Geographic Variation in the Color Pattern of Killer Whales *(Orcinus orca)*

W. E. Evans

Hubbs-Sea World Research Institute, San Diego, Calif. 92109 USA

A. V. Yablokov

Institute of Developmental Biology, Academy of Science, Moscow, USSR

A. E. Bowles

Hubbs-Sea World Research Institute, San Diego, Calif. 92109 USA

INTRODUCTION

Evans and Yablokov (1978) proposed a method for analyzing differences in the color pattern of killer whales *(Orcinus orca).* This species' rather complex pattern was divided into several distinct components. Using schemes similar to those proposed by Yablokov (1969), Mitchell (1970), Perrin (1972) and Evans (1975), each component was identified by a descriptive name associated with its anatomical location, e.g. post-dorsal fin saddle, flank field, post-ocular, etc. The observed variants of each component were compiled from illustrations in the literature, photographs taken in the field during various research cruises, and by examination, of live specimens at Sea World, San Diego, California, Orlando, Florida and at several other oceanaria in the United States and Canada. These components and the observed variations are presented in Fig. 1. In our original paper (Evans and Yablokov, 1978) it was hypothesized that the pigmentation pattern of *Orcinus* is geographically variable. If this assumption is valid it should then be possible to characterize different regional populations, based on analysis and quantification of color pattern types.

To test this hypothesis we collected samples of *Orcinus* color patterns from as many geographic areas as possible.

MATERIALS AND METHODS

The color pattern samples studied were collected using two different techniques: (1) photographing live specimens at sea and at oceanaria, (2) on-site scoring of color pattern components for specimens collected by the Soviet Antarctic whaling fleet, during 1977-78, 1978-79 and 1979-80 seasons. Samples collected by both techniques were scored using a data sheet based on Fig. 1. Summaries of all data are presented in Appendix Tables A-l and A-2.

Photographic material

Following the cautions presented by Mitchell (1970), only photographs of live specimens or recently killed specimens (less than 4 hours) were analyzed. In most photographs, only those components dorsally or laterally exposed during a blow or other surface activity were suitable for analysis. The material for analysis consisted of five components: post-ocular patch, sub-ocular notch, shoulder notch, anterior ventral field and post-dorsal fin saddle. The components are illustrated in Fig. 1 as sections 1, 4, 5, 6 and 14. Compared to actual examination of specimens, photographic material is limited by the inability to segregate the sample according to sex and age (size).

Most of the main color pattern components of *0. orca* are symmetrical, and therefore sampling only one side was considered adequate. The post-dorsal fin saddle is an exception, being quite asymmetrical in some individuals. We have compensated for the bias that could result by reducing the number of variants (16) originally suggested to three more generalized patterns not affected by the asymmetries: (a) extensive black in the saddle, (b) small black intrusion, and (c) no black intrusion in the saddle.

Table 1

Orcinus orca samples for color pattern in World Oceans (photographic material)

Locality	Sample size
Northwest Pacific (Puget Sound, Alaskan water, Bering Sea. western Aleutian Islands)	56
East Central Pacific (Baja California, Mexico)	38
North Atlantic (Iceland waters, North Sea)	15
South Atlantic (Argentina, off Punta Norte)	16
Antarctic—open waters (South Shetland Islands, Drake Passage, Weddell Sea)	36
Antarctic—in ice (McMurdo Sound, ice edge)	63

With the cooperation of several colleagues and institutions (see list in Acknowledgements) analyzable material was obtained from several locations in the Pacific, northeastern and southwestern Atlantic and three regions of the Antarctic (Table 1). Material was collected on an opportunistic basis: we cannot, therefore, guarantee that the sample is an unbiased representation of the actual distribution of the various color patterns. We did not attempt to control for homogeneities within pods, although we did obtain samples from as many different areas as possible.

On-site scoring of color pattern

Our data collection forms, patterned after Fig. 1, were used by Dr V. M. Veinger, Dr A. A. Kuzmin and Mr V. L. Vladimirov in the Antarctic during the 1977-78, 1978-79 and 1979-80 seasons to collect color pattern data from *O. orca.* Each specimen was sexed, measured and the color patterns scored as soon as possible after delivery by the

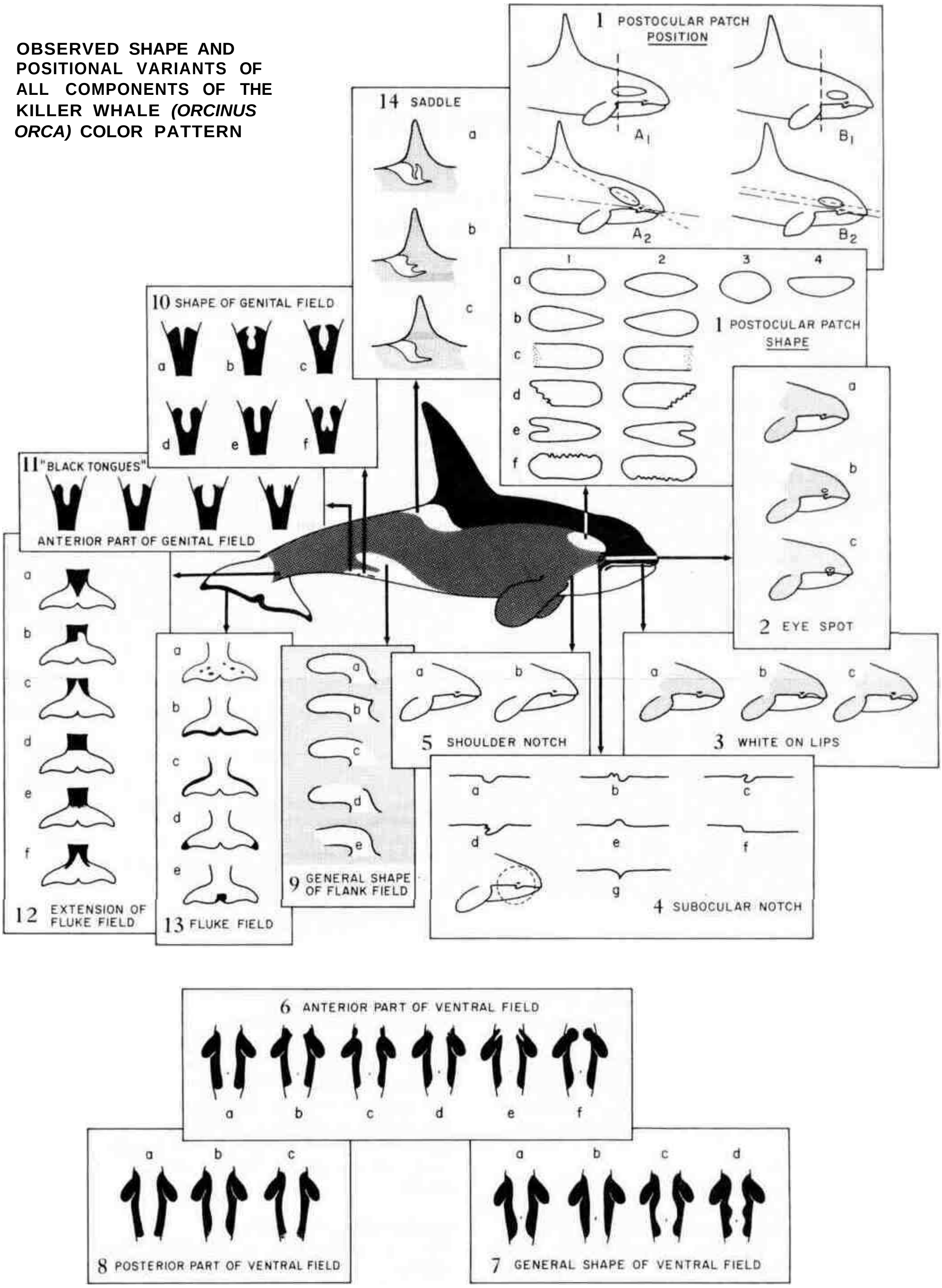

Fig. 1. Components of the *Orcinus orca* color pattern with all observed shape and positional variants of the killer whale color pattern (after Evans and Yablokov, 1978).

catcher boats. The IWC Area where each group of specimens was collected was designated on the data form. The largest sample (n = 177) was collected in Area V. The sample size from Areas III and IV was small (n = 38), and since all the material was collected between 40°E and 90°E, near the dividing line between these Areas, the samples were combined. In addition, it was also indicated whether pods were encountered far into open ice leads or in open water. Details of the numbers of individuals studied by sex and locality of collection are given in Table 2. Since the sample sizes for the longitudinally separate groups for open water were so small they were combined and only the latitudinally separated groups (in ice versus open water) were tested for differences.

Table 2

Orcinus orca sampled for color pattern in Antarctic by Soviet whaling fleets.

Locality	Sex		Total*
	Male	Female	
AreaV, 'in ice'	70	65	135
Area V, 'open water'	21	21	42
AreaIII-IV,'inice'	7	7	14
Area III-IV, 'open water'	12	12	24
Total	110	106	216

* 20 samples were from 1977-78 season, 5 from 78-79 and 190 from 79-80 season.

ANALYSIS AND SUMMARY OF RESULTS

General features of *Orcinus* color pattern

In Evans and Yablokov (1978), Guldberg-Nausen's (1894) description of the color pattern of a fetal *Orcinus* was briefly discussed. In their illustration the specimen had all the major components of the *Orcinus* pattern. In addition, their illustrations indicated the presence of a general dorsal cape similar to that described by Perrin (1972) as a general feature ofdelphinid color patterns. Based on photographic samples from Northern Hemisphere available at the time we considered this was a feature that apparently was not expressed in the adult color pattern. Upon more detailed examination of photographic samples from the Southern Hemisphere several individuals from the area of McMurdo Sound, Antarctic, illustrated a very visible dorsal cape (Fig. 2). The margin of this dorsal cape runs from near the apex of the melon to behind the dorsal fin, passing high over the eye, forming the dorsal margin of the post-ocular patch, and dipping below the dorsal fin to form the lower lateral margin of the post-dorsal fin saddle. On re-examination it was possible to detect this cape in the photographs of all specimens from Antarctic waters and from a few specimens from Argentina. G. M. Vienger (TINRO) also noted that all specimens taken by the Soviet Antarctic fleet had a pronounced cape pattern. This feature is not discernable in photographs of individuals from any of the other geographic areas studied. It is, however, possible with careful scrutiny to detect the margin of a cape in living specimens from Icelandic and Puget Sound waters on display at Sea World, San Diego.

Color pattern component analyses

Because of the previously mentioned differences in our data collection methods, the photographic material and on-site (Soviet Antarctic Whaling Fleet) data were analyzed separately. Depending on the sample size and consistency of the data, some samples from adjoining areas were combined. If the frequency of occurrence of a pattern variant was low for all geographic areas, we dropped the variant out of the analysis. We also assumed that the components of the color pattern varied independently. We would like to caution that in light of the observed connection (dorsal cape) between the post-dorsal fin saddle and post-ocular patch this assumption of independence may not be valid for these two components.

To test for homogeneity among variants of each color pattern component as a function of geographic area Chi-square (x^2) contingency tests were performed (Sokal and Rohlf, 1969). In 2 x 2 contingency tables where cell size was less than 5, Yates correction was used. All analysis was performed using SPSS (Statistics Package for the Social Sciences, Nie *et al.*, 1975).

Photographic data

All photographic material was segregated by geographic region (see Table 1). Material was pooled from all pods observed within these regions. Due to the gross level of the analysis, no attempt was made to control for interpod differences. Tracings were made of each visible component. These tracings were used to determine which variant of each component (Fig. 1) provided the best match. The frequency of occurrence of component variants for each geographic area was tabularized for comparison.

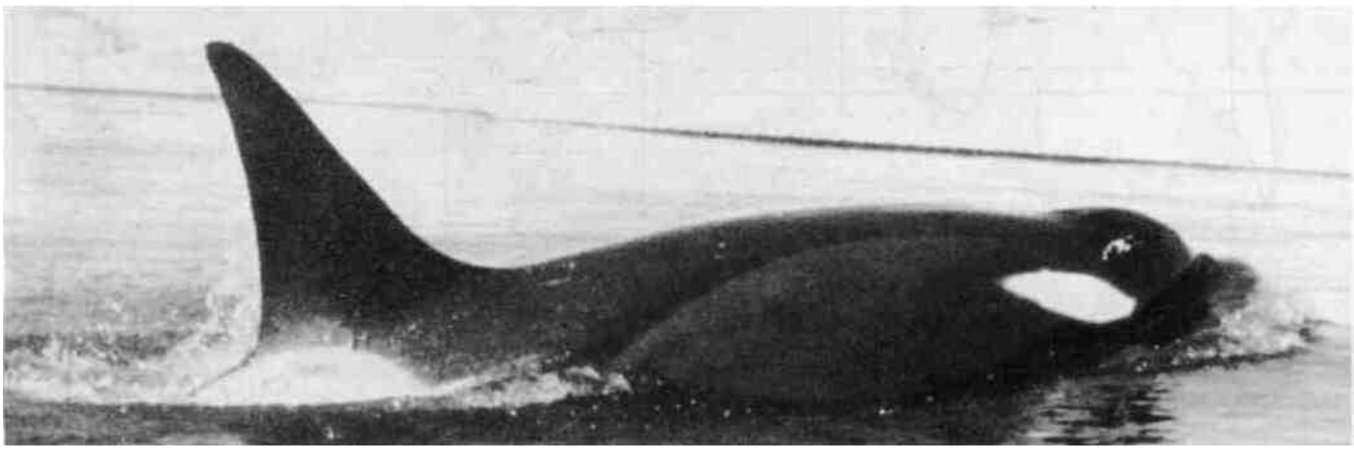

Fig. 2. Expression of dorsal cape pattern was observed in all Antarctic *Orcinus orca* studied. This photo illustrates the dorsal cape configuration of the McMurdo Sound group.

Of the fourteen components originally identified, only 5 could be scored on individuals representing the geographic areas indicated in Table 1. Each of these will be discussed separately. We examined data for only those geographic areas where sample sizes were large enough to insure that most cell sizes were greater than 5. These included the Northwest Pacific (Puget Sound, Gulf of Alaska, Aleutian Is.), East Central Pacific (Baja California, Mexico), North Atlantic (Iceland), South Atlantic (Argentina), Antarctic in-ice leads (McMurdo Sound), Antarctic open water (So. Shetlands, Antarctic Peninsula, and IWC Areas III-V pooled).

Post-ocular patch

Evaluation of the frequency of occurrence data indicated that symmetrical post-ocular patch patterns (a 1-4) were predominant in the sample from the Antarctic Peninsula, Antarctic Areas III-IV, and Iceland. The expression of this component is most variable in the samples from Puget Sound (Pacific Northwest) and McMurdo Sound. Antarctic, with all major variants represented (see Fig. 3). It is possible that this is a function of sample size and the existence of a high degree of individual variation in this component, since the largest samples are from these areas. In order to compensate for absence of some variants or small sample size in some samples all the symmetrical variants and asymmetrical variants were combined. X^2 values, testing symmetrical versus asymmetrical patterns from four geographical areas are presented in Table 3.

Table 3

Post-ocular patch shape symmetrical vs. asymmetrical for 4 geographic regions (Northwestern Pacific. East Central Pacific, McMurdo in ice, Antarctic open water Areas III-IV)

	Northwest Pacific	East Central Pacific	Antarctic in ice
East Central Pacific	X^2 =1.3973 NS n=97		
Antarctic in ice	X^2 = 0.9226 NS n = 124	X^2 = 0.8247 NS n=99	
Antarctic open water	X^2 = 15.1428 NS n=97	X^2 = 7.5988 $p<0.05$ n=72	X^2 = 11.7862 $p<0.05$ n=99

Whole table: X^2 =16.2652
p <0.05
n =196

Data from the North Atlantic (Iceland) and South Atlantic (Argentina) were not tested due to small sample size. As discussed above, samples from the Antarctic Peninsula and Areas III-IV (Antarctic open water) were combined. The hypothesis of homogeneity in the post-ocular patch shape by geographic areas was rejected at $p < 0.05$. Interestingly, it appears that this is largely due to a

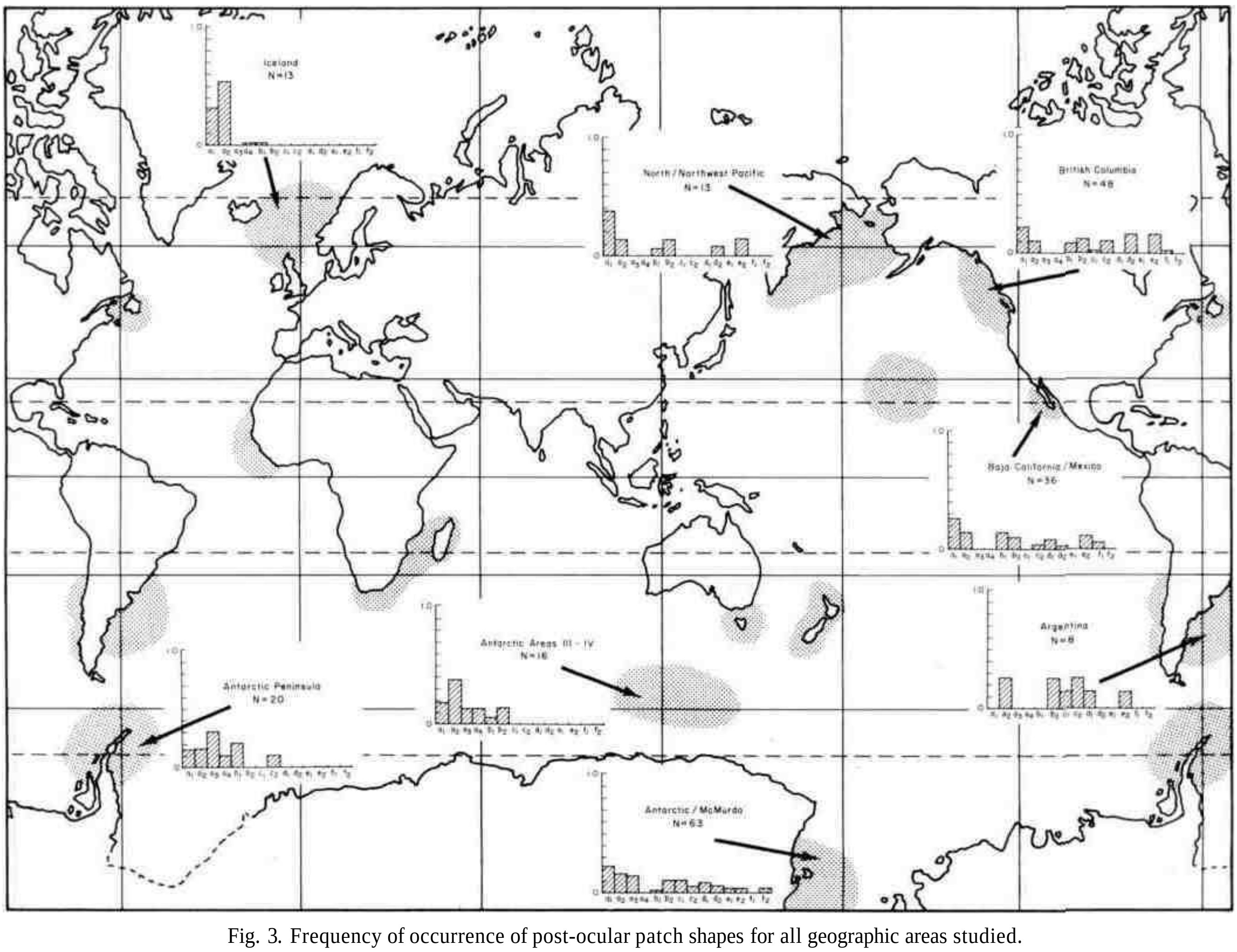

Fig. 3. Frequency of occurrence of post-ocular patch shapes for all geographic areas studied.

difference between McMurdo Sound and all other areas, including the Antarctic open water samples. To a lesser extent, Antarctic open water differs from the Northern Hemisphere and southern Atlantic areas examined.

In addition to variation in shape, the position and size of the post-ocular patch were also variable. The position and size differences were in angular orientation of the patch with the long axis of the body (A_2, B_2, Fig. 1, Section 1) and in posterior extension of the patch past the anterior insertion of the flipper (A_1, B_1). The A_2 variant was found only in high southern and northern latitude samples. Although this type occurs in the Northwest Pacific, it is quite rare. In the Antarctic it occurs with very low frequency in Areas III-V (7%), slightly higher near S. Shetland Islands (36%) and is quite common along the ice edge of McMurdo Sound (68%). The posterior extension of the patch (A1), also shows a marked north-south difference (Table 4). The X^2 values, levels of significance and sample sizes for the 5 geographical areas tested are presented in Table 5. The hypothesis of homogeneity was rejected at $p > 0.05$, and, as before, Antarctic in-ice was significantly different from all other areas. Northwest Pacific was different from all areas except East Central Pacific (Baja California, Mexico).

Table 4

Occurrence of variations in post-ocular patch position and size as function of geographic location. Variations A_1, A_2, B_1, B_2 appear in Fie. 1. Section 1

	Positions post-ocular patch					
	Patch size			Position		
Location	n	A_1	B_1	n	A_2	B_2
Northwest Pacific	44	2	42	47	12	35
East Central Pacific	17	0	17	9	2	7
North Atlantic	15	0	15	17	16	1
South Atlantic	16	1	15	5	1	4
Antarctic open water	28	7	11	17	16	1
Antarctic in ice	60	41	19	13	10	3

Sub-ocular notch

The expression of the sub-ocular notch is quite variable in all groups, especially the McMurdo Sound samples. The 'a' and 'c' variants predominate in most samples from the Pacific and McMurdo. However, in the Antarctic open water samples the 'b' and 'c' variants were the most frequently observed (Fig. 1, section 4). Table 6 lists X^2 values for the four geographic areas tested. This component was homogeneous for all areas tested except Antarctic open water versus the Northwest Pacific.

Table 6

Sub-ocular notch (3 variants) versus 4 areas from the photographic data

	North Pacific		
East Central Pacific	X^2=5.03 NS N=54	East Central Pacific	
Antarctic in ice	X^2= 1.6208 NS n=60	X^2= 1.37290 NS n=56	Antarctic in ice
Antarctic open water	X^2= 8.99646 $p<0.05$ n=55	X^2= 5.7616 NS n=51	X^2= 5.5299 NS n=57

Whole table: X^2 =16.3267
p <0.05
df =6
n =111

Anterior part of the ventral field

This component is relatively homogeneous in the Northern Hemisphere groups with variants 'a' and 'b' occurring with equal frequency. The only exception is, again, the Puget Sound sample, which is highly variable. Variants 'a' and 'b' have the highest frequency of occurrence but all variants of this component can be found. This character was non-homogeneous between McMurdo and other

Table 5

Post-ocular patch size (A), B,) and angle (Azi, B;) versus the six geographic areas from photographic data. We did not examine size and angle independently with area. (See Fig. 1, Section 1, and Fig. 3)

	North Pacific				
East Central Pacific	X^2= 3.22657 NS n = 106	East Central Pacific			
North Atlantic	X^2= 24/98-12- $p<0.05$ n=112	X^2= 15.05431 $p<0.05$ n=58	North Atlantic		
Southern Atlantic	X^2= 9.53457 p = < 0.05 n=102	X^2= 6.62338 NS n=48	X^2= 5.08442 NS n=54	Southern Atlantic	
Antarctic open-water	X^2= 29.18966 p = < 0.05 n=125	X^2= 19.09272 p = < 0.05 n=71	X^2= 5.97552 NS n=77	X^2= 3.81608 NS n=67	Antarctic open-water
Antarctic in ice	X^2= 64.03040 p = < 0.05 n=153	X^2= 33.21820 p = < 0.05 n=99	X^2= 32.85516 p = < 0.05 n=105	X^2= 19.46268 p=<0.05 n=95	X^2= 21.11264 p = < 0.05 n=118

Whole table: X^2= 161.14554 df = 15
p <0.05 n =278

populations (Table 7). As in the Northern Hemisphere samples, there is a high frequency of occurrence of variants 'a' and 'b': however, the 'd' variant occurs with the highest frequency in all Antarctic groups (see Fig. 1, Section 6).

Table 7

Chi-square test of anterior part of ventral field (a, b, d variants. Fig. 1, section 4) versus 4 areas from the photographic data

	Northwest Pacific	East Central Pacific	Antarctic in ice
East Central Pacific	2 $X^2=$ 16.4478 $p<0.05$ $n=46$		
Antarctic in ice	3 $X^2=15.3263$ $p<0.05$ $n=48$	$X^2=$ 14.471 $p<0.05$ $n=22$	
Antarctic Peninsula III-IV	4 $X^2=5.2738$ NS $n=47$	$X^2=$ 2.4436 NS $n=21$	$X^2=$ 12.4801 $p<0.05$ $n=23$

Whole table: $X^2=$ 43.8620
p <0.05
n =69
df =9

Post-dorsal fin saddle

All variants of the post-dorsal fin saddle occur in the Northern Hemisphere. Qualitatively, different geographic groups appeared to be non-homogeneous, however the sample size was not adequate for testing. In contrast, only variant 'c' of this component is observed in Southern Hemisphere samples (Fig. 1, section 4).

On-site whaling fleet data

The data from color pattern scoring forms for each individual examined were consolidated into tables. These data were segregated by the Areas designated in Table 2, by sex, and by the variant of each component observed. The frequency of occurrence of component variants for males and females was examined, and no sexual dimorphism in color patterns was observed for the characters examined in this paper. The data for males and females were then combined for further analysis. It should be noted that black pigmentation bordering the genital areas was not considered in this analysis; where observed it is sexually dimorphic.

Examination of the raw frequency data (Appendix Table A-2 indicated differences between the groups sampled in Area V and Areas III/1V. However, the differences between the 'in ice' samples and 'open water' samples are more pronounced and the sample sizes more balanced. Since this latter difference is also supported by analysis of more traditional morphological characters, such as length at sexual maturity and dentition (A. A. Berzin and V. L. Vladimirov, TINRO. 1981). we chose to test for homogeneity between the in ice and open water groups.

Chi-square contingency tests for homogeneity were made of Area V, III/IV ('in ice'), versus Area V, III/IV ('open water'). Three components, sub-ocular notch. shoulder notch, and the general shape of the ventral field exhibited non-homogeneities and were tested. In the sub-ocular notch 8 variants were tested for in-ice versus open water and the hypothesis of homogeneity was rejected ($X^2=$ 18.8080, n = 220, $p < 0.05$). The same is true for presence or absence of a shoulder notch for in-ice versus open water ($X^2=$ 10.8950, n = 215, $p < 0.05$). Finally, three variants of the general shape of the ventral field also showed significant non-homogeneities ($X^2=$ 9.9476, n = 213, $p < 0.05$). These results were consistent with the previously mentioned differences between in-ice and open water specimens, and with the photographic data. The expression of the variants of these three components appears to be quite complex. For example in the sub-ocular notch, high frequency of occurrence of pairs of variants contribute strongly to the observed non-homogeneity (Table 8).

Table 8

Prominent variants of non-homogeneous components of Antarctic *Orcinus* as a function of location

Component		AreaV	AreaIII/IV
4. Sub-ocular notch	ice	a/f	c/d
	open water	c/f	f/a
5. Shoulder notch	ice	b	b
	open water	a/b	a
6. Anterior part of ventral ice	ice	c/a	c
	open water	a/e	c/d
7. General shape of ventral field	ice	b	c
	open water	a	a/b/c

CONCLUSION AND DISCUSSION

Six of the fourteen components of the color pattern of killer whales examined are geographically variable. There are also significant geographic differences in the position of the post-ocular patch and expression of a dorsal cape. Differences in groups from the Northern and Southern Hemispheres are most pronounced. Fortunately some of the most variable, and therefore useful, components are displayed when individuals surface to blow. These components can be effectively sampled photographically and/or visually. Unfortunately, the photographic sample available from mid-latitude temperate and tropical waters was not large enough to do more than indicate trends. Availability of more data from these areas may make it possible to determine whether post-ocular patch shape and position, post-dorsal fin saddle shape and expression of the dorsal cape are clinal or antitropical in distribution.

It is important to caution that one of the main sources of errors in comparing the color pattern of animals from different areas is the danger of confusing pod (demes) characters with potential population characters. The data collected by two separate methods are supportive of the conclusion that significant geographic variations do occur in the color pattern of *Orcinus orca.* Groups of killer whales from McMurdo Sound (near the ice edge), open water areas near the Antarctic Peninsula, and in IWC Areas III-IV, differ from each other in the expression of several color pattern components. Additional differences also occur between Pacific and Atlantic samples. At the present, the data are not sufficient to determine whether the different color forms observed represent modes in a geographically continuously varying species or several reproductively isolated populations.

ACKNOWLEDGEMENTS

This project was done under the auspices of the joint US-USSR Environmental Protection Agreement Marine Mammals Program with significant support from NSF. The following institutions and individuals provided the material used in this study: The National Science Foundation, Division of Polar Programs; US Navy; National Marine Fisheries Service; Sea World, Inc. (San Diego, Calif., Orlando, Florida); Marineland of the Pacific, Los Angeles, Calif.; Marine World USA. Redwood City, Calif.; VNIRO, USSR; Moclips Cetological Society, Dr Michael Bigg, Kenneth Balcomb, DrJohn Hall, Dr Berne Wursig, Frank Todd. Dr Frank Awbrey, Scott Dreischman, Merrill White Jr., Jim Holbrook, Michael Rugh, Robert Vile, Dorothey Larsen, Dale Anderson, DrA. A. Berzin, G. M. Veinger, A. A. Kuzmin, V. L. Vladimirov, Yu. A. Michalev, and A. A. Lemberg.

REFERENCES

Evans, W. E. 1975. Distribution and differentiation of stocks and natural history of *Delphinus detphis* Linnaeus in the northeastern Pacific. Ph.D. Diss. UCLA, 1-57.

Evans, W. E. and Yablokov, A. V. 1978. Intraspecific variation of the color pattern of the killer whale *(Orcinus orca).* pp. 102-115. *In:* V. E. Sokolov and A. V. Yablokov (eds). *Advances in Studies of Cetaceans and Pinnipeds,* 'Nauka' Publ., Moscow. (English summary).

Mitchell, E. 1970. Pigmentation pattern evolution in delphinid cetaceans; an essay in adaptive coloration. *Canad. J. Zool.* 48: 717-40.

Nie, N. H. *etal.* 1975. *SPSS: Statistics Package for the Social Sciences.* 2nd ed. McGraw Hill, New York.

Perrin, W. F. 1972. *Color Pattern of Spinner Porpoises (Stenella cf. S. longirostris) of the Eastern Pacific and Hawaii.* Univ. Calif. Press, Berkeley, Los Angeles, London, 206pp.

Sokal, R. R. and Rohlf, F. J. 1969. *Biometry.* W. H. Freeman, San Francisco.

Yablokov, A. V. 1969. Types of color of the Cetacea. *Fish. Res. Board of Canada, Transl. Ser.,* N 1239, 1-28. (Orig. in Russian 1963).

APPENDIX

Table A-1

Raw data on four color pattern components (see Fig. 1) collected from analysis of photographic material. Not all photos could be scored for all components. Material was available from 12 areas; only those areas where a sample of 5 or more individuals for 2 or more components could be scored are included (8 areas).

Component	Northwest Pacific	Puget Sound (British Columbia)	East Central Pacific (Baja)	Iceland North Atlantic	Argentina S.W. Atlantic	McMurdo	Antarctic Peninsula	II-IV
Post-ocular patch (1)	5,al 2,a2 l,bl 2,b2 l,d2 2,e2	10,al 5,a2 4,bl 6,b2 l,cl 5,c2 8,d2 8,e2 l,fl	9,al 6,a2 6,bl 4,b2 l,c2 3,d1 l,d2 4,e2 2,fl	4,al 7,a2 l,a4 l,bl	l,al 2,b2 l.cl 2,c2 l,dl l,e2	14,a1 9,a2 8,a3 l,b1 6,b2 6,cl 4,c2 5,dl 4,d2 2,el 2,e2 2,f2	3,al 3,a2 6,a3 2,a4 4,bl 2,c2	3,al 6,a2 2,a3 2,a4 l,bl 2,b2
Sub-ocular notch (4)	4,a 4,c l,d l,g	5,a l,b 15,c 5,d	13,a 3,b 9,c 2,g	6,a l,c l,d	2,a l,c	12,a 3,b 16,c 4,d l,e 4,f 2,g	2,a l,d 2,8	4,a 9,b 1l,c l,e
Anterior part of ventral field (6)	4,a 4,b	10,a 12,b 2,c 4,d 5,e	l,b	3,a 3,b	2,a 2,b 6,d	l,a 3,b 8,d		3,a 5,b 3,d
Post dorsal fin saddle (14)	4,a l,b 8,c	32,a 43,b 33,c	4,a 38,c	2,a 10,c	16,c	24,c	19,c	5,c

Note: For purpose of analysis Pacific N/NW and British Columbia (Puget Sound) were combined as were Antarctic Peninsula and Areas III-IV.

Table A-2

Raw data on color pattern components (see Fig. 1) found to be non-homogeneous for sample. Collected by Soviet Antarctic whaling fleet, 1977-78,78-79, 79-80.

Component	All in ice	All open water	All Area V	All III Area IV
Sub-ocular notch (4)	53a* 5b 31c 6d 30e 1f 13g 11h***	10a 1b 30e 4d 12g 8h	57a 5b 53c 4d 34g 24h	6a 9b 7c 5d 7g 4h
Should notch (5)	116a 33b	36a 30b	131a 46b	16a 22b
Anterior part ventral field (6)	34a 32b 57c 27d	19a 10b 18c 9d 10e	49a 36b 57c 26d 10e	4a 6b 18c 10d
General shape ventral field (7)	55a 64b 29c	39a 16b 10c	79a 89b 7c	11a 18b 9c
	N = 150*	N=66*	N = 177*	N=35*

* Not all shapes could be seen due to damage to central areas duringtests.
** Variant designations refer to Fig. 1.
*** No detectable sub-ocular notch.