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PAPUA NEW GUINEA

Observations on the biology and ecology of rainbow trout, *Oncorhynchus mykiss*, and its implications for fisheries in the highlands of Papua New Guinea.

A report prepared for the Sepik River Fish Stock
Enhancement Project, PNG/85/001

by

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Papua New Guinea, Fisheries Production, River Fisheries, Fish Ecology, Fish Stocking, Fish Introductions, Salmonids.

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TABLES.

1. INTRODUCTION.

This report provides preliminary information on the biology and ecology of rainbow trout, *Oncorhynchus mykiss*, in highland streams of Papua New Guinea. The extent of success of its introduction and its implication on any future introductions of other coldwater fish species are discussed.

The relevance of trout to the Sepik River Fish Stock Enhancement Project (SRFSEP) is based on the fact that salmoniid trouts were the first exotic fishes to be introduced to Papua New Guinea for the purpose of enhancing fish stocks (West & Glucksman 1976). Furthermore, a follow-on project based on recommendations given by SRFSEP and dealing with stocking higher altitude rivers in order to improve fisheries in highland areas commenced in March 1993 (FISHAID; see Coates 1992). The presence of rainbow trout (presumably the only salmoniid species established) may have considerable implications for future stocking of other coldwater fish species recommended by SRFSEP and undertaken during the FISHAID project.

1.1. OBJECTIVES.

The objectives of the research project on which this report is based were:

1) to get information on previous trout stockings in Papua New Guinea.

2) to undertake a survey of the established trout population in the highland streams of Papua New Guinea (e.g. production, breeding habits, feeding, effect on other fish species).

1.2. THE SAMPLING AREA.

From August 1991 to August 1992 a survey of the highland streams of the southern flowing Purari River was undertaken. A report on the general results on fish production/diversity from that work and background information on the Purari River has been produced (Povlsen 1993b). The part of the results concerning rainbow trout is the basis of this report. The exact sampling sites are listed in a separate report (Povlsen 1993a).

The sampling for rainbow trout concentrated on lower order streams of the upper Purari River catchment. This is the area where most of the stockings have taken place. Van Zwieten (1990) sampled lower order streams of Sepik/Ramu catchment and didn't catch any trouts.

2. THE HISTORY OF TROUT IN PAPUA NEW GUINEA.

2.1. TROUT STOCKING.

The existing records of previous rainbow trout stockings in highland streams are listed in the Appendix.

Apart from rainbow trout there have been a few attempts to stock other salmoniid trout species. Brown trout, *Salmo trutta*, were stocked in the 1950's in Eastern Highlands Province, Simbu Province, Western Highlands Province and Southern Highlands Province (West & Glucksman 1976). Furthermore, during village survey work in 1989, this project received the information that brown trout were introduced to Lake Kundik at Maramuni, Enga Province, in 1981. People from Maramuni believed that it reproduced in streams around the lake; but it was subject to a heavy fishing pressure and subsequently disappeared. The total number of introduced brown trout was very small, and there has been no record of this species establishing in Papua New Guinea.

In 1974, the Mendi Hatchery received a shipment of 50,000 eyed ova of the brook trout, *Salvelinus fontinalis*, from New South Wales. Hatching was not successful, and only 4000 fry were released in Margarima River (West & Glucksman 1976).There are no records of people catching brook trout, and the species probably did not establish.

It seems that only the rainbow trout has been able to establish in the highlands of Papua New Guinea.

The first introduction of rainbow trout took place in 1952, when Bulolo Gold Dredging Ltd imported 10,000 ova from New Zealand and subsequently stocked the hatched fry in Bulolo River (West & Glucksman 1976). The private importations and stockings continued until 1959, and in 1964 the Division of Fisheries was involved in stocking operations for the first time, when 2000 fry were released in Gumanch and Baiyer Rivers in Western Highlands (West & Glucksman 1976). These early stockings were mainly undertaken for sport fishing purposes, and they didn't significantly support a subsistence fishery at village level.

Since 1971 the introduction of trout has been based on fingerlings hatched and reared at two government operated hatcheries, the Mendi hatchery in Southern Highlands established in 1971 and the Keglsugl hatchery in Simbu Province established in 1979. These hatcheries were abandoned in 1986. Since then, the only recorded trout stocking occurred in March 1992 when 10,000 fingerlings were stocked in Weile Dam at the Porgera mining site, Enga Province (Kawei, personal communication). These fingerlings were bought from Nupaha Trout Farm at Goroka, Eastern Highlands (see later).

Large areas in the highlands have never been stocked with rainbow trout. Those include areas in Western Province, West Sepik Province and East Sepik Province. This study didn't cover those areas. However, there are probably many rivers there, where sustainable populations of rainbow trout could establish.

In addition to the recorded stockings listed in the Appendix, unrecorded stockings have occurred on a private as well as governmental basis. According to Sagom (1989), the hatchery at Mendi alone produced over 700,000 fingerlings in the period from 1971 to 1982, which is more than twice the total number of fingerlings listed here.

2.2. TROUT FARMING.

The first attempt at farming trout commercially in Papua New Guinea was the establishment of Kutuni Trout Farm at Goroka in 1970 (Coates 1989). It operated until 1984, but re-opened again in early 1989 as "Gana Trout Farm". This re-opening was unsuccessful, and currently there are no fish farming activities at the Kutuni site.

In 1990 another trout farm was established at Goroka, the Nupaha Trout Farm, and this is currently the only trout farm in operation in Papua New Guinea.

There is considerable interest among the highlands people in trout farming; a fact that reflects the popularity of fish in the area. Unfortunately, trout farming is not a subsistence level activity; the fish is very demanding with regards to water quality, and food is very expensive.

A side-effect of the two farms at Goroka has been that unintentional stocking of streams adjacent to the farms have occurred by way of escaped fish. The present trout population in streams around Goroka may, partly, be a result of such escapes.

2.3. EXISTING REPORTS ON RAINBOW TROUT IN PAPUA NEW GUINEA.

Despite the long history of rainbow trout in Papua New Guinea, very little information exists on the biology and ecology of this fish species under New Guinea conditions and the success and limitation of its introduction.

The only available data originate from a fisheries survey of the Kandep Lakes, Enga Province, undertaken in 1979, where rainbow trout were caught seven years after introduction and were believed to reproduce successfully (Wright 1980).

3. METHODS AND RESULTS.

3.1. METHODS.

The methods used in this work are generally the same as used by Van Zwieten (1989).

In order to estimate trout production in the highlands, the rotenone method was applied for sampling trout, although this method is very difficult to use in the typical trout stream (fast current, steep gradient).

Additional trout specimens were purchased from villagers neighbouring trout streams.

3.2. PHYSICAL CHARACTERISTICS OF TROUT STREAMS.

The lower limit of trout, based on my survey, is 1760 m.a.s.l. This is in accordance with other tropical high-altitude areas, for example in Madagascar, where trout has established in streams above 1700 m (Kiener and Richard-Vinard 1972).

Trout streams in the highlands are typically fast-flowing soft-water streams with rocky and stony riverbeds and clear water; and usually with no macrophytes growing in the streams. Temperatures are within the range of 10-15°C.

The findings in this report are mainly based on trouts caught at the following three sampling stations: Anggura River, Southern Highlands; Kuragamba River, Simbu Province, and Omaigiha Creek, Eastern Highlands. A description of these streams is given in Povlsen (1993a).

3.3. CONDITION FACTOR

Mean condition factor for trout from the three sampling stations are listed in Table 1, together with individual data on standard length, total weight and condition factor.

Table 1. Standard length (SL), Total Weight (TW) and Condition Factor (CF) of rainbow trouts from 3 sampling stations in the highlands of Papua New Guinea. SL-value shown in millimetres; TW-value shown in grams.
$CF = TW \times 10^5/(SL)^3$.

Anggura River			Kuragamba River			Omaigiha Creek		
SL	TW	CF	SL	TW	CF	SL	TW	CF
240	192	1.39	217	166	1.62	182	95	1.58
190	79	1.15	252	275	1.71	221	170	1.57
212	175	1.85	230	199	1.63	216	260	2.58
202	159	1.93	238	202	1.50	230	170	1.40
210	143	1.54	245	239	1.63	208	140	1.57
191	112	1.61	252	258	1.61	223	135	1.22
183	86	1.40	89	13	1.85	194	105	1.44
233	235	1.86	67	5.2	1.72	172	75	1.47
			55	2.9	1.76	172	70	1.38
						102	15	1.41
						88	10	1.47
						73	5	1.29

<u>Mean Conditioning Factor (CF):</u>

Anggura River: CF = 1.59 ± 0.26

Kuragamba River: CF = 1.67 ± 0.10

Omaigiha Creek: CF = 1.53 ± 0.33

Data on condition factor of rainbow trouts from Victoria, Australia, revealed that the range of the condition factor varied from approximately 0.8 to 2.0 with the majority being in the range 1.0 to 1.4. A value of 1.25 was adopted as a satisfactory average condition factor for salmonid fishes (Baxter et.al. 1991).

Based on this, the CF-values in Table 2 (minimum=1.15; maximum=2.58; mean=1.60) indicate that rainbow trouts from Papua New Guinea streams are in very good condition.

There are no significant differences between condition factors of trouts from the three sites (t-test; $p > 0.05$).

3.4. STOMACH CONTENTS.

The stomach contents of rainbow trout caught at the three different sampling sites are listed in Table 2.

Table 2. Stomach content of rainbow trout from 3 sampling stations in the highlands of Papua New Guinea. %V = percentage volume of that food category of the total volume of food within all stomachs examined. %N = percentage of individuals having that food item within their stomach.

	Anggura River		Kuragamba River		Omaigiha Creek
Number of stomachs examined	8		9		*10
Mean fullness of all stomachs	81.8		73.6		--
	%V	%N	%V	%N	%V
Aquatic insects and larvae	**91.9**	**100**	**75.4**	**100**	**76**
Aquatic Coleoptera	1.8	38	2.2	44	10
Aquatic Ephemeroptera	3.5	75	0.6	44	1
Aquatic Hemiptera	3.7	13	4.9	44	0
Larval Coleoptera	6.7	88	2.7	78	5
Larval Diptera	22.3	100	9.6	89	15
Larval Ephemeroptera	6.5	100	18.8	100	10
Larval Odonata	15.0	100	6.8	67	5
Larval Trichoptera	32.4	100	29.8	100	30
Terrestrial Invertebrates:	**0.6**	**38**	**2.8**	**44**	**6**
Hymenoptera	0.2	13	0.4	33	6
Hemiptera	0.4	25	0	0	0
Arachnida	2.4	11	0	0	0
Plant matter:	**2.1**	**88**	**16.7**	**100**	**11**
Fruits/Seeds	0.5	50	0.1	11	0
Plant fragments	0.6	75	14.8	78	10
** FPOM	1.0	100	1.8	100	1
Unidentified animal/Other	**5.4**	**100**	**5.1**	**100**	**7**

* The content of all stomachs were pooled prior to analysis.
** FPOM = Fine Particulate Organic Matter.

The main food item at all sites is benthic insects, which make up as much as 91.9 % of the food at Anggura River and 74 and 76 % at Kuragamba River and Omaigiha Creek, respectively. Of the benthic insects, larval caddis flies (Trichoptera) are the most abundant prey constituting around 30 % of the stomach content at all three sites. The other major taxa are larval Diptera, Ephemeroptera, Coleoptera and Odonata. Non-insect benthic fauna (e.g. crustaceans and molluscs) were not found in trout stomachs. This is in accordance with Dudgeon (1989), who found that in the Sepik/Ramu non-insect benthic taxa are confined to lower altitudes (below 250 m.a.s.l.).

At Kuragamba River a considerable part of stomach contents was plant matter (16.7 %), mainly in the form of terrestrial plant fragments (often 1-2 cm twigs). At Omaigiha Creek plant matter constituted 11 %, whereas at Anggura River it constituted only 2.1 % of the stomach content.

Plant material is often found in large amounts in trout stomachs (Cadwallader & Eden 1982). Plant fragments are probably taken "accidentally" during the voracious feeding behaviour of rainbow trout.

Terrestrial invertebrates seem to play a minor role as food organisms for trout in Papua New Guinea.

No fish were found in the stomachs, although, at least in Anggura River, a native gudgeon species (Eleotrididae) occurs (a juvenile gudgeon was caught during my visit) (see later).

The differences between the three sites probably reflects the difference in availability of food items. The wide Anggura River carries relatively less terrestrial input than the other streams, and terrestrial input (of both plant and animal origin) therefore contribute relatively less to the diet of trouts from Anggura River.

Terrestrial invertebrates have previously been recognised as a very important food source for trouts (Waters 1988), and in general for fishes in lower order tropical forest streams (Lowe-McConnell 1987). Surprisingly, this doesn't seem to be the case in the three streams sampled here. The aquatic insect production in the highland streams of Papua New Guinea may be sufficient to support the trout population. Unfortunately, no data exist on benthic production in tropical high-altitude streams. However, Dudgeon (1989) concluded from his investigations of potential food availability for fishes in the Sepik River that stream benthic communities at higher altitudes are as diverse as those elsewhere in the tropics, and species richness peaked at an altitude of 1800 m.a.s.l. This is further discussed in section 3.6.

3.5. BREEDING HABITS.

Gonadal stage and sex of trouts caught at the three sampling stations are listed in Table 3.

Table 3. Gonadal stage of rainbow trout from three sampling stations in the highlands of Papua New Guinea.

Anggura River (9 April 92)		**Kuragamba River** (12 Sept. 91)		**Omaigiha Creek** (4 August 91)	
Gonadal Stage	Sex	Gonadal Stage	Sex	Gonadal Stage	Sex
2	male	1	male	1	male
1	male	3	male	1	female
1	male	3	male	5	male
2	female	1	-	4	female
2	male	3	male	1	-
1	-	3	male	3	male
1	-	1	-	1	-
2	female	1	-	1	-
		1	-	1	-
				1	-
		* 5	male	1	-
		* 5	female	1	-

* Caught downstream sampling area.

Nothing conclusive can be said about the breeding habits of rainbow trout in Papua New Guinea. I consider all the trouts caught in Kuragamba and Anggura rivers to be a result of successful natural reproduction (i.e. the last stockings in both areas occurred no later than 1985-86). It seems that spawning occurs in remote, high-altitude streams (above 2300 m.a.s.l.) in very sparsely populated areas. Especially the juvenile trouts caught in Kuragamba River (September 2, 1991), suggest that successful breeding occurs in that area. In support of this, a male and a female with running-ripe gonads (stage 5) were caught downstream the sampling area.

In Omaigiha Creek a male with running-ripe testes was caught by villagers during our visit on August 2, 1991.

It has been suggested that spawning occurs in July - September in Papua New Guinea (Sagom 1989). October - November has also been suggested as the main breeding season, a time when upstream migrations of large trout has been reported (Cadwallader 1991).

In some areas people reported that female trout with eggs were caught all year round (for example, at Komea, Southern Highlands Province).

In temperate parts of the world, variations in stream discharge and temperature have been reported to play a role in upstream movement (and spawning) of salmoniid fishes (Gordon & MacCrimmon 1982). This may also be the case here, although further studies are needed on established trout populations in tropical areas, including Papua New Guinea, to elucidate this matter.

3.6. PRODUCTION OF RAINBOW TROUT IN HIGHLAND STREAMS.

3.6.1. Salmonid production and Production/Biomass (P/B) ratios.

Salmonid production in rivers and streams in temperate regions has been studied extensively and a lot of data exist on annual production and production-biomass ratios, P/B (Waters 1977 & 1988). But currently, no data exist on salmonid production in tropical regions.

In general, annual production depends on the alkalinity/hardness of the water (Waters 1977; Waters et.al. 1990; Whitworth and Strange 1983). In infertile softwater streams in northern (temperate) or mountainous streams annual salmonid production is generally below 60 kg/ha, while in hardwater streams, often in limestone geology, the estimates are between 100-300 kg/ha (Waters et.al. 1990).

The P/B ratio for salmonid streams has been estimated to vary from a low of 0.9-1.5 to a high of 2-2.4 (Chapman 1978). The highest P/B ratios were in streams in which the winter low temperature did not reach below 6-7°C and the yearly mean was 10°C or more. Under PNG conditions with water temperatures of 10-15°C in the rainbow trout range and no winter low, P/B ratios are probably higher. Chapman stated that under the majority of environments in which salmonids dominate the P/B ratio is around 2. Waters (1988) used a P/B ratio of 1.25, a ratio "commonly reported for stream trout populations".

Several methods have been applied for estimating secondary production in rivers (Waters 1977). One is the instantaneous growth rate method using the formula P=GB, where P is production (for a given period of time), G is instantaneous growth rate (for the time period) and B is standing stock (during time period).

It follows from this formula that G=P/B.

Consequently, a rapid (though perhaps less precise) method of estimating production is to multiply a "known" P/B ratio by an appropriate measure of standing stock. This is used in the following to estimate trout production in New Guinea streams.

3.6.2. Trout production in streams in Papua New Guinea.

Due to the steep gradients and high water velocities in the altitudinal range where rainbow trout occur in the highlands, it is difficult to undertake thorough sampling with rotenone.

I succeeded in doing two samplings from which I can use the data for estimating biomass/production of trout. In Omaigiha Creek near Goroka, Eastern Highlands Province, the biomass was 69.3 kg/ha, and in Kuragamba River, Simbu Province, the biomass was 46.3 kg/ha.

Using those figures as mean standing stock (assuming no significant variations throughout the year) and assuming a P/B ratio of 1.25 as suggested by Waters (1988) (which might be an under-estimate for PNG-conditions) gives a production estimate of 86.6 kg/ha/year in Omaigiha Creek and 57.9 kg/ha/year in Kuragamba River.

Of course, this is very rough estimates based on uncertain assumptions. But they give an indication of the range of potential production in the highland streams of Papua New Guinea.

Neves et.al. (1985) estimated annual production of rainbow trout at 36 kg/ha in an Appalachian stream in Virginia, USA. They found that for older trouts (2 years and older) production was negative during winter. Other estimates for annual production of rainbow trout (as listed in Neves et.al. 1985) range from a maximum of 132 kg/ha in Bothwell's Creek, Ontario, Canada, to a minimum of 24 kg/ha in Lemhi River, Idaho. As Neves et.al. point out, these varying estimates of rainbow trout are not directly comparable because of differences in species composition and physicochemical variables among the streams.

A comparison between temperate and tropical environments is even more problematic. However, an important factor for production in tropical streams is without doubt the lack of a winter-low, which is seen in temperate streams. As a result, the growth rate (P/B-ratio) is probably higher under tropical conditions. Since I have used a "temperate" P/B-ratio in my calculations, the estimates of rainbow trout production are conservative.

According to Coates (unpublished data), the Sepik/Ramu catchment has 148.9 km^2 of streams suitable for fish production in the altitudinal range of 1800-2800 m.a.s.l. (the expected altitudinal range of rainbow trout in Papua New Guinea). This gives a total potential trout production of 1074 tons/year in the Sepik/Ramu catchment alone.

Most of the streams where trout populations could establish in Papua New Guinea are low-fertile softwater streams with alkalinities ranging from 30 to 70 mg/l (Petr 1983). In low-fertile, softwater streams in temperate regions, benthos production has often been reported to be much too low to support the levels of trout production commonly reported (Waters 1988); a phenomenon known as the "Allen Paradox". An obvious explanation of this is that trout exploits other food sources than benthic invertebrates. Waters (1988) suggests that trout, more than other stream-dwelling fish species, appear to feed on terrestrial surface-drift.

In this study, investigation of stomach content revealed that terrestrial invertebrates play a minor role in the diet of trout in Papua New Guinea. Aquatic insects constitute the dominant part of the diet.

According to Dudgeon (1989) stream benthic communities in the Sepik River seem as diverse as those elsewhere in the tropics. At an altitude of 2990 m.a.s.l. species richness had not declined, and it peaked at an altitude of 1800 m.a.s.l. Although benthic production was not estimated, it seems that the production of benthic invertebrates may be sufficient to support the estimated production of trout.

Allochthonous/terrestrial invertebrates may be a supplemental food source (especially after rain showers) for trout in tropical environments, but may not be as important as for trout in temperate environments. The "Allen Paradox" may be a phenomenon restricted to temperate regions, although further investigations on benthic production in tropical high-altitude streams are needed to elucidate this.

Neves et.al. (1985) compared available production estimates of rainbow trout with estimates of brook trout production. They found that rainbow trout is more productive than brook trout (brook trout production estimates ranged from 3.1 kg/ha/year to 19.3 kg/ha/year). Rainbow trout has higher growth rates and fecundities, a larger maximum size and greater tolerance of flooding and water temperature variations (Neves et.al. 1985). Due to the very limited data available on production of non-salmonid fishes, it is difficult to compare production of rainbow trout with other coldwater fish species (i.e. the Himalayan cyprinids recommended for stocking Sepik/Ramu, see later). Shrestha (1990) noted that the production of Mahseer, *Tor putitora*, in natural waters in Nepal is in the range of 12-18 kg/ha/year. No calculation method was given. Data on other coldwater species are very limited.

In conclusion, rainbow trout is one of the most productive salmonid species in low-fertile, cold-water streams and is suitable for rivers and streams at altitudes above 1800 m in Papua New Guinea.

4. GENERAL DISCUSSION.

4.1. EFFECT OF TROUT ON OTHER FISH SPECIES.

Being a predator, rainbow trout has been considered detrimental to native fish fauna in many places where it has been introduced (for example, McDowall 1989). Due to the lack of native fishes in the altitudinal range where trout occur (or could be stocked), this seems to be a minor problem in Papua New Guinea.

There are two native species in the Purari catchment which might have been effected by the introduction of rainbow trout. The goby, *Glossogobius brunnoides* and the highlands gudgeon, *Mogurnda sp.3* (see: Allen 1991).

G. brunnoides occurs in mountainous headwaters of the Purari River system, e.g. tributaries to Asaro River near Goroka and to Waghi River near Mount Hagen (Allen 1991). The effect of trout on *G. brunnoides* is probably very minimal, since the upper altitudinal limit of the goby (1800 m) seems to correspond to the lower altitudinal limit of rainbow trout. In this study, *G. brunnoides* was found at three sampling stations, the highest altitude was 1720 m.a.s.l. (see Povlsen 1992a,b).

Mogurnda sp.3 occur around Mendi, Southern Highlands, in streams where trout has established (e.g. Anggura River). It is impossible to scientifically estimate the effect of trout on the gudgeon, since no data are available from the period before introductions occurred. According to local people the gudgeon has decreased in numbers in recent years, but 20 years after the trout-introductions it still occurs in the river. As mentioned earlier, no fish specimens were found during stomach content analysis of trouts from Anggura River. Although this is not a proof that trout doesn't prey on the gudgeon, it indicates that the detrimental effect on the gudgeon resulting from predation by trout is minimal. Spending most of the time hiding underneath rocks and stones, the gudgeon might avoid becoming easy prey for trout.

The effect of trout on coldwater fish species recommended for introduction by Sepik River Fish Stock Enhancement Project is, of course, of major interest to the project.

Four fish species have been recommended by the project for stocking mid- and high-altitude streams in the Sepik-Ramu catchment: *Schizothorax richardsonii*, *Tor putitora*, *Acrossocheilus hexagonolepis* and *Labeo dero*, all belonging to the cyprinid family native to the Himalayan region (Coates 1991). Povlsen (1993b) discussed their suitability for the upper Purari and recommended the snow trout, *Schizothorax richardsonii*, for stocking high-altitude rivers in the Purari catchment.

Snow trout lives in a temperature range of 8°C to 22°C (Coates 1991). Consequently, rainbow trout may have some effect on snow trouts in areas where they overlap, but will not be a hindrance to its establishment in Papua New Guinea.

In the native range of the four species in India, rainbow trout is not considered detrimental to any of them (Sehgal, personal communication).

4.2. OVERFISHING.

During my work, I have several times heard villagers report that the trout has decreased in recent years. In some places it was even reported that the trout has disappeared (streams along the Kundiawa-Keglsugl road, southern part of Gembogl District, Simbu Province). The most important reason for that is probably overfishing. Being the only fish species in most areas, trout is subject to a high fishing pressure.

As opposed to the disappearance of trout in some streams in Gembogl District, the trout population in Anggura River, Ialibu District, Southern Highlands Province, seems to be able to cope with the fishing pressure. According to people from Kireni Village nearby, trout was introduced in the early seventies, and there are no signs of a decrease in numbers.

In the Gembogl District the human population density is 47 per km^2; in Ialibu District it is 21.6 per km^2 (1980 census).

This is a clear indication that trout has problems establishing in densely populated areas due to high fishing pressure.

Other parts of the tropics have had the same experiences with rainbow trout. In Nyanga National Park in Zimbabwe, rainbow trout have been stocked for many years, but even though wild breeding is very successful in many streams, the resulting recruitment is not sufficient to keep up with the angling pressure (Bell-Cross and Minshull 1988). Thus, continual stocking will always be necessary in those streams.

The trout fishery in Zimbabwe is mainly a sport fishery, and it is strictly controlled to avoid overfishing. A solution which is not applicable under PNG conditions, where trout is mainly caught by local villagers for subsistence purposes.

The vulnerability of trout to overfishing in Papua New Guinea is, partly, due to the fact that trout currently is the only exploitable fish species within its altitudinal range, and the problem may be reduced if other coldwater fish species are introduced.

4.3. FUTURE STOCKING OF RAINBOW TROUT ?

The rainbow trout has some drawbacks with regards to suitability for stocking purposes, as also mentioned by Coates (1989). These are:

1) The preference of trout for streams in the altitudinal range of 2000-2500 m, where relatively few people live.

2) The lack of dispersal ability. Due to its coldwater-preference trout seems to stay in the area where it was introduced.

3) Vulnerability to high fishing pressure.

4) The predatory nature of rainbow trout.

On the other hand, this study indicates that trout has some advantages:

1) In cold-water, low-fertile streams trout may be more productive than other coldwater species.

2) People living in the altitudinal range where trout occur, although relatively few, they have nutritionally less options than people living at lower altitudes.

Furthermore, the argument that few people live in the altitudinal range of rainbow trout is true for the Sepik/Ramu catchment, but may not apply for the Purari. No exact data exists on altitudinal distribution of people outside the Sepik/Ramu, but based on 1990-census figures (1990 National Population Census. Preliminary figures, Census Division Populations), it seems that the number of people living above 1800 m.a.s.l. (including both Sepik/Ramu and Purari) is equal to the number of people living below 1000 m.a.s.l. in the Sepik/Ramu catchment. And fish stocking has already been justified in that area (Coates 1990a). Socio-economic data on the current catch of rainbow trout in the highlands is urgently needed to evaluate its importance.

This study indicates that there may still be streams and rivers in the highland area, which could be stocked successfully with rainbow trout. However, the aim of a stocking programme should be to establish a sustainable, self-reproducing fish stock. Consequently, fish stocking is a temporary activity. When the stocking programme has finished and a self-reproducing stock has been established, further stocking should be unnecessary. In fact, further stocking will not result in any significant increase in returns (Davies et.al. 1988).

The question then rises, why, after more than 30 years of trout stocking practices in Papua New Guinea with more than 300,000 trout fingerlings stocked, there may still be a need for further stocking of trout ?

There are two main reasons for this:

1) Vulnerability to high fishing pressures. In densely populated areas, it may not be possible to establish a self-sustainable trout stock without continual stocking (or stocking of additional fish species). This is probably the main reason why rainbow trout have never been able to support a fishery for the majority of the people in some of the areas where it was stocked.

2) The lack of dispersal ability. Trout will not move between different sub-catchments, and consequently will have to be stocked in each catchment area. This problem is intensified by its vulnerability to high fishing pressures.

Any future plans for stocking of rainbow trout should be considered in the light of possible introductions of other coldwater species. Trout seems to be a suitable species for altitudes above 1800 m. At altitudes lower than 1800 m, where the majority of people live, other species are more suitable as suggested by the Sepik River Fish Stock Enhancement Project.

This project, as well as the FISHAID-project for stocking higher altitudes, emphasizes that the stocking programme should improve the fish stock for the majority of people. Compared to the coldwater species recommended by SRFSEP, rainbow trout is not an optimal species (i.e. it has a more narrow altitudinal range). On the other hand, in many areas it may a nutritionally important supplement to people, and in these areas it may prove to be a good complementary species to those recommended by SRFSEP.

4.4. FURTHER RESEARCH.

In general, there is an urgent need for more knowledge on biology and ecology of rainbow trout in tropical high-altitude environments.

This study of rainbow trout under New Guinea conditions can be regarded as initial, and further research should be carried out on a more regular basis (i.e. regular sampling at selected sites). This should lead to more accurate measures of production and reveal any seasonal differences in growth and production.

Research on breeding habits of rainbow trout in Papua New Guinea should be undertaken, including identification of breeding sites and establishment of the breeding season (if any).

Finally (but not least important), a socio-economic study on the importance of rainbow trout in the highlands should be undertaken.

Further research on rainbow trout could be initiated as part of the FISHAID project and in cooperation with fisheries officers from the highland provinces.

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APPENDIX

Recorded introductions of rainbow trout in Papua New Guinea.
Based on West & Glucksman (1976), Gendua (personal communication) and Kawei (personal communication).

MOROBE PROVINCE.

Date	Locality	Number
01/10/52	Bulolo River	10.000 (ova)
06/10/54	Bulolo River	20.000 (ova)
--/--/55	Bulolo River	20.000 (ova)
--/--/59	Komo & Ove rivers	500

EASTERN HIGHLANDS PROVINCE.

Date	Locality	Number
--/--/55	Goroka	?
11/10/73	Henganofi area	5.000
11/10/73	Kainantu area	5.000
--/--/85	Wattabung area	5.000

SIMBU PROVINCE.

Date	Locality	Number
19/11/73	Nomandi River	2.000
--/--/79	Gembogl area	40.000
--/--/85	Gembogl area	9.600
--/--/85	Kundiawa area	1.600
--/--/85	Kerowagi area	1.800
--/--/85	Chuave area	2.000

WESTERN HIGHLANDS PROVINCE

Date	Locality	Number
--/03/56	Minj River	?
--/03/56	Mimbul River	?
--/03/56	Kayne River	?
--/03/56	Aviamp River	?
--/03/56	Limil River	?
--/--/64	Gumanch River	1.000
--/--/64	Baiyer River	1.000
--/--/68	Nebilyer River	?
16/09/72	Korman River	2.000
16/09/72	Tuman River	2.000
16/12/72	Nebilyer River	1.000
30/08/73	Kum River	1.000
30/08/73	Kuna River	5.000

(continued...)

04/09/73	Minj River	3.000
04/09/73	Arl River	3.000

ENGA PROVINCE.

Date	Locality	Number
09/12/71	Kompiam area	4.000
18/08/72	Kandep area	7.000
12/09/72	Lai River	1.500
13/09/72	Ambun River	2.000
15/09/72	Lake Iviva	2.000
15/09/72	Ailee River	2.000
03/10/73	Kompiam area	5.000
10/10/73	Wapenamanda area	10.000
08/11/73	Lake Iviva	1.000
08/11/73	Nijo River	2.000
08/11/73	Kandep area	10.000
29/11/73	Kandep area	6.000
--/03/92	Weile Dam (Porgera)	10.000

SOUTHERN HIGHLANDS PROVINCE

Date	Locality	Number
24/11/70	Iaro River	400
08/12/70	Piwa River	400
04/08/71	Andel River	1.700
30/08/71	Mangani River	1.500
01/09/71	Tongo River	5.000
02/09/71	Lake Egari	200
02/09/71	Lake Pipak	200
06/09/71	Mendi area	5.000
21/09/71	Aip River	500
22/09/71	Margarima River	4.000
06/12/71	Tongo River	6.500
18/08/72	Andabare River	3.000
24/08/72	Pangia area	4.000
31/08/72	Lake Egari	2.000
04/09/72	Aweta River	1.000
04/09/72	Paga River	1.000
05/09/72	Iaro River	4.000
05/09/72	Konju River	1.000
06/09/72	Sau River	2.000
06/09/72	Kai River	2.000
07/09/72	Wabaga River	1.000
07/09/72	Tamaria River	1.000
09/09/72	Aiyena River	3.000
09/09/72	Aura River	3.000
09/09/72	Wanbip Creek	2.000
09/09/72	Wapu Creek	2.000
10/09/72	Arkim River	1.000
10/09/72	Anga River	3.000
12/09/72	Andabare River	3.000
15/09/72	Andawe River	2.000
15/09/72	Iaro River	1.000

(continued...)

15/09/72	Linengi River	1.000
17/09/72	Mendi River	6.000
18/09/72	Kagua area	5.000
20/11/72	Kiburu River	2.000
09/12/72	Cath.Miss.Dam, Pangia	100
12/12/72	Anggura River	5.000
13/12/72	Pino River	2.000
13/12/72	Anga River	2.000
13/12/72	Biani River	1.000
20/12/72	Colba Creek	1.500
09/01/73	Aip River	1.500
09/01/73	Enep Creek	2.300
10/01/73	Mangani River	3.400
31/08/73	Kagua River	1.000
07/09/73	Piwa River	2.000
07/09/73	Huria River	4.000
01/10/73	Korn River	1.400
04/10/73	Arou River	1.000
15/10/73	Nali River	2.000
17/10/73	Bernaria River	1.000
17/10/73	Tebi River	1.000
19/10/73	Nembi River	3.000
24/10/73	Ialibu area	4.000
25/10/73	Kolba River	2.000
07/11/73	Ialibu area	4.000
13/11/73	Pangia area	9.000
14/11/73	Ingish River	1.000
21/10/73	Nipa River	2.000
27/11/73	Tilipa River	1.000
05/12/73	Mubi River (Kutubu)	2.000
11/12/73	Mendi area	3.000
12/12/73	Lake Kopiago and tributaries	2.000
17/12/73	Tongo River	2.000

WEST SEPIK PROVINCE.

Date	Locality	Number
04/12/72	Telefomin area	1.000
16/10/73	Telefomin area	2.000
16/10/73	Feramin River	2.000
16/10/73	Tifalmin area	2.000

CENTRAL PROVINCE

Date	Locality	Number
--/--/73	Kosipe River	?

TOTAL (FINGERLINGS ONLY)
(excluding ?-marks in table)

	Number
Morobe Province	500
Eastern Highlands Province	15.000
Simbu Province	57.000
Western Highlands Province	19.000
Enga Province	53.500
Southern Highlands Province	149.000
West Sepik Province	7.000
TOTAL	310.000