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Can Nitrogen Pollution from Aquaculture Be Reduced?

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Abstract

Nitrogen is essential for the normal growth of fish. It is an important ingredient in fish feed but is very expensive. There is evidence that nitrogen loading from feeding and metabolic activities of fish can cause pollution of the receiving waters. This paper reviews nitrogen losses and nitrogen retention in fish and suggests ways of reducing nitrogen loading to the environment for a sustainable aquaculture program.

Introduction

Proteins are the main source of nitrogen and essential amino acids, and also the most expensive energy source (Pillay 1990). To maximize the nutrient utilization and minimize the solid and soluble waste load, it is essential to provide cultured fish with the optimum level of protein (Cho 1993). Generally, nutrients absorbed in excess of requirements may be excreted as ammonia and urea (Beveridge and Phillips 1993). When food wastage is high and the nitrogen retention and assimilation are poor, a major portion of nitrogen is added to the culture system which may ultimately pollute the environment (Handy and Poxton 1993). The aim of aquaculture should be to provide sufficient nitrogen for good growth through balanced feed. Nitrogen pollution from aquaculture can occur in three ways, namely: (i) overfeeding of fish or feeding of fish at a time when they are not growing; (ii) feeding unstable and highly soluble diets; (iii) providing a diet of poor absorption and nitrogen retention efficiency (Handy and Poxton 1993).

Nitrogen which has not been absorbed by the fishes' gut and retained in the tissues may be excreted through the gills or through fecal loss (Fig. 1), leading to nitrogen pollution of the receiving waters (Handy and Poxton 1993). This article examines general issues of nitrogen pollution from aquaculture with particular reference to nitrogen losses and nitrogen retention, and suggests possible ways for reducing nitrogen loading to the environment.

Discussion

Nitrogen Losses in Fish

GILL EXCRETION

The main product excreted by teleost fish is total ammonia nitrogen (TAN), which is formed in the liver and excreted across the gills (Smith 1929; Randall and Wright 1987; Ramnarine et al. 1987; Sayer and Davenport 1987; Kelly et al. 1994). About 80-90% of nitrogen loss from fish is through gill excretion (Wood 1958; Sayer and Davenport 1987) and the fecal nitrogen loss accounts for 10-20% (Fivelstad et al. 1990). Nitrogen is also lost through uneaten feed or dust (Beveridge et al. 1991; Bergheim and Asgard 1996) (Fig.1).

INGESTED NITROGEN AND AMMONIA EXCRETION

The level, quality and quantity of ingested nitrogen are the most important factors in determining ammonia production. The higher the nitrogen ingestion by the fish, the more ammonia and urea are excreted (Savitz 1971; Savitz et al. 1977; Rychly 1980; Dosdat et al. 1995). A linear relationship has been found between the nitrogen ingestion and ammonia excretion in rainbow trout (Nose 1971; Rychly 1980), while the relationship is linear or logarithmic in both trout and carp (Kaushik 1980). Dosdat et al. (1995) established a strong relationship between the ingested nitrogen and TAN for both hourly and daily ammonia excretion.

TEMPERATURE AND AMMONIA EXCRETION

Nitrogen losses increase with an increase in temperature (Jobling 1981; Kaushik 1981) resulting in greater plasma ammonia concentration. The level of ammonia loss through the renal/branchial paths is increased (Pequin and Serfaty 1968) thereby affecting hourly and daily patterns of nitrogen excretion (Kikuchi et al. 1995).

DIET AND AMMONIA EXCRETION

Dabrowski and Kaushik (1984) reported that feed type may affect the timing of excretion. Fish fed on live *Artemia* showed maximum excretion after two hours, whereas in fish fed on dry diets it was after 4-6 hours. Lengthening of excretion period was also observed with diets containing a higher protein level (Ballestrazzi et al. 1994). Since nitrogen excretion in fish is related to the amount of nitrogen ingested by fish (Kaushik 1980), the nitrogen excretion profile is seen to be a function of the ingested nitrogen.

OTHER FACTORS AFFECTING AMMONIA EXCRETION

Nitrogen excretion may also be influenced by rearing conditions (Fromm and Gillette 1968; Olson and Fromm 1971; Sukurmaran and Kutty 1977; Wilkie and Wood 1991), body weight (Jobling 1981; Kikuchi et al. 1995), species (Davenport et al. 1990; Gershanovitch and Pototskij 1992), intra-species families (Gallagher et al. 1984; Kaushik et al. 1984; Ming 1985), physiological status (Wiggs et al. 1989), temperature (Speece 1973; Paulson 1980; Jobling 1981; Clark et al. 1985; Beveridge and Phillips 1993; Kelly et al. 1994), pH, dissolved oxygen concentration, life stage, protein level and protein utilization efficiency, exercise or activity state, group-effect, time of day (Maetz 1972; Brett and Zala 1975; Rychly and Marina 1977; Leid and Bratton 1984; Preez et al. 1986; Davenport et al. 1990; Paul et al. 1990; Cai and Summerfelt 1992), nitrogen, feeding rate (Beveridge and Phillips 1993), and stocking density (Rowland 1996).

Nitrogen excretion increases with increased protein level (Ballestrazzi et al. 1994; Lanari et al. 1995a) and higher temperature (Jobling 1981). It decreases with high energy or extruded diets (Lanari et al. 1995b) or when the

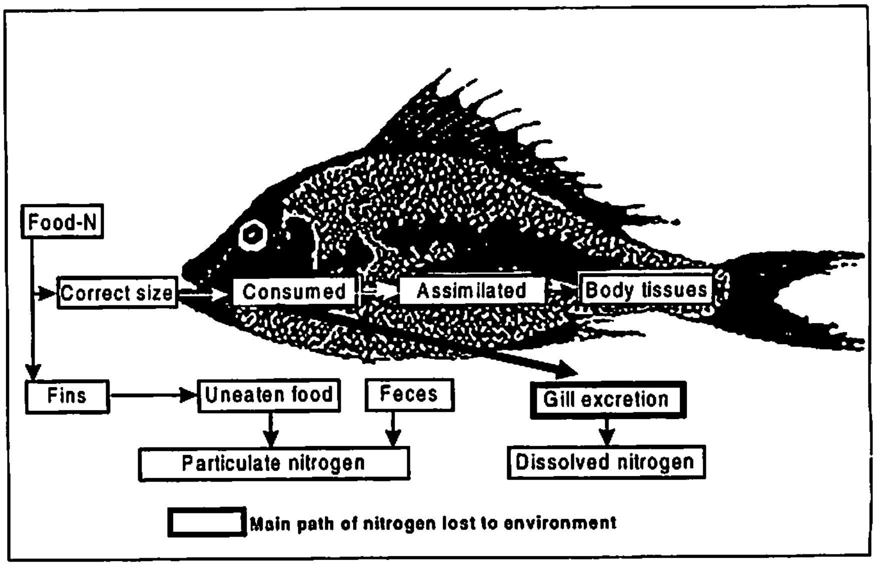

Fig. 1. General flowchart of origin of nitrogen in aquaculture from feeding (source: Kibria et al. 1997a).

protein:energy ratio in the diet is at an optimum level (Gallagher and Matthews 1987). A single factor or a combination of the above factors may make a difference in ammonia excretion.

FECAL NITROGEN LOSS

Iwata (1970) and Kibria et al. (1997b) observed a direct relationship between the nitrogen intake and the fecal nitrogen losses in silver perch and crucian carp. Kaushik (1981) and Kikuchi et al. (1995) reported higher fecal nitrogen loss at a higher temperature in rainbow trout and flounder *(Paralichthys olivaceus)*. The reported fecal nitrogen loss from aquaculture is in the range of 5.5% to 15.7% of nitrogen intake (Kaushik 1980; Porter et al. 1987; Beveridge and Phillips 1993). In general, the fecal nitrogen loss could be up to one-third of the nitrogen excreted by fish (Porter et al. 1987).

Nitrogen Retention in Fish

Measuring the amount of nitrogen retained in fish carcass is a useful means of evaluating diet and the nitrogen retention efficiency. Diet, rearing temperature and body weight of fish are the primary factors determining the nitrogen retention efficiency in fish. They can be quantified simply and economically through carcass analysis (Cho 1993) or by nitrogen balance equations (Rychly 1980; Hall et al. 1992). The nitrogen balance is determined from the proportion of nitrogen absorbed into the blood stream (nitrogen retention) from the food and the metabolic output (nitrogen loss) as shown in the following equations :

N retention=[final body nitrogen - initial body nitrogen x 100 / total dietary nitrogen supplied] (Brown et al. 1993)

and

N balance = N consumed - N retained - N excreted - Fecal N (Hall et al. 1992)

The average nitrogen retention efficiency in fish carcass is 34.5%, showing that more than 60% of nitrogen fed to fish can be lost through gill excretion and feces (Table 1).

DIET AND NITROGEN RETENTION

The diet composition is the most important factor determining the nitrogen retention efficiency in fish. The rainbow trout retained 46-49% dietary nitrogen when fed on extruded diets compared to 35-36.5% for the normal diets with the same protein levels (Lanari et al. 1995a). Diets containing high levels of raw starch or materials with low digestibility generally have a low nitrogen assimilation efficiency (Jobling 1986).

REARING TEMPERATURE AND NITROGEN RETENTION

Rainbow trout utilized diet more efficiently at 21°C than at 15.7°C signifying that at a higher temperature digestion and nitrogen retention function better (Kaushik and Oliva-Teles 1985). However, Kaushik (1981) did not find any significant temperature effect on nitrogen retention in rainbow trout reared at 10 and 18°C. Kibria et al. (1997b) observed that silver perch grown at their optimum tempera-

Table 1. Nitrogen retention and nitrogen losses in fish fed on artificial diets.

Retained (%)	Dissolved (%)	Fecal (%)	Uneaten (%)	Diet	Species	Reference
27.8	56.48	15.74	-	-	-	Ackefors and Enell (1990)
49.1	37.3	13.5	-	HED*	-	Johnsen et al. (1993)
36.0	-	-	-	Pellet	Rainbow trout	Lanari et al. (1995a)
48.0	-	-	-	Extruded	Rainbow trout	Lanari et al. (1995a)
20.8	48.74	30.50	-	Dry diet	Rainbow trout	Phillips and Beveridge (1986)
-	78.0	22.0	-		Salmon	Enell (1995)
36.8	28.1	35.0	-	Dry diet	Rainbow trout (15.7°C)	Oliva-Teles and Rodrigues (1993)
45.0	32.1	22.9	-	Dry diet	Rainbow trout (21.5°C)	Oliva-Teles and Rodrigues (1993)
24.7	60.3	15.0	-	-	-	Hakanson et al. (1988)
36.0	54.3	-	-	Dry diet	Rainbow trout	Gomes et al. (1993)
23.44	42.2	14.40	20.0	-	Tilapia	Beveridge and Phillips (1993)
28.0	48.0	23.0	-	Dry diet	Rainbow trout	Hall et al. (1992)
43.1	52.0	5.6	-	Dry diet	Silver perch (25°C)	Kibria et al. (unpublished)
29.4	61.0	9.86	-	Dry diet	Silver perch (30°C)	Kibria et al. (unpublished)

*HED = High energy diet

ture (25°C) retained maximum nitrogen but not when reared at other temperatures (Kibria et al. 1997b).

FISH SIZE AND NITROGEN RETENTION

Nitrogen retention can vary with fish size (Pandian 1967; Gerking 1971) or growth rate (Brown et al. 1987). Adult fish with low growth rates may retain 15-20% of the absorbed nitrogen, whereas rapidly growing fish can retain 40% of nitrogen supplied in diet (Handy and Poxton 1993).

Impacts of Nitrogen Loading on the Environment

Although nitrogen loading from aquaculture is relatively low (4-13%) compared to agriculture and other point sources (Table 2), it is one of the primary limiting nutrients in freshwater (Kelly et al. 1994) and marine environments (Ryther and Dunstan 1971; Makinen 1991; Kelly et al. 1994; Brodle 1995). Nitrogen discharges through fish farm effluents can enter the environment in different nitrogenous forms such as ammonia, total organic nitrogen, total nitrogen, nitrite and nitrate (Erskine and Saynor 1996).

An abundance of nitrogen in aquatic systems may not only have a toxic effect on resident biota (Carr and Goulder 1990; Foy and Rosell 1991a, 1991b), but it can also stimulate primary production (Makinen 1991) resulting in eutrophication in coastal waters (Ryther and Dunstan 1971). An abundance of nitrogen encourages growth of seagrasses, phytoplankton, benthic organisms, epiphytic and toxic algae in marine waters (Cambridge et al. 1986) making waters slimy and emanating offensive odors (Lancelot et al. 1987). The nitrogen loading from aquaculture is in the range of 75-221 kg/t fish produced (Table 3). The intensive systems can generate 7-31 times more nitrogen load than semi-intensive systems (Edwards 1993). In the semi-intensive systems, a significant part of unutilized nutrient is lost in the pond sediments (Pullin 1989; Bergheim and Asgard 1996).

Reduction of Nitrogen Discharge from Aquaculture

To reduce nitrogen loading from aquaculture, a better feed conversion is essential, as has been observed in yellowtail and red sea bream. A food conversion ratio of 1.0-1.2 is also highly desirable (Cowey and Cho 1991). It has been suggested that improvement in feed quality and feeding techniques can result in reduction of nitrogen pollution from aquaculture (Eikebrokk et al. 1991; Jensen 1991). High energy diets increase the utilization of nutrients and as a consequence reduce the solid waste and nutrient load in the water (Johnsen and Wandsvik 1991). Extended diets can reduce nitrogen and phosphorus discharge from aquaculture (Table 4). For

Table 2. Pollution (total nitrogen) loading rates from various sources.

Polluter	Country	Total N	TN/TP
Agriculture (t/d)	Japan	5.59	18.03
Domestic wastes (t/d)	Japan	3.56	10.47
Industrial effluents (t/d)	Japan	0.60	1.82
Aquaculture (t/d)	Japan	1.49	5.51
Aquaculture (as % of the total)		**13%**	
Forestry (t/y)	Finland	505.5	6.6
Industry (t/y)	Finland	3 340.0	32.6
Aquaculture (t/y)	Finland	240.0	4.0
Aquaculture (as % of the total)		**4%**	

Source: FNBW (1981) and Watanabe (1991).
(t/y) tons per year; (t/d) - tons per day; TN - total nitrogen; TP - total pollution

Table 3. Nitrogen loadings (total nitrogen) per tonne of fish production per year.

Country	Species	Culture system	Diets	TN/t (kg)	Reference
Denmark	Rainbow trout	Ponds	Dry feed	75	Warren-Hansen (1982)
Poland	Rainbow trout	Cages	Moist diet	90	Penczak et al. (1982)
Sweden	Rainbow trout	Cages	Dry feed	81	Enell and Lof (1983)
Scotland	Rainbow trout	Cages	Dry feed	99	Phillips (1985)
UK	Rainbow trout	Ponds	-	-	Solbe (1982)
USA	Rainbow trout	-	Dry feed	-	Ketola (1982)
UK	Rainbow trout	-	Dry diet	103.8	Phillips and Beveridge (1986)
Scotland	Rainbow trout	Cage			Merican and Phillips (1985)
Scotland	Rainbow trout	-	-	83-104	NCC (1990)
Norway	-		-	95-102	Hall et al. (1992)
UK	Salmonid		-	123	HRPB (1987)
Nordic	Salmon	Cages		78	Enell (1995)
Europe	-		-	108.4 ± 47.3	IOA et al. (1990)
Indonesia	Carp		-	0.1 ± 0.2	Costa-Pierce and Roem (1990)
Japan	Yellowtail	Cages	-	68	Watanabe (1991)
Europe	Marine fish		-	190	Handy and Poxton (1993)
Japan	Yellowtail	Cages		109	Watanabe (1991)
Japan	Bream	Cages		211	Watanabe (1991)
Thailand	Marine shrimp	-	-	102.3	Briggs and Funge-Smith (1994)

example, extruded diets fed to rainbow trout improved growth rate, feed utilization and gross protein retention, compared to normal diets (Lanari et al. 1995b). Japanese yellowtail fed on moist pellets reduced the nutrient load by 50% over fish fed with raw fish, while nitrogen excretion was reduced by another 25% when fed with dry pellets (Watanabe 1991). Furthermore, diets of suitable carbohydrates and optimum protein levels may improve the nitrogen retention in fish (Alsted and Jokumsen 1989; Johnsen and Wandsvik 1991; Johnsen et al. 1993; Hillestad and Johnsen 1994; Bergheim and Asgard 1996).

Nutrient loading can also be minimized by controlling the feeding regimes. At restricted feeding, nutrient load could be lower since restricted feeding gives a higher nitrogen assimilation efficiency to fish (Usher et al. 1990). Lowering of nitrogen content in feed may be the alternative for reducing the nitrogen into the effluent water (Handy and Poxton 1993; Lanari et al. 1995b). In Nordic countries, nitrogen content in feed has been decreased from 7.8% (1974) to 6.8% (1994) resulting in reduction of nitrogen pollution by 58% with concurrent improvement of food coefficient (Enell 1995).

The main food wastage in aquaculture appears to be due to mismatch between the farming practice and the feeding behavior and nutritional physiology of the species being cultured. Many marine fish species show feeding periodicity (Hall 1987; Sagar and Glova 1988) so feeding time should be matched to the maximal appetites. Some species feed exclusively during the day (haddock), some mostly at dusk (Hall 1987), while some feed continuously provided the stomach remains partly empty (Smith et al. 1989). Since optimum growth can be achieved below the maximum ration level (Brett and Groves 1979), a satiation ration can be avoided to reduce the nitrogen pollution.

Uneaten food is one of the paths for nitrogen wastage in aquaculture, and may contribute to 1 to 30% of food fed (Beveridge et al. 1991). Food dispersion by automatic feeders may cause waste up to 40.5% of food offered because the food is localized, resulting in a few dominant aggressive fish overfeeding close to the dispenser (Thrope et al. 1990). Hand feeding minimizes wastage in salmonid culture and therefore may reduce the nutrient load (Beveridge et al. 1991). Polyculture of fish rather than monoculture may reduce food wastage and nitrogen pollution. Avoiding feeding immediately after stressful treatments, such as handling or the administration of therapeutants, could further reduce nutrient load (Poxton 1992).

Table 4. Effect of fat content on nitrogen loadings in rainbow trout.

Diet	Fat (%)	Protein (%)	FCR*	Nitrogen load (kg/t)
Normal pellet	20.45	36.7	1.31	46.0
Normal pellet	20.45	39.0	1.27	47.6
Normal pellet	20.45	43	1.17	49.7
Extruded diet	28.0	39.4	0.94	20.9
Extruded diet	28.0	42.0	0.90	29.8
Extruded diet	28.0	45.0	0.84	29.1

Source: Lanari et al.(1995b).
*FCR - food conversion ratio

Feed can be manufactured according to the feeding behavior of fish, whereby a floating pellet (extruded pellets) can be offered to a surface feeder and sinking pellets (compressed pellets) to column or bottom feeders (Hardy 1989). The disintegration of pellets can be delayed by coating or encapsulating the food in agar, alginates or synthetic materials (Hardy 1989).

Conclusion

Quantification of nitrogen excretion in fish is important as it indicates the amount of nitrogen loading to an environment (Handy and Poxton 1993). Moreover, data on nitrogenous waste production helps to improve the dietary protein utilization of fish (Kaushik et al. 1984). Metabolic loss such as ammonia excretion is a valuable means of evaluating a diet and its ingredients (Brett and Groves 1979). Research on the improvement of nitrogen utilization and simultaneous reduction of nitrogen loss is highly desirable for sustainable aquaculture development (Cho 1993). In this perspective, it is essential to identify the optimum protein requirements of a species that will assure higher growth and lower nitrogen waste to the environment. Nevertheless, discharge of nitrogen via gill excretion and fecal loss could be substantial and may cause pollution in both fresh and marine waters. Although Asia is the source for 80% of the world's aquaculture production, there has not been much research on impacts of nutrient loading on the environment. Such research is vital for environmental management strategies and the development of diets with low pollution potential.

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