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標識放流データを用いたカラフトマスの母川回帰行動の解析

Analysis of pink salmon homing migration by tagging data

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平松一彦・石田行正．1986．標識放流データを用いたカラフトマスの母川回帰行動の解析．10頁．（第33回ＩＮＰＦＣ定例年次会議提出文書．1986年10月．米国，アンカレッジ市）．水産庁，遠洋水産研究所．日本．〒424 清水市折戸５－７－１．

標識放流データを用いたカラフトマスの母川回帰行動の解析

Analysis of pink salmon homing migration by tagging data

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1. はじめに

北太平洋におけるさけ・ます類の標識放流試験は、長年にわたり多数行なわれている。本報告では、日本・米国・カナダによって1956～1984年に行なわれた、カラフトマスの標識放流のデータ*を用い、西部アラスカを除いた北米起源と思われるグループ（以下北米群と略記）と、東カムチャッカ起源と思われるグループ（東カムチャッカ群）について、その母川回帰途上の回遊行動の解析をおこなった。

通常標識放流データからは放流・再捕間の最短距離の日数に対する直線回帰をとることにより、平均移動速度および平均移動距離が得られる。データ数が多い場合には、これに加えて平均移動距離からの分散を見ることにより、回帰行動のばらつきを推定することが可能である。そこで北米群と東カムチャッカ群について移動速度と分散を求め、両者の比較を行なった。

2. 方法

データのうちから放流・再捕位置や月日等が不明であるものをまず除いた。また放流・再捕位置間の最短コースが陸上を通り、そのために実際の移動距離との差が大きくなると思われるものについても今回の解析からは除いた。北米群と東カムチャッカ群の分類は、放流・再捕位置を地図上にプロットすることによって行なった。したがってこれらの分類は決定的なものではない。

海洋における母川回帰途上の行動を見るために、明らかに河川における再捕であるものは除いた。また回帰途上にあると思われる6月以降の放流データにかぎった。海の広さは有限であるために、再捕までの日数が長期にわたるデータでは移動距離が頭うちとなってしまい、回帰式をとるにあたってバイアスが入る。そこで今回は再捕までの日数が30日以内であるものに限った。

解析に使用したのは、北米群1770データ、東カムチャッカ群517データである。北米群はすべて沿岸での再捕であるが、東カムチャッカ群は沖合・沿岸両方の再捕を含む。

脚注）* INPFCの下において日・米・加三国科学者によって行なわれたさけ・ます標識放流試験の再捕魚資料（1956～1984年）を収録した磁気テープを使用した。

まず放流・再捕間の最短距離の日数に対する原点を通る直線回帰式を求め、その傾きを平均移動速度とする（Fig. 1, 2）。同日の再捕は1日として扱った。このように分散が大きい場合には、通常の直線回帰式より原点を通る直線回帰式の方が適切であると思われる。

次に各日における回帰直線のまわりの分散を求める。分散はほぼ時間に比例して増加しているので、分散の日数に対する原点を通る直線回帰式を求めた（Fig. 3, 4）。

結果は次の通りである。

	平均移動速度	分散の増加率
北　米　群	18.5 km／day	2874 Km^2／day
東カムチャッカ群	46.9 km／day	3445 Km^2／day

Fig. 3, 4から明らかなように、北米群は回帰直線とよく一致しているが、東カムチャッカ群ではかなりのばらつきがみられる。これは後者のデータ数が少ないためであるが、特に異常値が原因と思われるものがある。異常データと思われるものを2データほど取り除くと、ばらつきは小さくなるが回帰式自体はあまり変化しないため、以下の解析では上記の数値を用いた。

3. 考　　察

平均移動速度をu、分散の増加率をσ^2とすると、時間tで距離x（$x \geqq 0$）に存在する確率f（x、t）は、tの大きいところでは正規分布

$$f(x, t)\,dx = \frac{1}{\sqrt{2\pi\sigma^2 t}} \exp\left(-\frac{(x-ut)^2}{2\sigma^2 t}\right) dx \quad \cdots\cdots\cdots\cdots ①$$

によって表わせることが予想される。

そこで各日における魚の分布と上式との比較を行なった。結果をFig. 5, 6に示す。両者はおおよそ一致しており、したがって時間tにおけるカラフトマスの移動距離の分布は、近似的に①式で表わすことが可能である。

移動速度は北米群と東カムチャッカ群とでは明らかに異なっており、東カムチャッカ群の方が速い。一方分散は比較的両者の差が小さく、両群ともほぼ同じ割合で時間とともに分散していくことを示している。比較のため①式を用いて両群の分布の時間変化を示しておく(Fig. 7)。

北米群の移動速度が小さいことの原因としては、回遊経路が大きく曲がっている[1]ためにみかけ上移動距離が小さくなり、速度が遅くなることが考えられる。しかしこのような回遊には1か月以上必要と思われ、30日以内のデータでは移動は比較的直線に近く、したがって回遊経路の曲がりはあまり大きなバイアスにはなっていない。他の可能性としては、北米群はすべて沿岸再捕であるにもかかわらず、東カムチャッカ群は沿岸と沖合の両方の再捕データを含むことによる両群のデータの質の違いが考えられる。しかし東カムチャッカ群において沿岸再捕と沖合再捕に分けて移動速度を比較してみても大差はなく、したがって両群の移動速度の差は本質的なものと思われる。

一方両群とも時間にほぼ比例して増大する分散がみられた。この分散の原因としては例えば個体間の体長の差が考えられるが、両群とも放流時の体長と速度の間には相関はみられなかった。

一般に魚は回遊期であっても直進運動をすることはなく、かなり頻繁に方向転換をする複雑な行動[2]を行ないながら目的の方向に進んでいく。そこでこの直進運動からのずれを、random walk によるものとみなし、その行動を解析することも可能である。[3] この場合魚の行動は直進成分と random walk 成分の和とみなすことができ、分散の時間に比例する増大は random walk によるものとみなすことができる。

分散が時間とともに増大することは、回帰式を求めるにあたって分散が一定であることを仮定している通常の回帰式よりも、分散の変化を考慮した重みづき回帰の方が適切であることを示唆している。

4. 結　　論

カラフトマスの標識放流データを用いて、平均速度および分散の増加率を求めた。これらの値は回帰行動を解析する上で基礎的なものとなろう。たとえば魚の放流点からの移動距離の分布をこれらの値を用いて、①式のような正規分布で近似することも可能である。

北米群と東カムチャッカ群では明らかに行動の違いがみられる。分散はあまり差がないが、平均移動速度は東カムチャッカ群の方が速い。

本報告ではカラフトマスを扱ったが、他の魚種においても標識放流データが多数ある場合にはここで用いられた解析方法が適用可能である。

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2) T. Ichihara, T. Yonemori, and H. Asai (1975) Bull. Far. Seas Fish. Res. Lab. 13 : 63 − 77.

3) K. Hiramatsu and Y. Ishida in preparation.

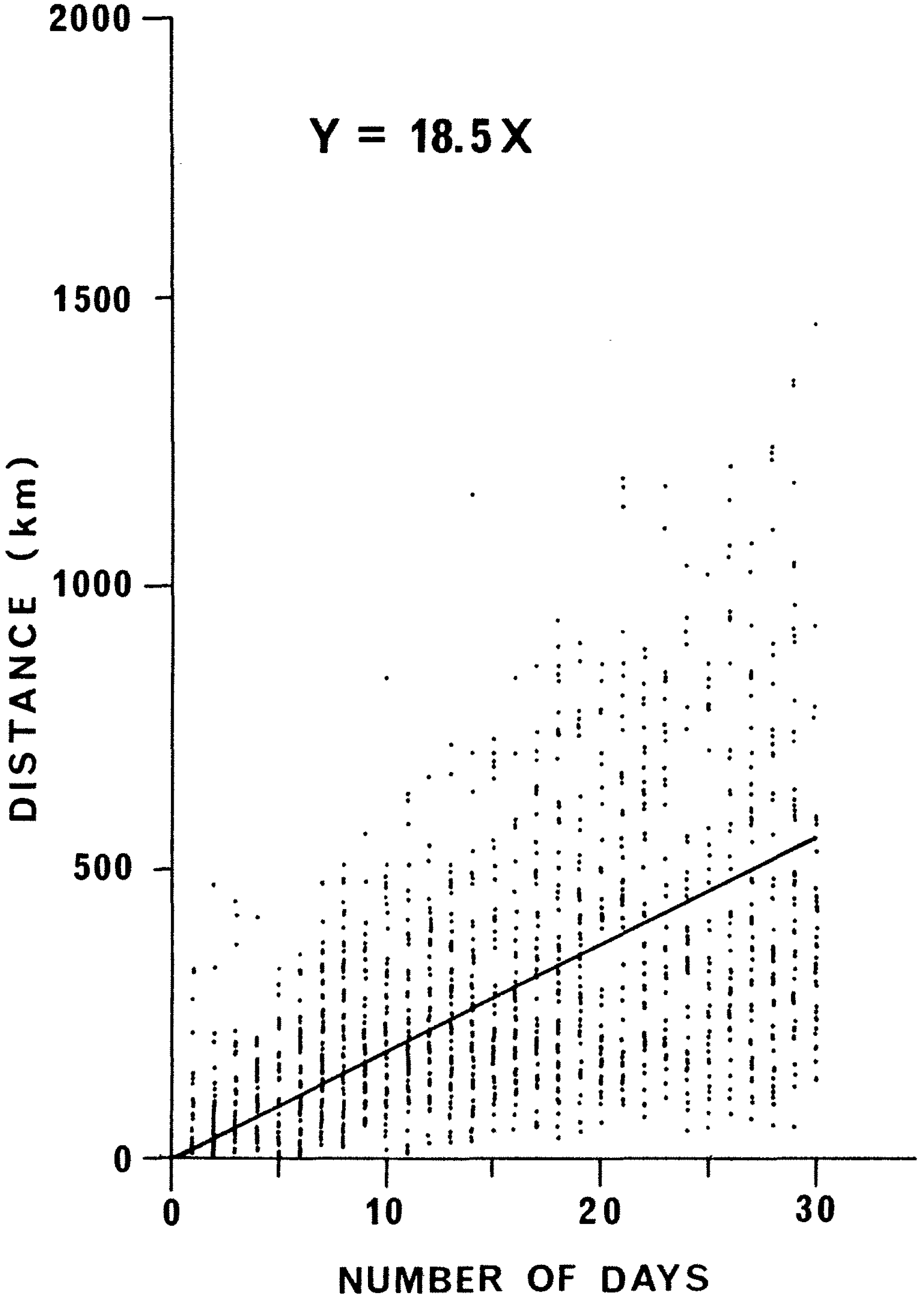

Fig.1 Relationship between number of days and distance traveled from release to recovery points. North America origin.

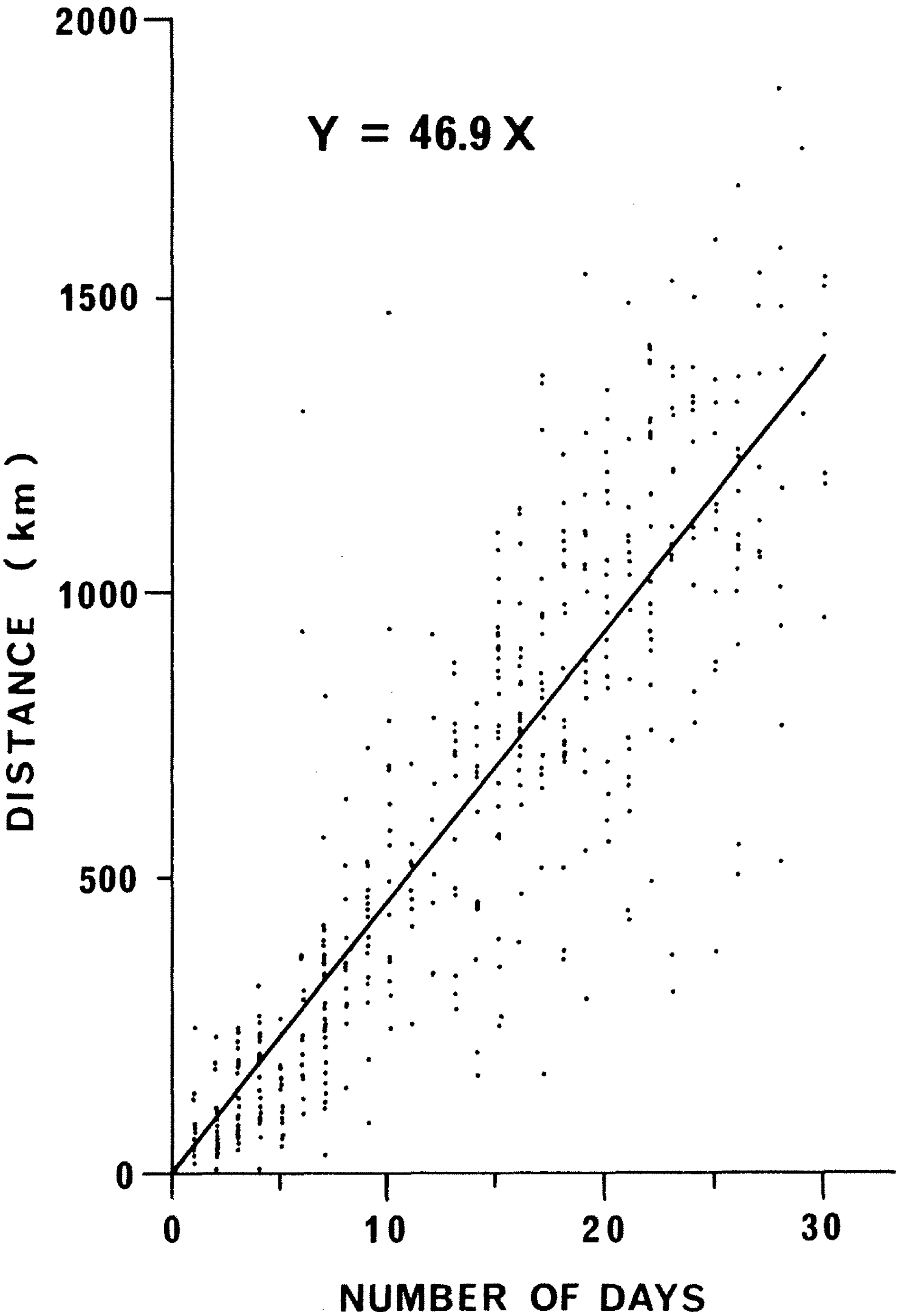

Fig.2 Relationship between number of days and distance traveled from release to recovery points. East Kamchatka origin.

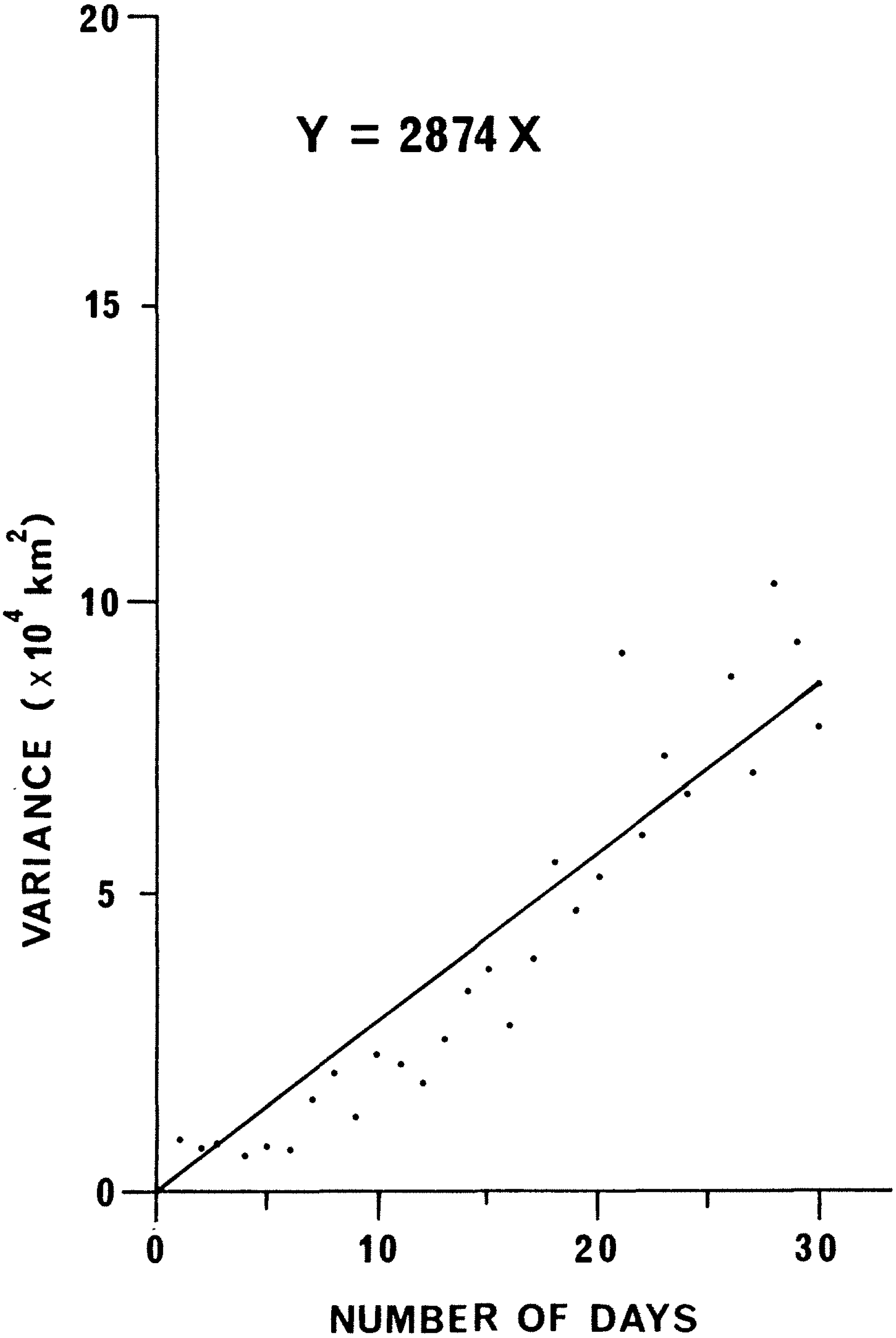

Fig.3 Relationship between number of days and variance from average distance traveled.
North America origin.

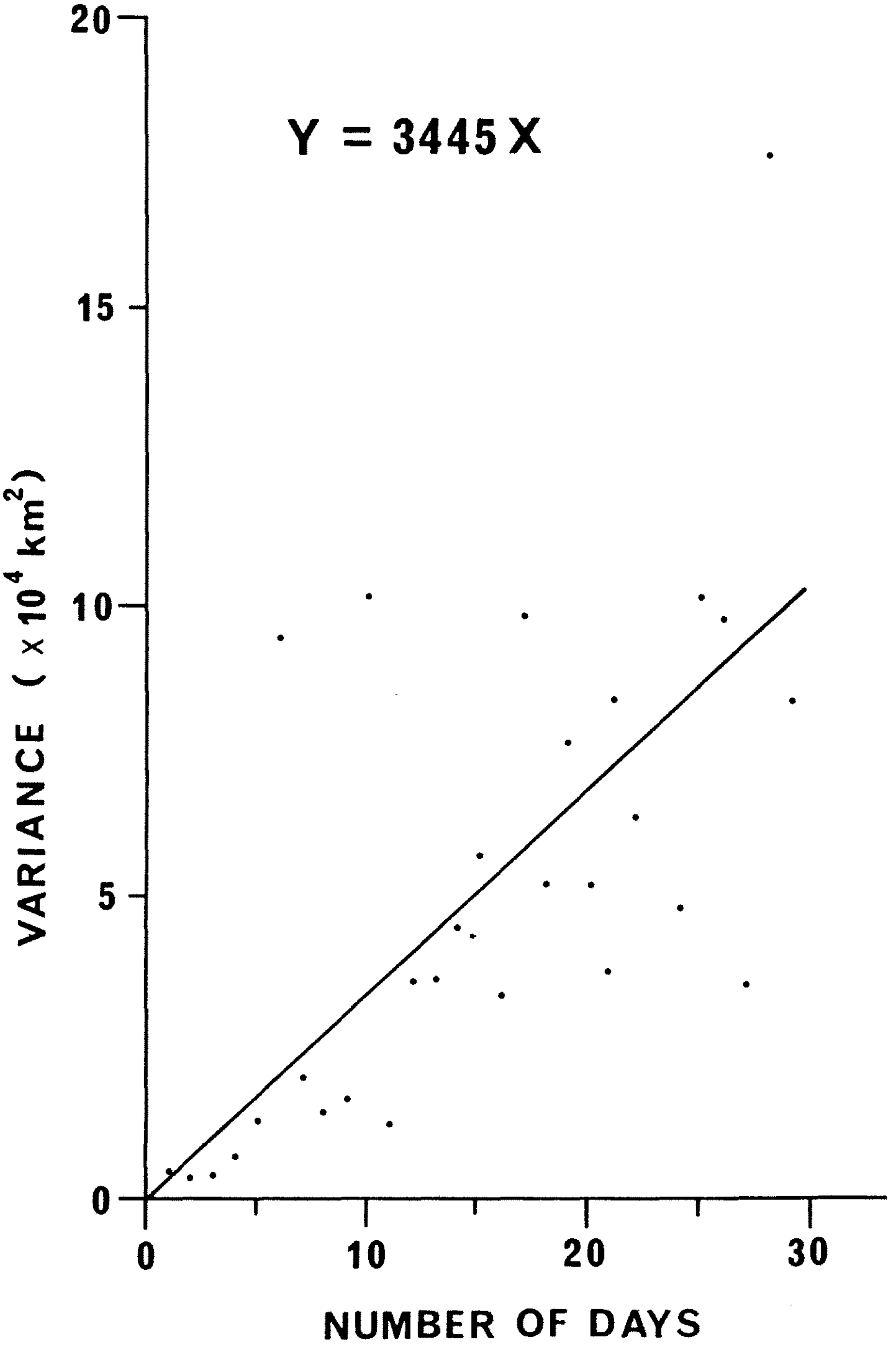

Fig.4 Relationship between number of days and variance from average distance traveled. East Kamchatka origin.

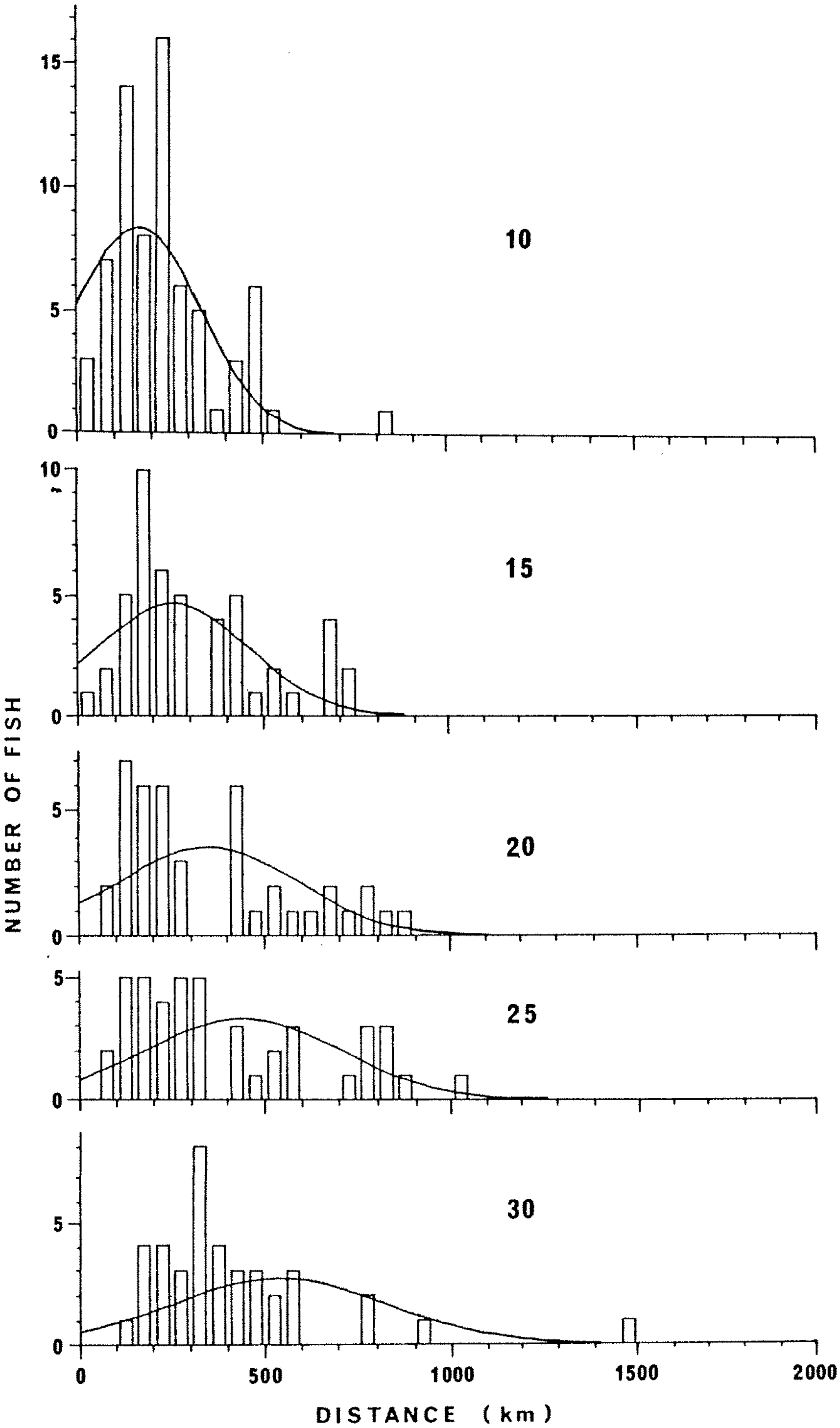

Fig.5 Frequencies of distance traveled of North America group at 10,15,20,25,30 days.
Solid line indicates the normal distribution.

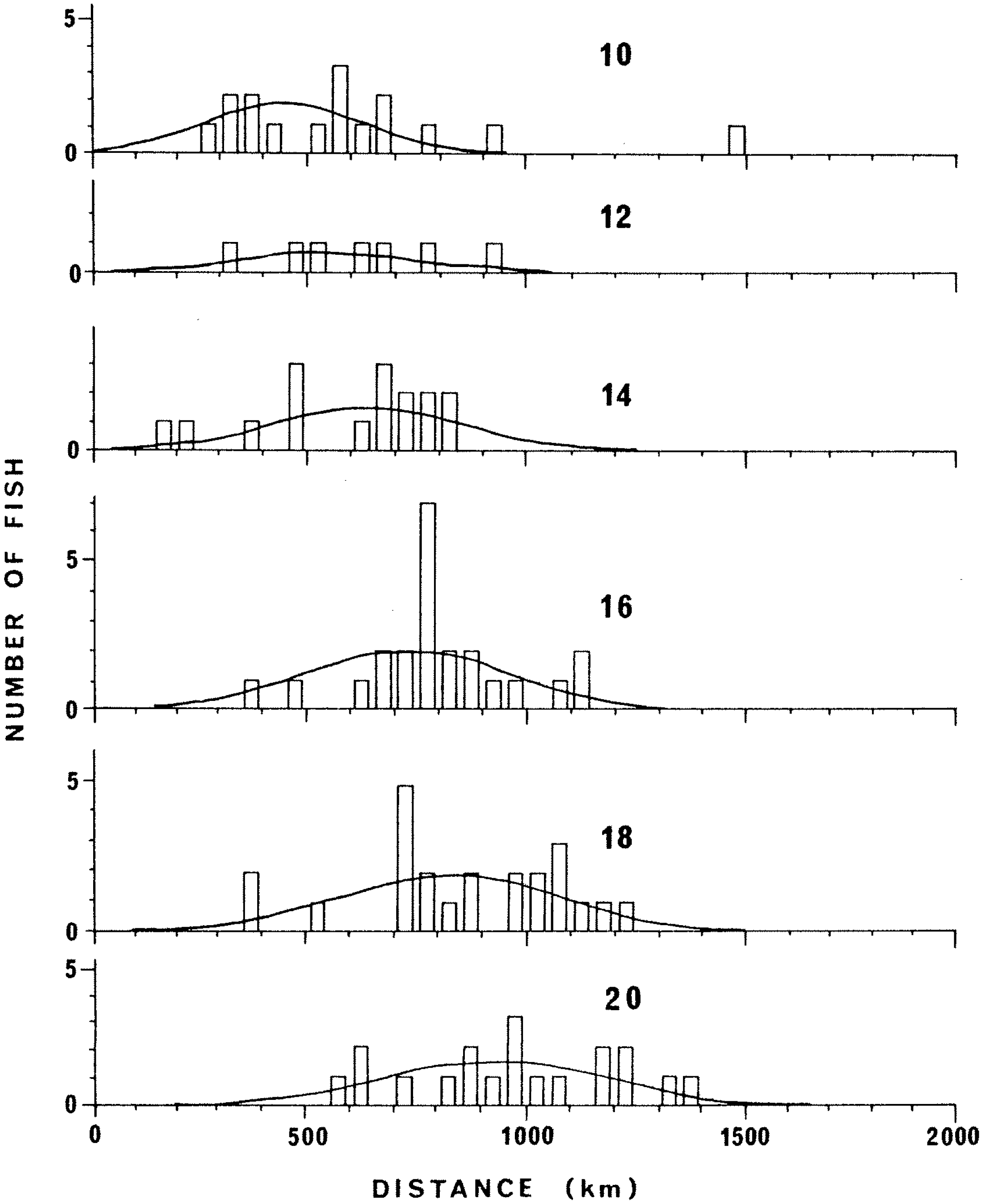

Fig.6 Frequencies of distance traveled of East Kamchatka group at 10,12,14,16,18,20 days.
Solid line indicates the normal distribution.

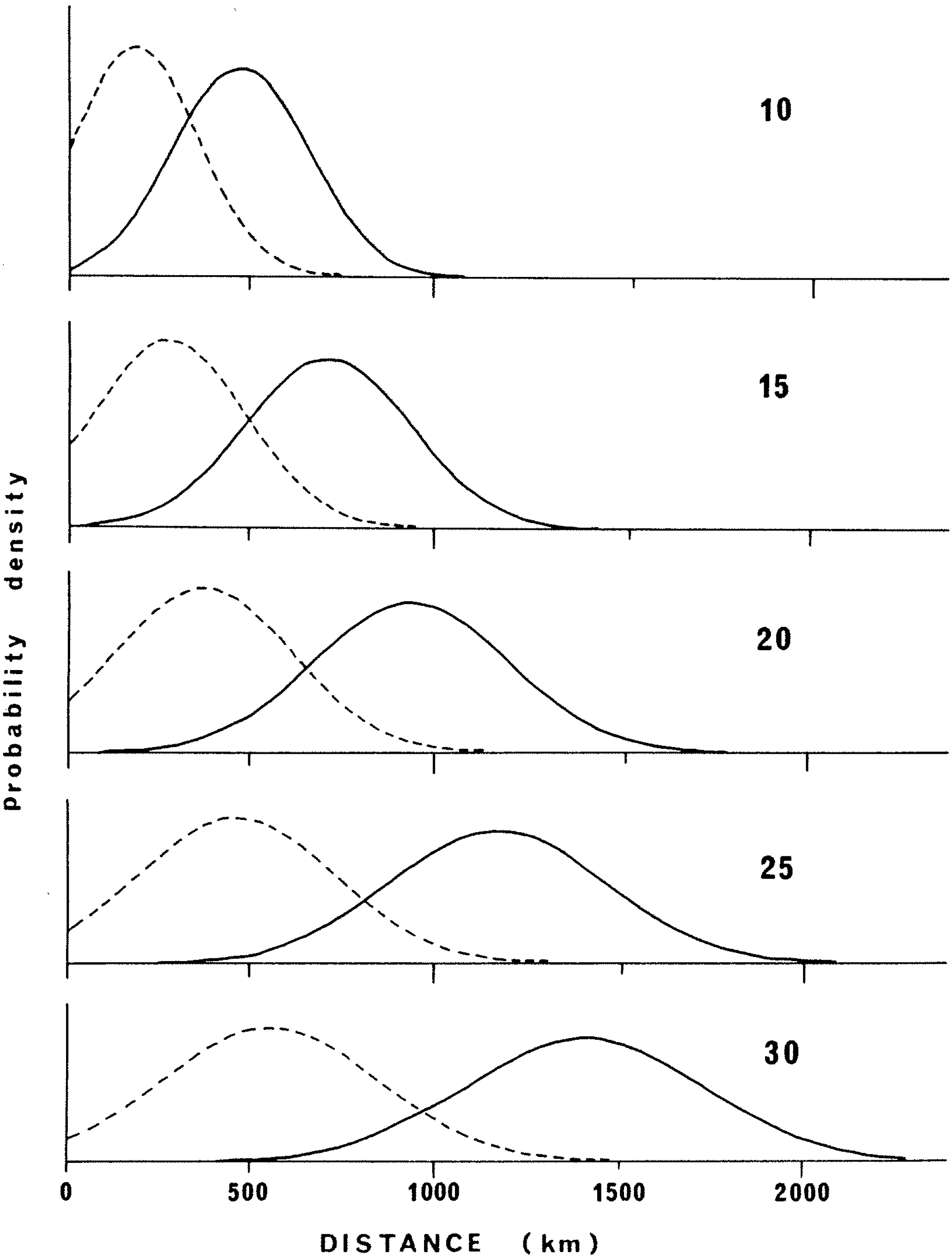

Fig.7 Comparision of distribution of distance traveled based on the assumption of the normal distribution between North America group (dashed line) and East Kamchatka group (solid line).

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TRANSLATION

ANALYSIS OF PINK SALMON HOMING MIGRATION BY TAGGING DATA

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1. Introduction

A great number of salmon tagging experiments in the North Pacific have been conducted over the course of many years. In this report, using the data[1] for pink salmon from the tagging experiments conducted by Japan, the United States, and Canada, during the period from 1956 to 1984, analyses on migration to home rivers were made for groups of pink salmon presumed to have originated from North America (except western Alaska) (North America group) and from eastern Kamchatka (East Kamchatka group).

Generally, by calculating the linear regression of the shortest distances between points of release and recovery to the number of days travelled, the average travelling speed and average distance travelled are obtained from the tagging data. In addition, where a large amount of the data are available, the dispersion in the migration movements can be estimated based on the variances from the average distance travelled. Thus, the average travelling speeds and variances were calculated and compared for the North America and East Kamchatka groups.

2. Methods

Tagging data for which location and/or date of release or recovery were unknown, were not considered. Data for which the shortest distance between locations of release and recovery crossed land and for this reason were considered to be largely different from actual distance travelled, were also excluded from the analysis. Data were

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[1]Material used in this report was the magnetic tape recording recovery data (1956 to 1984) for salmon tagging experiments conducted by the scientists from the three countries; Japan, the United States, and Canada, under the INPFC.

classified into North America and East Kamchatka groups by plotting geographic locations of release and recovery. Therefore, the results from this grouping are not conclusive.

Since this report addresses the ocean migration of pink salmon on their way to their home rivers, tagging data for which the recoveries were made on rivers were excluded. Furthermore, the data used were limited to those for which releases were made in and after June when the fish were presumed to be on their way to their home rivers. Since the breadth of the ocean is limited, the distance travelled reaches an asymptote when the number of days travelled extends over a lengthy period of time and thus brings some bias into the regression equation. Therefore, the data used in this report were limited to those for which the number of days from release to recovery was within 30.

Tagging data for 1,770 fish of the North America group and 517 for the East Kamchatka group were used for this analysis. The North America group consisted of coastal recoveries only while the East Kamchatka group was composed of both offshore and coastal recoveries.

The equation for the linear regression of the shortest distances between release and recovery and the number of days travelled passing through the origin was calculated and its slope regarded as the mean travelling speed (Figs. 1 and 2). For fish with recovery made on the same day as released, the number of days travelled was regarded as one. As shown in Figs. 1 and 2, the variances are large. Under these conditions, the application of the linear regression passing through the origin is assumed to be appropriate rather than the normal fitted regression.

Next, the variances around the regression line for each group were calculated for each day travelled. Since the variances appeared to increase generally with increase in number of days travelled, the linear regression (passing through the origin) between the variances and the number of days travelled was calculated (Figs. 3 and 4).

The results obtained were as follows--

	Average travelling speed	Rate of increase in variance
North America group	18.5 km/day	2,874 km^2/day
East Kamchatka group	46.9 km/day	3,445 km^2/day

As clearly shown in Figs. 3 and 4, while the tagging data for the North America group show good agreement with the regression line, those for the East Kamchatka group show considerable dispersion. The dispersions for the latter are not only due to the limited data available but are also attributable to some extent to the anomalous values included in the data. Although the dispersions became smaller when the tagging data considered to be anomalous were removed, the regression equation itself did not show significant changes. Therefore, the value of the variance described above was used for the following analysis.

3. Discussion

With v, the average travelling speed and σ^2 the rate of increase in the variance, it is presumed that the probability f(x,t) of the existence of the fish at distance x ($x \geq 0$) at time t can be described by the following normal distribution where t is large.

$$f(x,t)dx = \frac{1}{\sqrt{2\pi\sigma^2 t}} \exp\left(-\frac{(x-vt)^2}{2\sigma^2 t}\right) dx \qquad (1)$$

Comparison was made between the fish distribution and equation (1) for certain numbers of days travelled. The results obtained are shown in Figs. 5 and 6. Since these two show fairly good agreement, the distribution of distance travelled at time t for pink salmon can be approximated by equation (1).

There is a distinct difference in the travelling speed between the North America and East Kamchatka groups; the latter showing greater speed.

On the other hand, these groups show relatively small differences in variances. This suggests that both groups disperse at almost the same rate. The change with time in the distribution of both groups, using equation (1), is shown in Fig. 7.

A possible reason for the North America group showing the low travelling speed is presumed to be that because the migration course describes a great arc[1], the apparent distances travelled become smaller and accordingly the travelling speed becomes low. However, migration appears to take more than one month to show such a feature and the migration course is relatively straight for data with a period from release to recovery of not more than 30 days. Therefore, the arc of the course of migration does not appear to be a significant source of bias.

Another possible reason for the low travelling speed of the North America group may be a qualitative difference in data between that for the North America and the East Kamchatka groups; while all fish of the former group were recaptured in coastal waters, the latter group consisted of fish recaptured in both coastal and offshore waters. However, division of the data for the East Kamchata group into those obtained from the coast and those from offshore and comparison of the travelling speeds showed no significant difference. Therefore, the difference in the travelling speeds between the North America and East Kamchatka fish is considered to be real.

On the other hand, variances increasing in proportion to time were observed for both groups. As possible sources of these variances, there are, for example, differences in body length between the fish. For both groups, no relationships were identified between the body length at time of release and the travelling speed.

Generally, fish do not continually swim in a straight line even in the period of migration but show complicated movements[2] with frequent change of swimming direction but on the whole migrating toward their destination. Therefore, it is possible to analyze fish movement by assuming that the divergence from straight movement results from "random walk"[3]. In this approach, fish movement can be assumed as the sum of the straight movement component and the "random walk" component and the increase in variance in proportion to time is attributable to the "random walk".

The increase in variance in proportion to time suggests that in calculating a adequate regression equation, it is more appropriate to use a weighted regression which takes into account the change in the variance rather than a normal regression which assumes that the variance is constant.

4. Conclusion

Using tagging data for pink salmon, their average travelling speed and rate of increase in the variance were calculated. These values should provide a basis for the analysis of homing migration. For example, using these values, the distribution of the distance travelled from the location of release can be approximated by a normal distribution such as shown in equation (1).

Distinct differences were observed in the migration movement between North America and East Kamchatka groups of pink salmon. While there was no significant difference in the variances, the East Kamchatka group showed a higher average travelling speed.

This report deals with pink salmon. For other species, where a large amount of tagging data are available, the analytical procedure used in this report should be applicable.

REFERENCES AND FIGS. 1 TO 7 ARE IN ENGLISH IN THE JAPANESE DOCUMENT