found, (3) ENP region off California where 2 genetic matches were found (Lang 2010), (4) ENP region off Baja California where 4 photographic matches to Sakhalin individuals were found, (5) WNP region of Japan where a photographic match was found (Weller et al. 2008), and (6) WNP region of China where a gray whale stranded in November 2011 (Zhu 2012)

MATERIALS AND METHODS

Photo-identification images of 181 Sakhalin gray whales (the Sakhalin catalog, hereafter SAK catalog) collected off Sakhalin Island (Area 1 in Fig. 1) between 1994 and 2009 by a joint Russia-U.S. research program (Weller et al. 1999, 2002) were compared to a catalog of 1064 'Pacific Northwest gray whales' (hereafter, PNW catalog) identified by Cascadia Research Collective and collaborators working in U.S. and Canadian waters from California to Alaska (Area 2 in Fig. 1) primarily between 1998 and 2009 (Calambokidis et al. 2002, 2010). The PNW catalog focuses on gray whales that feed during summer and fall in coastal waters between northern California and the Gulf of Alaska, referred to as the Pacific Coast Feeding Group (PCFG), but also includes some migrating whales identified in the spring (March to May) during their northward passage to high-latitude feeding grounds.

Of the 181 whales in the SAK catalog, all were represented by a right-side dorsal flank image, and 179 were associated with a left-side dorsal flank image. Of the 1064 whales in the PNW catalog, 845 were represented by a right-side dorsal flank image, and 898 were associated with a left-side dorsal flank

image. Each individual in the SAK catalog was compared in numerical order to all individuals in the PNW catalog as follows. First, the left-side dorsal flank of each individual in the SAK catalog was compared to the left-side dorsal flank of all individuals in the PNW catalog. This process was then repeated using the right-side dorsal flank and ventral aspect of the tail flukes. Comparisons were made by a single analyst (A.K.), but resulting matches were confirmed by 3 independent researchers skilled in gray whale photo-identification (including A.L.B. and J.C.).

Similarly, photo-identification images of 181 whales in the SAK catalog were compared to an online catalog of 2514 'Laguna San Ignacio gray whales' (hereafter, the LSI catalog) identified between 2006 and 2010 in Baja California, Mexico (Area 4 in Fig. 1). This assessment was not comprehensive or systematic, as was the case for the PNW catalog, because the LSI catalog represented a collection of 'annual working catalogs' rather than a single multi-year catalog of known individuals. Thus, the comparison to the SAK catalog reported herein was undertaken opportunistically. A single analyst (A.L.B.) conducted the appraisal, with identified matches confirmed by 2 additional observers (including D.W.W.).

RESULTS

The comparison of the SAK catalog to the PNW catalog resulted in a total of 6 confirmed matches of individuals, including 3 males, 2 females, and 1 whale of unknown sex (Table 1). None of these 6 whales is a known PCFG animal, and, to date, each one has only ever been photographed a single time during either April or May.

Remarkably, all 6 of the matches were from only 2 days of effort, with 3 whales identified on 2 May 2004 and 3 on 25 April 2008. The 3 whales identified on 2 May 2004 were together in a single group, while the 3 whales recorded on 25 April 2008 were in 2 separate groups but in close proximity. All of the sightings of Sakhalin whales in the Pacific Northwest occurred near Barkley Sound off the west coast of southern Vancouver Island, British Columbia, Canada.

Three of the 6 whales were first identified as calves (with their mothers) on the Sakhalin feeding ground during 1997 (no. RUS-U.S. 032/CRC 1045), 2003 (no. RUS-U.S. 119/CRC 1040), and 2004 (no. RUS-U.S. 135/CRC 1042; Table 1). Interestingly, a genetic analysis of paternity classified one of the matched males (no. RUS-U.S. 035/CRC 0809) as the putative father of 2, or possibly 4, calves identified off Sakhalin (Lang 2010). All 6 whales had sightings off Sakhalin prior to their respective sightings off Vancouver Island, and 5 (83%) had sightings off Sakhalin subsequent to their Vancouver sightings. Four whales were sighted off Vancouver Island and Sakhalin in the same year: 3 in 2004 and 1 in 2008. Of the 3 whales identified off Vancouver Island on 2 May 2004, 2 were resighted off Sak-

halin on 31 July 2004, while the third was first resighted on 6 August 2004. Whale no. RUS-U.S. 032/CRC 1045 was sighted off Sakhalin in 2007 during July (29), August (4,18,25), and September (7,8,9), off southern Vancouver Island on 25 April 2008, and then back off Sakhalin on 19 July 2008. This whale is the same individual satellite-tracked from Sakhalin to the ENP in 2010/2011 (Mate et al. 2011).

The comparison of the SAK catalog to the LSI catalog resulted in a total of 4 confirmed matches of individuals, including 2 males and 2 females (Table 2). Three of these 4 whales were photographed in Laguna San Ignacio in only 1 year, while whale no. RUS-U.S. 052 was identified in both 2007 and 2010. All 4 whales had sightings off Sakhalin prior to their respective sightings in Laguna San Ignacio, and 3 (75%) had sightings off Sakhalin subsequent to their lagoon sightings. Two whales were sighted in Laguna San Ignacio and Sakhalin in the same year: one in 2008 (no. RUS-U.S. 063) and one in 2010 (no. RUS-U.S. 052).

One of the 4 whales (no. RUS-U.S. 020) was first identified as a calf on the Sakhalin feeding ground

Table 2. *Eschrichtius robustus*. Sighting summary information for 4 gray whales matched between Sakhalin Island, Russia (SAK), and Laguna San Ignacio (LSI), Baja California, Mexico. Years shown with a dash (–) are inclusive. RUS-U.S.: joint Russia-U.S. research program; M: male; F: female

Whale ID	Sex	Years sighted in SAK	Years sighted in LSI
RUS-U.S. 020 ^a	M	97, 02–04, 07–09	2006
RUS-U.S. 042 ^b	F	97–00, 03–05	2009
RUS-U.S. 052 ^c	M	98–03, 05–06, 08–10	2007, 2010
RUS-U.S. 063 ^d	F	97–98, 00–02, 05, 07, 08, 10	2008

^aFirst identified off Sakhalin in 1997 as a calf. Photo-matched to Bering Island in June 2000 (Weller et al. 2003). ^bIdentified as a mother with calf in LSI 2009. Never seen with calf off Sakhalin. ^cPutative father of a 1998 Sakhalin calf (Lang 2010). ^dIdentified as a mother with calf in LSI 2008. Known mother from Sakhalin in 1998

Table 1. *Eschrichtius robustus*. Sighting summary information for 6 gray whales matched between Sakhalin Island, Russia (SAK), and the Pacific Northwest coast of North America (PNW). Years shown with a dash (–) are inclusive. RUS-U.S.: joint Russia-U.S. research program; CRC: Cascadia Research Collective; M: male; U: unknown; F: female

Whale ID	Sex	Years sighted in SAK	PNW sighting	PNW sighting coordinates
RUS-U.S. 002 / CRC 0817	M	94–95, 97, 99–01, 04–09	02 May 2004	48° 41.41' N, 124° 58.06' W
RUS-U.S. 032 / CRC 1045 ^a	M	97–98, 01–05, 07–10	25 April 2008	48° 53.81' N, 125° 24.54' W
RUS-U.S. 035 / CRC 0809 ^b	M	95, 97, 98–07, 09–10	02 May 2004	48° 41.41' N, 124° 58.06' W
RUS-U.S. 078 / CRC 0825	U	97, 99, 02–04, 06–10	02 May 2004	48° 41.41' N, 124° 58.06' W
RUS-U.S. 119 / CRC 1040 ^c	F	03, 10	25 April 2008	48° 44.01' N, 125° 07.70' W
RUS-U.S. 135 / CRC 1042 ^d	F	04	25 April 2008	48° 44.01' N, 125° 07.70' W

^aSame whale satellite-tagged in 2010 (Mate et al. 2011). First identified off Sakhalin as a calf in 1997. ^bPutative father of 2 (strict criterion) or 4 (relaxed criterion) Sakhalin calves (for definitions see Lang 2010). Years that these calves were first identified are: 1998, 2001, 2002, and 2003. ^cFirst identified off Sakhalin in 2003 as a calf. ^dFirst identified off Sakhalin in 2004 as a calf

during 1997 (Table 2) and photographically matched to the Commander Islands in June 2000 (Weller et al. 2003). A genetic analysis of paternity classified 1 of the matched males (no. RUS-U.S. 052) as the putative father of a calf identified in 1998 off Sakhalin (Lang 2010). Both of the matched females were identified as mothers with calves while in Laguna San Ignacio. Whale no. RUS-U.S. 042 was identified as a mother with a calf in 2009 but has never been seen with a calf off Sakhalin. Whale no. RUS-U.S. 063 was identified as a mother with a calf in 2008 and was also observed with a calf off Sakhalin (in 1998).

DISCUSSION

The photographic matches reported here provide new information that is of broad significance to understanding the migration patterns and mixing of gray whales in the North Pacific. The high number of matches made between the SAK and PNW catalogs is particularly intriguing given that the PNW catalog used for comparison focuses on PCFG whales and thus greatly underrepresents individuals that pass off the Pacific Northwest during the spring migration. Limited numbers of whales in the PNW catalog have been photographed during the spring off the coast of Vancouver Island where the 6 matched whales were observed ($n = 26$ for southern Vancouver Island; $n = 48$ for all of western Vancouver Island). Thus, 6 of the 74 (8.1%) whales identified off Vancouver Island in the PNW catalog were known Sakhalin individuals. Given that the PNW catalog contains only a small fraction (1064) of the estimated total number of individuals (~19000) in the ENP population, it is likely that more WNP/ENP exchange has occurred than was detected during this comparison.

The high match rate observed between the SAK and PNW catalogs suggests a spatio-temporal behavioral factor that makes Sakhalin whales more likely to have been identified in the small PNW spring sample. The fact that all the matches came from sightings made on only 2 days, mostly in the same groups and in localized areas, indicates that whales from the Sakhalin feeding ground associate, at least to some degree, even when utilizing migratory routes in the ENP. These 6 whales were sighted in an area where some whales tend to linger and feed during the northbound migration (Darling et al. 1998). Feeding whales are often found in more nearshore waters and over extended periods of time, potentially making them more likely to be photographed than animals rapidly migrating past the area (Darling et al. 1998,

Calambokidis et al. 2010). The long distance and potential open water crossing required for transit from the ENP to the WNP may make it advantageous for whales to spend time feeding in the Pacific Northwest (e.g. Vancouver Island) prior to undertaking a westerly passage to Sakhalin.

The preliminary comparison of the SAK and LSI catalogs revealed 4 additional matches. Since the SAK to LSI catalog comparison was conducted in a non-comprehensive manner, relying on long-term familiarity with whales in the WNP catalog, it is probable that additional matches exist. Given the importance of conducting further comparisons to the wintering lagoons of Baja California, Mexico, a systematic and comprehensive comparison of the SAK catalog to a recently compiled multi-year catalog from LSI and Laguna Ojo de Liebre (Scammon's Lagoon) is presently underway (see IWC 2011).

When the 10 WNP/ENP photo-identification matches reported here are combined with the 2 genetic matches noted by Lang (2010), a total of 12 gray whales (6 males, 5 females and 1 whale of unknown sex) identified in the WNP off Sakhalin Island have been matched to 3 locations in the ENP (Vancouver Island, Southern California, Laguna San Ignacio), providing evidence that both sexes, in approximately equal numbers, move between the WNP and the ENP. Despite this level of mixing, significant mtDNA and nuclear genetic differences between whales utilizing the Sakhalin feeding ground and those summering in the ENP support the continued recognition of Sakhalin animals as a distinct genetic unit (Lang et al. 2011).

Adding to the complexity of mixing between the WNP and ENP are contemporary records of gray whales off Japan and, to a lesser degree, China. As previously mentioned, there have been only 13 records of gray whales in Japanese waters since 1990 (Nambu et al. 2010). One of these reports includes a whale first identified as a calf accompanied by her mother on the Sakhalin Island feeding ground in July and August 2006 that was later fatally entrapped in a set net off the Pacific coast of Honshu (Area 5 in Fig. 1) in January 2007 (Weller et al. 2008). While observations of gray whales in Japan have been made between November and August, most of these records are concentrated between March and May. This March to May period coincides with the sightings in the ENP of the 10 matched whales described here. Observations of gray whales in China are exceptionally rare. Only 24 sightings and/or strandings have been recorded since 1933, including obser-

vations of 2 mother–calf pairs (Wang 1984, Zhu 2002). However, a 13 m female gray whale stranded in the Taiwan Strait near the town of Baiqingxiang (Pingtan County), China (Area 6 in Fig. 1), in November 2011 (Zhu 2012). These findings, in combination, suggest that not all gray whales identified in the WNP share a common wintering ground.

The use of photo-identification methods, together with genetic and telemetry techniques, is essential to furthering our understanding of gray whale population structure. We recommend that other existing photo collections and tissue samples of gray whales in the WNP and ENP (e.g. those from Sakhalin, Kamchatka, Chukotka, Mexico, and Japan) be used to further examine gray whale movement patterns and population mixing within the Pacific. Ideally, a collaborative Pacific-wide study should be undertaken, similar in scope to those conducted for humpback whales in the Atlantic and Pacific (Smith et al. 1999, Calambokidis et al. 2008).

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