A Test of Computer-assisted Matching Using the North Pacific Humpback Whale, *Megaptera novaeangliae*, Tail Flukes Photograph Collection

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Introduction

In the mid 1960's, researchers began to photograph individual marine mammals with the express purpose of using the images to identify individual animals on the basis of natural markings. Over time, researchers began to develop photo catalogs of individuals as they were sighted and photographed in different years and areas (Hammond et al., 1990). As the number of photographs has increased, so did the need for computer assistance to help with the collation and integration of the large collections.

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ABSTRACT—Testing was conducted of a computer-assisted system for matching humpback whale tail flukes photographs. Trials with a 12,000-photographs database found no differences in match success between matching by computer and matching by comparing smaller catalogs ranging in size from 200 to 400 photographs. Tests with a 24,000-photographs database showed that, on average, the first match was found after examining about 130 photographs whether the photograph quality was excellent, good, or poor. Match success did not appear to be strongly related to whether the tail flukes had especially distinctive markings or pigment patterns (recognition quality). An advantage of computer-assisted matching is the ability to compare new photographs to the entire North Pacific collection, where no bias is introduced based on expectation of resightings within or between specific areas, or based on expectation of behavioral role (e.g. matching "known" females to "known" females).

Starting in the mid 1980's, computer-assisted systems began to be developed to aid in the identification of individual marine mammals (Hiby and Lovell, 1990; Mizroch et al., 1990). The system developed by Hiby and Lovell use a scanned image and a 3-dimensional computer model to interpret the photograph and to develop an identification algorithm. Their system is considered semi-automated because the computer system measures some of the photograph's characteristics independent of the system operator. The system developed by Mizroch and colleagues is categorical and requires that identification photographs be classified visually by a trained observer. This system is based on a categorization scheme of natural marks and scars, and data related to each photograph are entered into a computer database. The system operator controls all of the matching information and uses a computer to query the database for possible matching choices.

The NMFS National Marine Mammal Laboratory (NMML) has been developing and curating a collection of humpback whale, *Megaptera novaeangliae*, tail flukes photographs taken in North Pacific waters since 1985. This collection has grown from about 750 images in 1986 to about 24,000 in 1999, representing contributions from over 18 research groups from all regions in the North Pacific (Table 1). Unique NMML identification numbers (NMMLID) are assigned only when there are at least 2 photographs of a particular individual whale in the database. As of April 1999, 3,093 unique NMMLID numbers had been assigned and 12,057 tail flukes photographs had been assigned a NMMLID; 11,156 tail flukes photographs had not yet been assigned a NMMLID. Overall, the 23,213 tail flukes photographs evaluated

Table 1.—Major contributing research groups and primary contact people.

Research group/affiliation	Primary contact
Center for Coastal Studies	D. Mattila
Cascadia Research Collective	J. Calambokidis, G. Steiger
Center for Whale Research	K. Balcomb, D. Claridge
Center for Whale Studies	D. Glockner-Ferrari, M. Ferrari
Glacier Bay National Park and Preserve U.S. Dep. Interior, Gustavus	C. Gabriele
Hawaii Whale Research Foundation	D. Salden
J. Straley Investigations	J. Straley
Kewalo Basin Marine Mammal Laboratory University of Hawai'i	L. Herman, A. Craig
Moss Landing Marine Labs California State Universities	S. Cerchio
North Gulf Oceanic Society	O. von Ziegesar, C. Matkin
National Marine Mammal Laboratory NMFS, NOAA, Seattle	S. Mizroch
Okinawa Expo Aquarium	S. Uchida, N. Higashi
Pacific Biological Station Dep. Fish. Oceans, Nanaimo	G. Ellis
SeaSearch	C. and S. Jurasz
Univ. Autonoma de Baja Calif. Sur	J. Urban
Univ. Nacional Autonoma de Mexico	M. Salinas, J. Jacobsen
West Coast Whale Research Foundation	J. Darling, E. Mathews, D. McSweeney, K. Mori

in this paper may represent the sightings and resightings of no more than 6,000 individual humpback whales.

When conducting certain numerical studies using photo-identification data (e.g. capture-recapture analyses), it is important to segregate the photographic data strictly on photographic quality only (Hammond, 1986; Hammond et al., 1990; Mizroch et al., 1990). Photographs in the NMML database are given two different ratings: one based on photographic quality (focus, angle, distance), and the other based on recognition quality (distinctive pattern, marks, or scars) (Mizroch et al., 1990, provide more details). The analysis conducted in this paper stratified the photographs by three levels of photographic quality (hereafter simply referred to as photo quality), examples of which are shown in Figure 1. Matching was conducted using the system described in Mizroch et al. (1990), except that the patterns in use today (Fig. 2) have been simplified and improved. The tail flukes map (Fig. 3) has not been modified.

Tests of the NMML system (i.e. stratified by recognition quality) were first presented in Mizroch et al. (1990), when the database contained 9,353 photographs. Here, we present test results for the NMML database when it contained 12,000 photographs (using ad hoc tests conducted from 1991 to 1995), and tests with the database at its current size of nearly 24,000 photographs.

Methods

Categorizing Whale Tail Flukes

Humpback whale tail flukes have black and white pigment patterns that can match one or several categories (Fig. 2). For each photograph, a selection of patterns that most closely resembled the tail flukes was chosen. In general, the user selected between one and six patterns for each photo being matched, depending on what characteristics were visible on the photograph to be matched. In addition to selecting patterns, the user evaluated locations of natural markings, scars, or other unique marks on the tail flukes (Fig. 3), and selected any or all sectors that contained the markings (e.g. a distinctive line in Sector 5 and an open circle in Sector 6). If the mark extended across sectors, it was described in both. If it was not clear which sector to select, a mark was described as being in one or the other.

Table 2.—Number of photographs in the database stratified by photo quality (focus, etc.) (Fig. 1) and recognition quality (distinctiveness).

	Recognition quality						
Photo quality	1	2	3	0[1]	Total photos	1% of database	0.5% of database
1, excellent	2,742	420	40		3,202	30	15
2, good	7,255	6,627	1,642		1,5,524	160	80
3, poor	1,032	2,152	2,434	84	5,702	60	30
Total	11,029	9,199	4,116	84	24,428	250	125

[1] Category 0 means that the recognition quality cannot be evaluated due to poor photo quality

For each photograph matched, after the input criteria were selected, the matching program queried the database and brought up a subset of all photographs in the database that matched the input criteria and displayed each photograph sequentially on a television monitor, with related data for each photograph on a computer monitor. The operator compared each photograph on the television monitor to the photograph to be matched and determined if there was a match or not. In cases where the photograph on the television monitor was difficult to interpret, the operator pulled the original photograph from the files for further evaluation.

Testing with 12,000 Photographs

As part of data preparation for analyses of calf mortality and birth interval, humpback whale researchers in the North Pacific conducted an ad hoc matching test in the early 1990's. Researchers from Glacier Bay National Park and Preserve[1] (Gabriele), University of Alaska[2] (Straley), and North Gulf Oceanic Society (currently known as Eye of the Whale[3]) (von Ziegesar), working independently of each other and NMML staff (primarily A. Wolman), compared their catalogs to a catalog of known females prepared during a workshop on calf mortality (called here the "calf mortality" catalog, containing 352 individual whales, unpubl. data on file at the NMML). Their catalogs, which represented Alaska areas including Glacier Bay, portions of southeastern Alaska, and Prince William Sound, ranged in size from about 200 individuals to about 400 individuals. The tail flukes photograph collection at the NMML at the time of the matching exercise numbered about 12,000 photographs including photographs from all regions in the North Pacific. The matching success of computer-assisted matching at the NMML was compared with the matching success of each individual researcher visually inspecting their own hard-copy catalogs (Mizroch[4]).

Testing with 24,000 Photographs

A random selection of about 0.5% of the database (116 photographs) was made, stratified by photo quality codes (Table 2). Based on the stratification, there were 15 photo quality 1 (excellent) photos, 75 photo quality 2 (good or moderate) photos, and 26 photo quality 3 (poor) photos selected. The draw from the database was independent of recognition quality and of whether the animal had been matched previously.

At the time of the matching exercise, we did not know whether the photographs had been matched previously. For each photograph selected, the computer-assisted matching program was used to match each photograph to the entire collection, and matching was halted either when the first match was found, or when about 5% of the database (1,250) photographs had been examined. If the photograph was of a well-known animal, the match criteria used for this exercise were based strictly on the detail showing on the photograph

[1] Humpback Whale Monitoring Program, Glacier Bay National Park and Preserve, P.O. Box 140, Gustavus, AK 99826.

[2] University of Alaska Southeast Sitka Campus, 1332 Seward Avenue, Sitka, AK 99835.

[3] Eye of the Whale, P.O. Box 15191, Fritz Creek, AK 99603.

[4] Mizroch, S. A. Report of the workshops on the estimation of calf mortality in North Pacific humpback whales. 38 p., Unpubl. data.

45598

23407

Excellent: Photo Quality 1

50236

10465

Good: Photo Quality 2

60328

23141

Poor: Photo Quality 3

Figure 1.—Photographs that illustrate the photo quality codes.

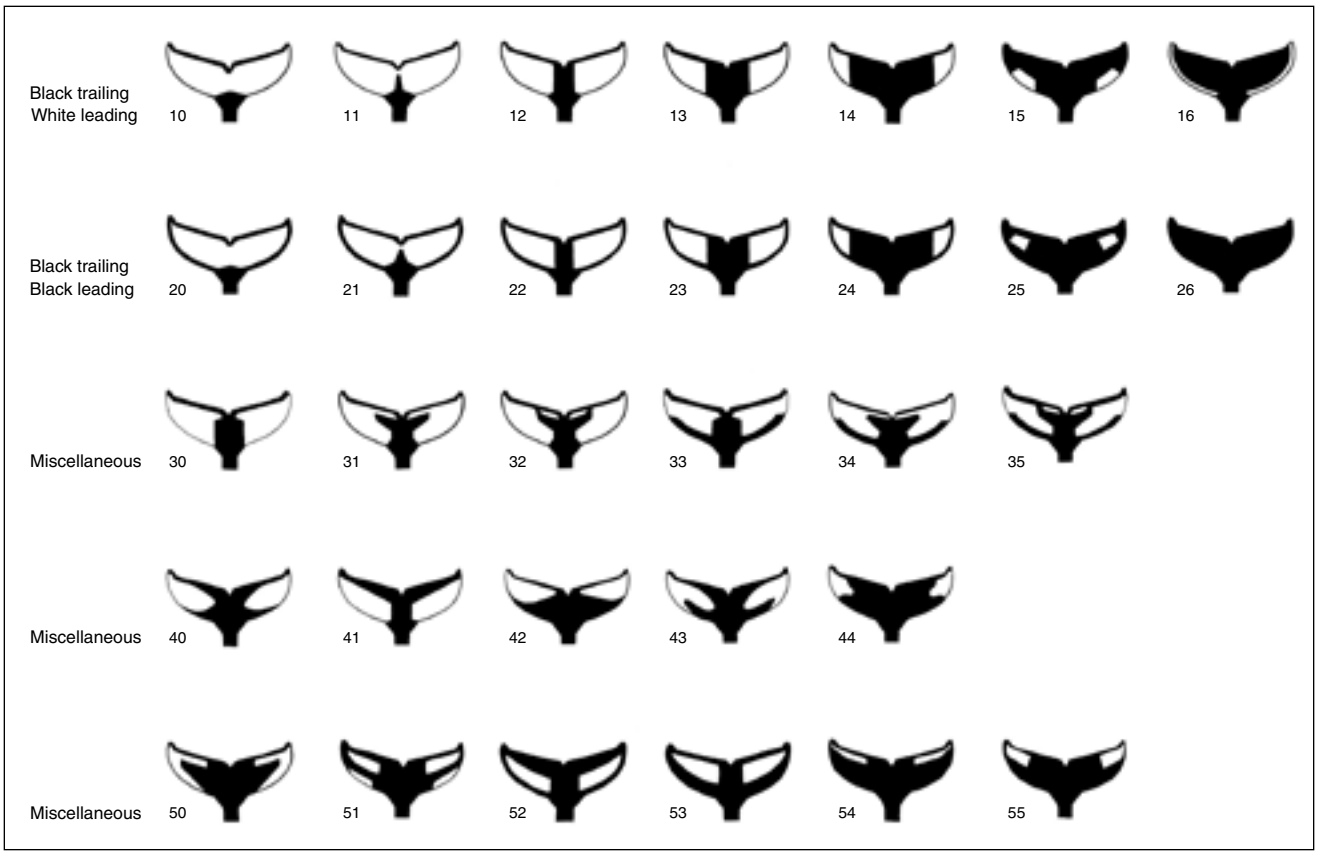


Figure 2.—Tail flukes patterns (numbers shown at lower left of each pattern are the pattern codes used in the database), slightly modified and updated from the patterns presented in Mizroch et al. (1990).

drawn randomly, rather than on other known marks or scars that the individual may have accumulated over time.

Results

Testing with 12,000 Photographs

The Glacier Bay catalog (unpubl. data) numbered about 200 individual whales at the time of the matching exercise. Ten of the 12 matches between the "calf mortality" catalog and the Glacier Bay catalog were found independently by both Gabriele and Straley and by NMML staff. Gabriele and Straley found one match that NMML staff missed and NMML staff found one match that Gabriele and Straley missed (Table 3).

The southeastern Alaska catalog numbered about 400 individual whales at the time of the matching exercise. Both Straley and NMML staff found 19 of the 21 matches between the "calf mortality" catalog and the southeastern Alaska catalog independently. Straley found one match that was missed by NMML staff, and NMML staff found one match that was missed by Straley (Table 3).

Table 3.—Comparisons of computer-assisted matches and matches from each Alaska research group, matching the "calf mortality" catalog to each independent collection. The "calf mortality" catalog included photographs of about 350 individual whales, and the NMML database contained about 12,000 tail fluke photographs at the time of this matching exercise.

Catalog	Approx. sample size	Observed by both NMML and research group	Total no. of matches found
Glacier Bay (Gabriele)	200	10	12
Southeastern Alaska (Straley)	400	19	21
Prince William Sound (von Ziegesar)	200	6	10

The Prince William Sound catalog numbered about 200 individual whales at the time of the matching exercise. Both von Ziegesar and NMML staff found 6 of the 10 matches found between the "calf mortality" catalog and the Prince William Sound catalog independently. Von Ziegesar found three matches that NMML staff missed and NMML staff found one that von Ziegesar missed. The number of matches missed from this set was somewhat larger than the others (Table 3). For at least one of the matches made by von Ziegesar and missed by NMML staff, the photo quality was poor, and the match was based mainly on trailing edge shape and detail, and not the marks, scars, and pigment patterns that

were apparent on a good quality photograph of the tail.

Overall, 38 of the 43 total matches found (88%) were made using the computer-assisted system. There was no significant difference in matches found for each area (Chi-square = 4.37, P = 0.11).

Testing with 25,000 Photographs

Photo Quality 1

Of the 15 images in this category, matches were found for all 15 photographs. In 10 cases, the first match was found in the top 0.0027 of the database (fewer than 70 photographs evaluated). In all 15 cases, the first match was found in the top 0.031 of the database (Table 4, Fig. 4). On average, the first match was found in the top 0.0052 of the database (about 130 photographs) (SD = 0.0079).

Examples of two of the photo quality 1 matches, including the pattern and marks selections are presented in Figures 5 and 6. Figure 5 shows a match that was found after making one change in selection criteria and evaluating 69 photographs. Figure 6 shows a whale that had no apparent marks, and the match was found after evaluating 793 photographs.

Photo Quality 2

Of these 75 images, matches were found for 45 photographs. Of these 45, in 27 cases the first match was found in the top 0.0027 of the database (70 or fewer photographs evaluated) (Table 5, Fig. 4). On average, the first match was found in the top 0.0056 of the database (about 130 photographs) (SD = 0.0072).

In only three cases, known matches of photo quality 2 photos were missed, due to the following reasons (Fig. 7):

1) For photograph 5889, the flecked markings (speckled or streaked pigment markings which were present in both Sectors 5 and 8) did not appear to be present in Sector 5 on the photograph missed in the database, so the matching photograph was not selected in any of the matching selections.
2) For photograph 50363, the matching photograph lacked any detail, and would have been found only after looking at more than 1,250 photographs, the arbitrary cut-off point for this exercise, because of where it was on the list of photos selected from the database.
3) For photograph 61147, the distinctive circle in Sector 6 was present but not coded as such on the photograph in the database, so the matching photograph was not selected in any of the matching selections.

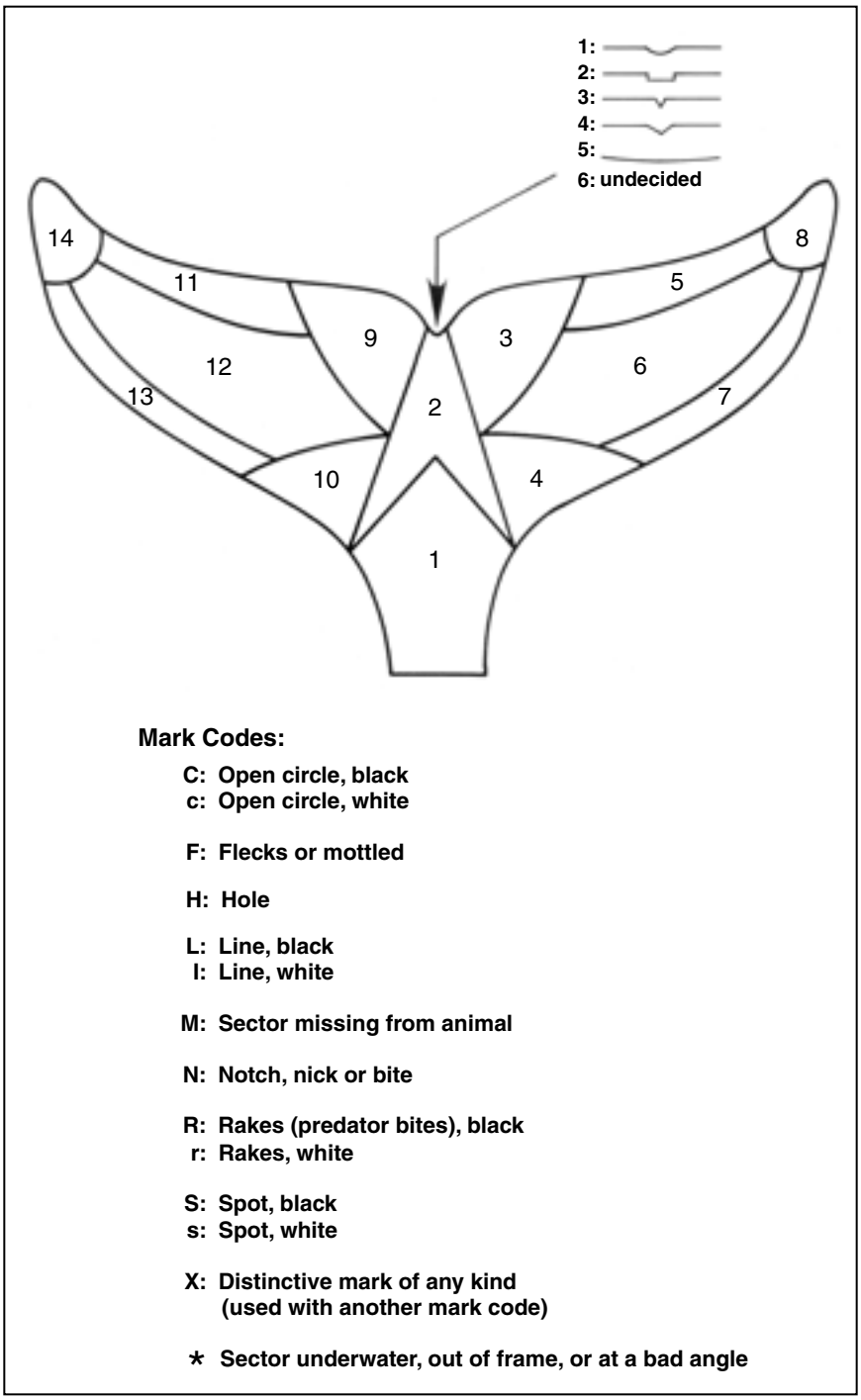


Figure 3.—Tail flukes map.

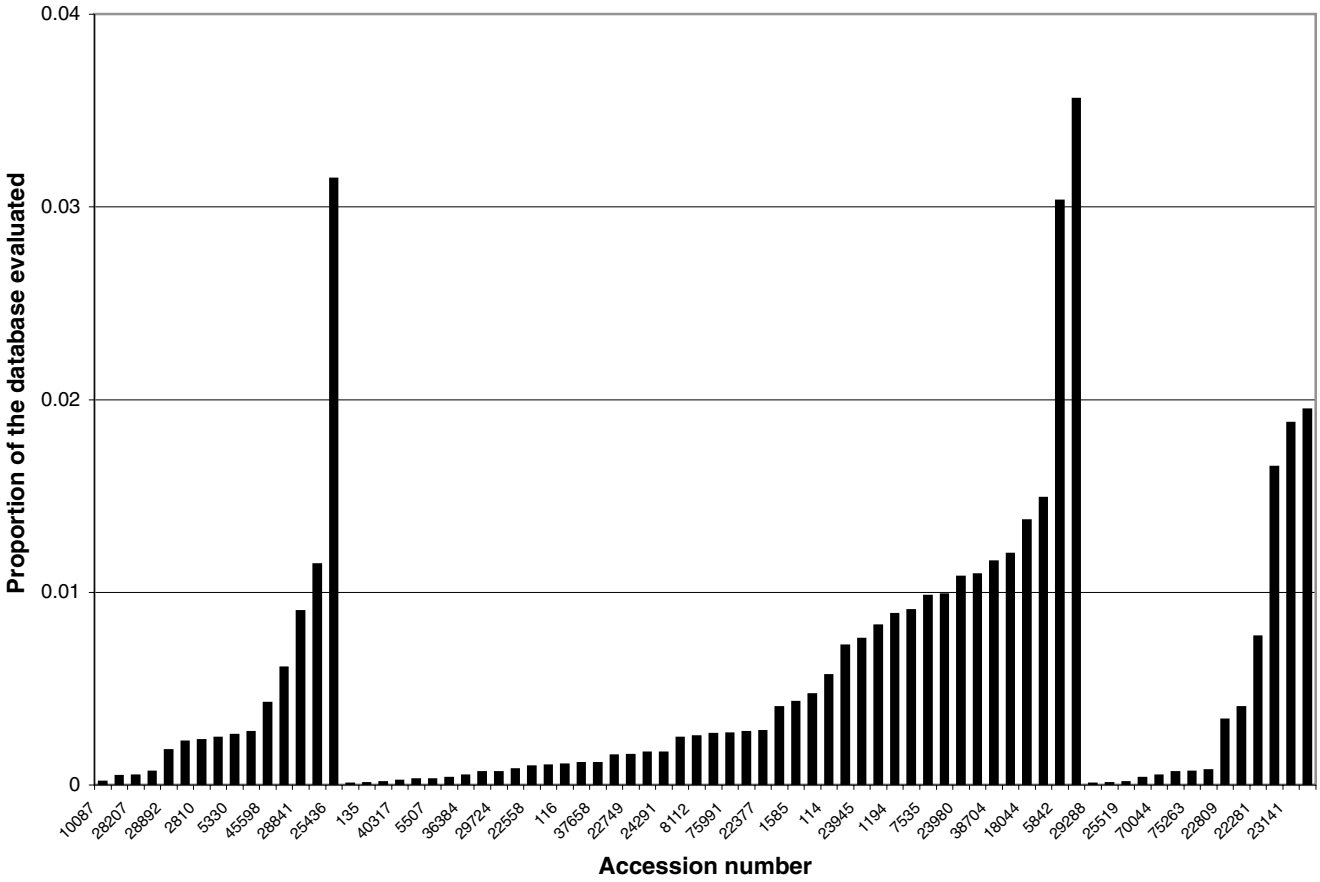


Figure 4.—Test results for photographs where matches were found, photo qualities 1–3.

Examples of two of the photo quality 2 matches, including the pattern and mark selections, are presented in Figure 8. Figure 8 shows a match that was found after making two changes in selection criteria and evaluating 764 photographs.

Photo Quality 3

Of these 26 images, matches were found for 14 photographs. Of these 14 photographs, in 9 cases the first match was found in the top 0.0034 of the database (85 or fewer photographs evaluated) (Table 6, Fig. 4). On average, the first match was found in the top 0.0052 of the database (about 125 photographs) (SD = 0.0071).

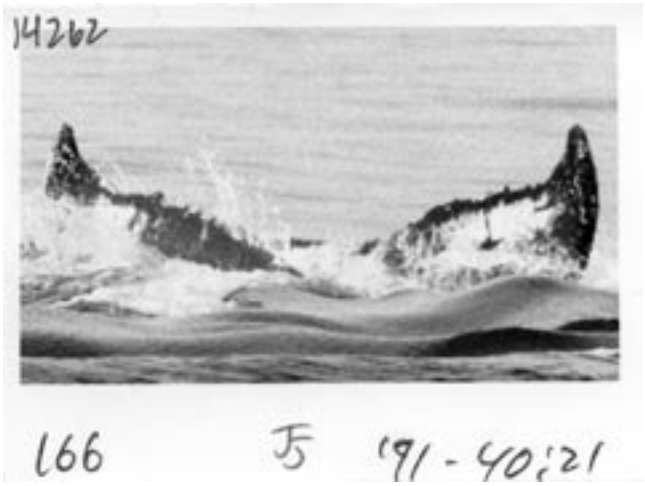
In only two cases, known matches of photo quality 3 photographs were missed due to the following reasons (Fig. 7):

Table 4.—Photo quality 1 results, including numbers of photographs examined and origin of each photo.

Accession no.	Recognition quality	No. photographs examined until first match was found	Proportion of the database examined	Geographic origin of photo
10087	1	4	0.000158648	Hawaii
848	1	11	0.000436283	Hawaii
28207	1	12	0.000475945	Hawaii
23827	1	17	0.000674255	Hawaii
28892	1	45	0.001784794	Hawaii
29233	1	56	0.002221076	Hawaii
2810	1	58	0.002300401	Mexico
23407	1	61	0.002419387	Hawaii
5330	1	65	0.002578035	Alaska
2053	1	69	0.002736683	Mexico
45598	1	107	0.004243842	California
9115	1	153	0.006068298	California
28841	1	227	0.009003292	Hawaii
9768	2	288	0.011422679	California
25436	2	793	0.031452029	Alaska
Average (Standard Deviation)		131.0667	0.005198 (0.007949)	

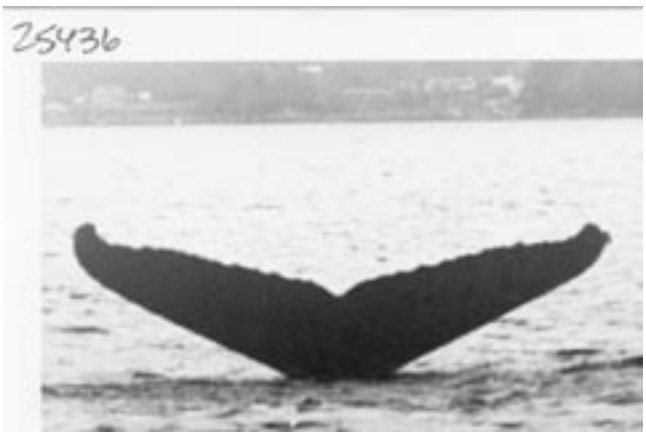
1) For photograph 9774, only part of one tail fluke was showing, and there were very few distinguishing marks present.

2) For photograph 34697, the photo quality was so poor that the match could only be confirmed by the researcher who took the photo.



Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
54, 55	XL in 11	57
54, 55	L in 5 and 11	12
		69

Figure 5.—Example of the evaluation of photo accession number 2053, coded as photo quality 1.



Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
26	none	793

Figure 6.—Example of the evaluation of photo accession number 25436, coded as photo quality 1.

An example of a photo quality 3 match, including the pattern and marks selections (Fig. 9) shows a match that was found after making two changes in selection criteria and evaluating 101 photographs.

Results for photos of qualities 1 though 3 were surprisingly similar. In Figure 10, results are presented independent of photo quality, sorted by match success, with recognition quality plotted for each photograph. Recognition quality is based on the presence of distinctive markings or pigmentation, which should affect one's ability to recognize the individual even if photo quality is very poor. There did not appear to be a trend in recognition quality with respect to known matches that were

missed. Also, there did not appear to be a trend with respect to the photographs as yet unmatched (Fig. 11).

Overall, matches were found for 74 of the 116 photographs, and on average, the first match was found in the top 0.0054 of the database (about 130 photographs) (SD = 0.0073).

Discussion

Testing with 12,000 Photographs

This exercise confirmed that computer-assisted matching was an effective tool, especially considering that NMML staff was comparing the "calf mortality" catalog to a collection of over 12,000 photographs and not to individual catalogs ranging in size from 200–400 photographs.

Testing with 25,000 Photographs

Figure 10 indicates no trend in match results with respect to recognition quality, which may mean that even the less distinctive tail flukes photographs have enough detail so matches can be found.

Of the 116 photographs selected at the time the matching exercise began, only 52 had been previously matched (i.e. assigned a NMMLID). New matches were found for 26 of the photographs and 38 remain without known matches. Overall, only five known matches were missed.

An advantage of computer-assisted matching is the ability to compare new photographs to the entire North Pacific collection and the potential to find matches to whales photographed in other regions. No bias is introduced based on expectation of resightings within or between specific summer or winter grounds. Another advantage in using computer-assisted matching is that by matching to the entire collection, no bias is introduced based on expectation of behavioral role (e.g. matching "known" females to "known" females).

At this time, the NMML computer matching system is able to match images effectively with a database of over 25,000 photographs to choose from. The computer-assisted system has continued to be an efficient matching system for such a large number of photographs because the matching criteria are always con-

Table 5.—Photo quality 2 results, including numbers of photographs examined and origin of each photo.

Accession number	Recognition quality	No. photographs examined until first match found	Proportion of database examined	Geographic origin of photo
29213	1	1	3.96621E-05	Hawaii
135	2	2	7.93242E-05	Alaska
37195	1	3	0.000118986	Alaska
40317	2	5	0.00019831	Hawaii
6832	1	7	0.000277635	Alaska
5507	2	7	0.000277635	Alaska
39389	1	9	0.000356959	Hawaii
36384	1	12	0.000475945	Alaska
28227	1	16	0.000634593	Hawaii
29724	2	16	0.000634593	Hawaii
39914	2	20	0.000793242	Hawaii
22558	1	24	0.00095189	Hawaii
23683	2	25	0.000991552	Hawaii
116	1	26	0.001031214	Alaska
39138	1	28	0.001110538	Hawaii
37658	3	28	0.001110538	Alaska
60184	2	38	0.001507159	Hawaii
22749	1	39	0.001546821	Hawaii
34584	1	42	0.001665807	Hawaii
24291	2	42	0.001665807	Hawaii
36179	2	61	0.002419387	Alaska
8112	1	63	0.002498711	Hawaii
16240	1	66	0.002617697	Mexico
75991	1	67	0.002657359	Alaska
38357	1	69	0.002736683	Alaska
22377	1	70	0.002776346	Hawaii
23914	2	101	0.00400587	Hawaii
1585	1	108	0.004283505	Hawaii
5502	3	118	0.004680125	Alaska
114	2	143	0.005671677	Alaska
28574	1	182	0.007218498	Hawaii
23945	3	191	0.007575457	Hawaii
39955	2	208	0.008249712	Hawaii
1194	1	223	0.008844644	Hawaii
50236	1	228	0.009042954	Hawaii
7535	1	247	0.009796534	Alaska
39102	1	249	0.009875858	Hawaii
23980	2	272	0.010788086	Hawaii
25855	2	275	0.010907072	Alaska
38704	2	292	0.011581327	Alaska
44091	2	302	0.011977948	Hawaii
18044	2	346	0.013723079	Alaska
9078	1	375	0.01487328	California
5842	1	764	0.030301828	Alaska
12102	2	897	0.035576885	Alaska
1547	2	No match	0.05	Hawaii
2003	2	No match	0.05	Mexico
2935	2	No match	0.05	Mexico
5380	2	No match	0.05	Alaska
5889	1	No match	0.05	California
10465	1	No match	0.05	Hawaii
10592	1	No match	0.05	Hawaii
10848	2	No match	0.05	Hawaii
10973	1	No match	0.05	Hawaii
11171	2	No match	0.05	Hawaii
14802	3	No match	0.05	Mexico
16300	1	No match	0.05	Mexico
16327	1	No match	0.05	Mexico
17430	1	No match	0.05	Alaska
23506	1	No match	0.05	Hawaii
27102	2	No match	0.05	Hawaii
30394	2	No match	0.05	Japan
37170	3	No match	0.05	Alaska
37410	2	No match	0.05	Alaska
39090	3	No match	0.05	Hawaii
40418	2	No match	0.05	Hawaii
44567	2	No match	0.05	Hawaii
45217	3	No match	0.05	California
45651	3	No match	0.05	Oregon
50363	2	No match	0.05	Hawaii
50400	2	No match	0.05	Hawaii
60328	3	No match	0.05	Hawaii
60620	2	No match	0.05	Hawaii
61147	2	No match	0.05	Hawaii
99914	2	No match	0.05	Colombia
Average (Standard Deviation)		133.4127	0.00556 (0.00729)	

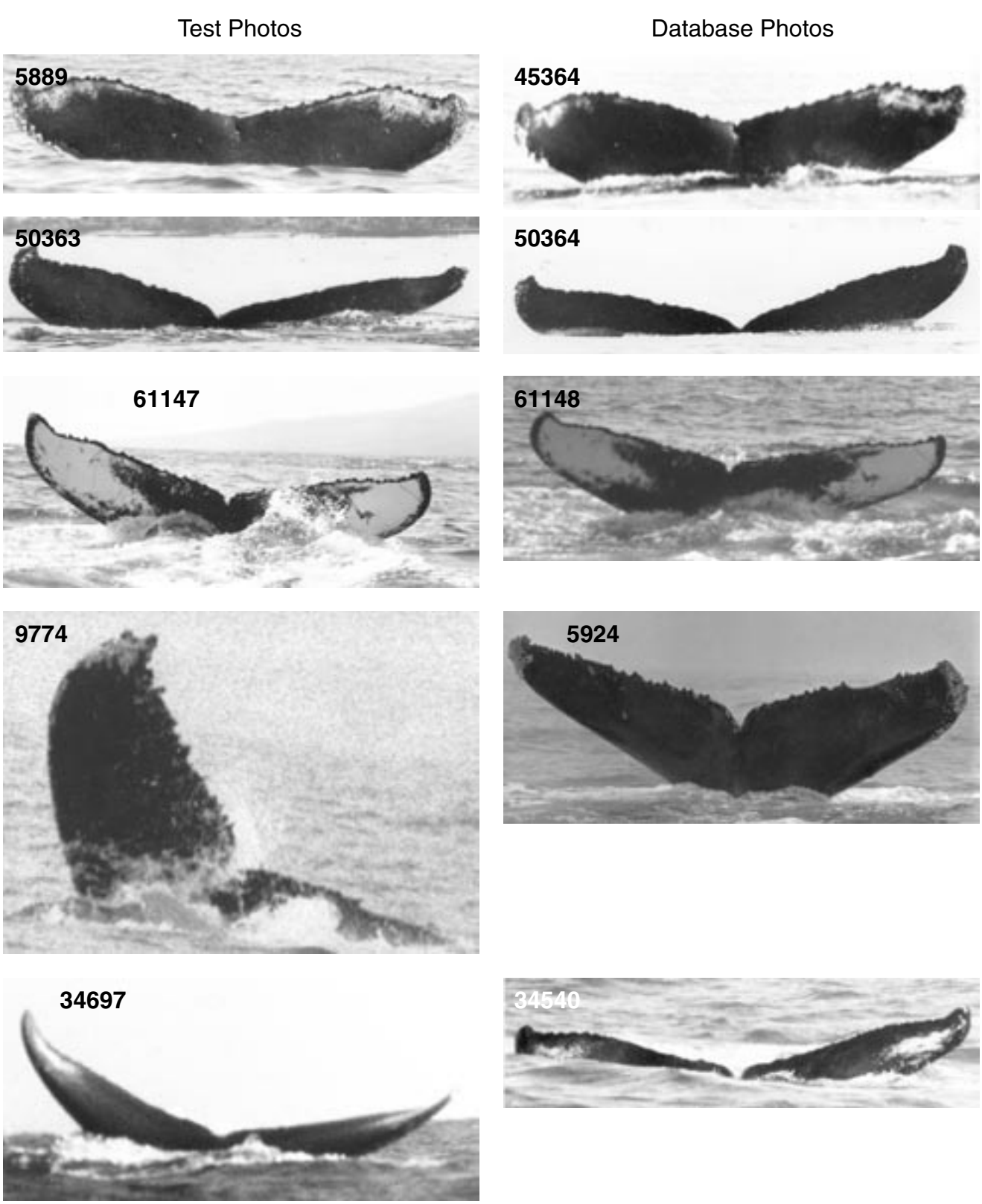


Figure 7.—Examples of photographs where matches were missed. These photographs were coded as photo quality 2 and 3. The test photos are on the left, and the missed matches are on the right.

Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
13, 40, 41, 43	X in 11 or 13	170
13, 40, 41, 43	L in 5 and S in 13	344
13, 40, 41, 43	F in 6	250
		764

Figure 8.—Example of the evaluation of photo accession number 5842, coded as photo quality 2.

Patterns used to find the match	Marks/Scars used	Number of photographs evaluated
12, 13, 40	XS in 11	74
12, 13, 40	XC in 11	4
12, 13, 40	XC or XS in 12	23
		101

Figure 9.—Example of the evaluation of photo accession number 2658, coded as photo quality 3.

Table 6.—Photo quality 3 results, including numbers of photographs examined and origin of each photo.

Accession no.	Recognition quality	No. photographs examined until first match found	Proportion of database examined	Geographic origin of photo
29288	2	1	3.96621E-05	Hawaii
34937	3	2	7.93242E-05	Hawaii
25519	3	3	0.000118986	Alaska
80029	2	9	0.000356959	Mexico
70044	2	12	0.000475945	Mexico
174	2	16	0.000634593	Hawaii
75263	0	17	0.000674255	Alaska
5755	0	19	0.00075358	Mexico
22809	3	85	0.003371277	Hawaii
2658	1	101	0.00400587	Mexico
22281	1	194	0.007694443	Hawaii
9418	2	416	0.016499425	California
23141	2	473	0.018760163	Hawaii
37034	1	491	0.019474081	Alaska
1783	1	No match	0.05	Hawaii
9774	2	No match	0.05	California
10725	2	No match	0.05	Hawaii
22031	2	No match	0.05	Hawaii
23785	3	No match	0.05	Hawaii
28185	3	No match	0.05	Hawaii
29292	3	No match	0.05	Hawaii
34549	2	No match	0.05	Hawaii
34697	3	No match	0.05	Hawaii
37237	3	No match	0.05	Alaska
46410	3	No match	0.05	California
50102	2	No match	0.05	Hawaii
Average (Standard Deviation)		125.0375	0.005210 (0.007131)	

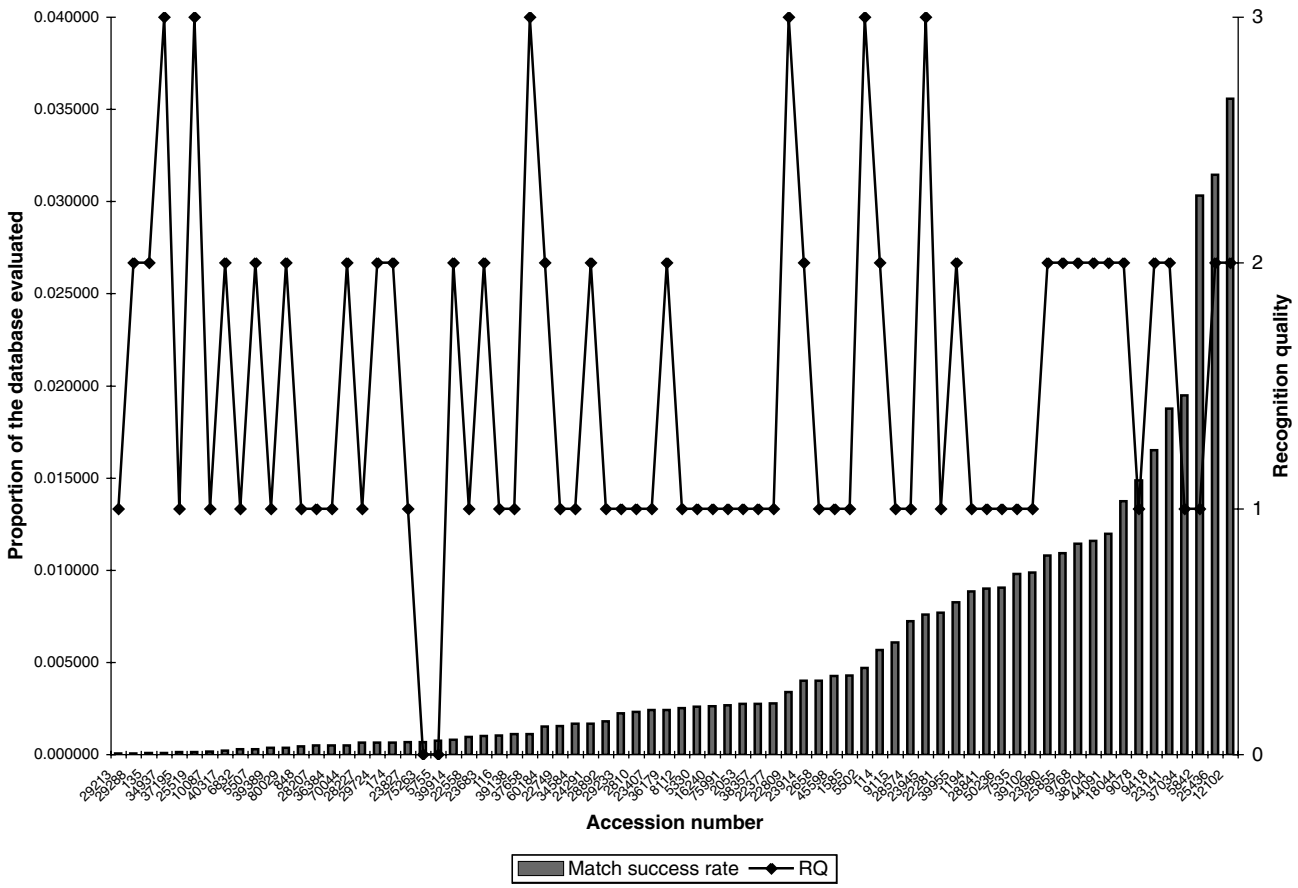


Figure 10.—Recognition quality (RQ) vs proportion of the database evaluated for each photograph. RQ 0: photo cannot be evaluated for recognition quality; RQ 1: Excellent; RQ2: Good or moderate; RQ3: Poor.

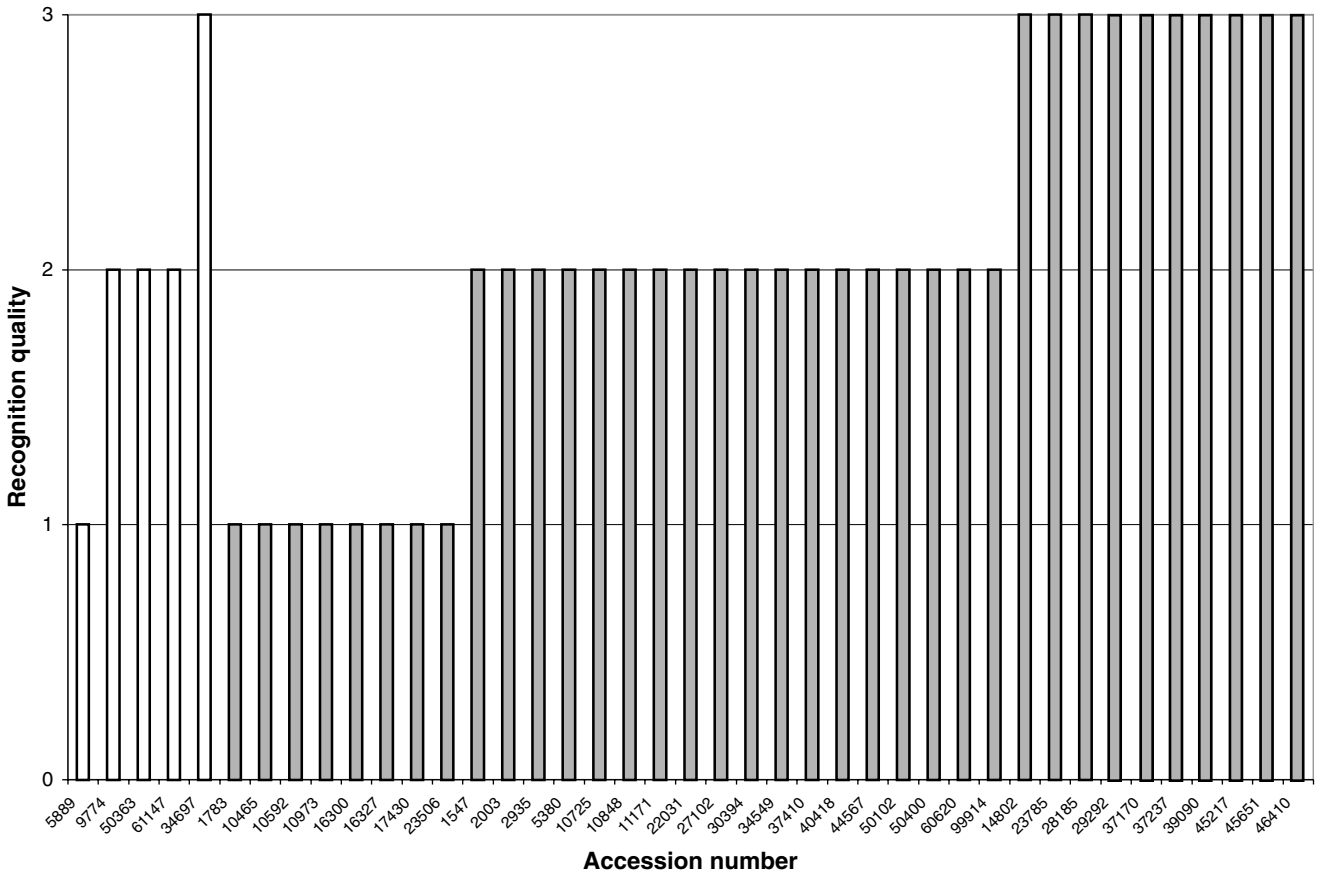


Figure 11.—Recognition quality of photographs where matches were not found. The first 5 bars (no color) represent photographs for which known matches were missed (see Fig. 7).

trolled by a human operator and because database performance is not constrained by size. Data entry is fast (between 100–200 photographs entered per day). Image capture and retrieval is fast, with the capability of capturing 5,000 images per day on a videodisc that holds 54,000 images. Image retrieval time ranges from a fraction of a second to perhaps 2 seconds, depending on the distance between images on the videodisc.

Conclusions

Since the NMML system has been in use, there has been a desire to develop computer-assisted systems that are more "automated." The NMML system takes advantage of the human brain's ability to instantly rotate, adjust, compensate, and recognize similar images. Computer technology cannot yet compete with the image processing power of the human brain, and it is not so advanced that a completely automated system is possible. Both the categorical systems used here and the other systems developed by Hiby take some operator training and intervention.

New systems are being developed for identifying individual Alaska harbor seals which should provide a direct comparison of categorical versus semi-automated systems. Future sample sizes will likely be large enough to compare the two approaches with rigor.

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(Fig.1: photos 50236 and 60328; Fig. 7: 61147 and 61148), J. Straley Investigations (Fig. 8: photo 5842), J. Jacobsen and Universidad Nacional Autónoma de México (Fig. 5: photo 14262; Fig. 9: photos 2658 and 2722), Sal Cerchio and Moss Landing Marine Labs (Fig. 7: photo 34540 and 34697), National Marine Mammal Laboratory (Fig. 6: photo 25436), NMFS, Alaska Region (Fig. 8: photo 25013), Jorge Urbán currently of Universidad Autónoma de Baja California Sur (Fig. 5: photo 2053), West Coast Whale Research Foundation (Fig. 1: photo 10465).

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