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# Social Dynamics Shaping the Diffusion of Sustainable Aquaculture Innovations in the Solomon Islands

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Academic Editor: Shelley Burgin
Received: 16 December 2016; Accepted: 10 January 2017; Published: 17 January 2017

**Abstract:** Sustainably feeding the world's growing population represents one of our most significant challenges. Aquaculture is well positioned to make contributions towards this challenge. Yet, the translation of aquaculture production innovations into benefits for rural communities is constrained by a limited understanding of the social dynamics that influence the adoption of new agricultural practices. In this paper, we investigate the factors that shape the spread of small-scale tilapia aquaculture through rural Solomon Islands. Based on diffusion of innovation theory, we focus on three potentially influential factors: (i) socio-economic characteristics of adopters; (ii) the role of opinion leaders; and (iii) characteristics of the innovation. We find that farmers who were wealthier, older, and had more diverse livelihoods were most likely to be adopters. Opinion leaders facilitated the adoption of tilapia aquaculture, but lacked the capacity to provide fundamental knowledge necessary to realize its potential benefits to food security. The paper argues for more explicit attention to the poorest households and makes the case for a deeper engagement with the broader social and institutional contexts that shape the adoption process. Aquaculture interventions that account for these social dynamics are critical for translating production innovations into sustainable benefits to rural communities.

**Keywords:** sustainable aquaculture; diffusion of innovation; small-scale aquaculture; tilapia; Melanesia

## 1. Introduction

Sustainably feeding the world's growing population represents one of our most significant contemporary challenges [1]. Aquaculture is well positioned to make a direct contribution towards this challenge and is amongst the most sustainable of animal protein production systems [2,3]. Given this potential, aquaculture is receiving considerable attention as an innovative food source [4–6]. While substantial production innovations in medium and large-scale farms have driven the momentous growth of the aquaculture industry, the small-scale sector, which consists of 70 to 80 percent of all actors involved in fish farming, is well situated to make substantial contributions to global food security [3,7]. In this context, meeting the food security requirements of more than 7 billion people will require scaling out of sustainable aquaculture innovations, particularly in the small-scale sector in the developing world [8].

In response to the well-documented limitations of transfer of technology in the 1980s, farmer-led approaches are increasingly seen as a promising way to support the spread of more productive, equitable, and sustainable agricultural practices in rural contexts [9]. In farmer-led approaches, local resource users work in partnership with scientists and extension agents to develop contextually relevant innovations [10]. The presence of extension support has been a supposition in much of the research on fostering sustainable agricultural innovation systems [11]. Yet, public sector support for agriculture has declined markedly over recent decades, leaving many small-holder producers without access to vital inputs and extension services [9,12]. Effective knowledge sharing and farmer to farmer learning is, therefore, crucial for the development and uptake of sustainable agricultural innovations [13].

While many scholars theorize that sustainable aquaculture innovations will spread through farmer to farmer transfer of knowledge [14,15], few studies have traced the adoption of aquaculture by small-scale farmers empirically to validate this proposition, particularly in the Pacific context. To assume a linear relationship between farmer to farmer knowledge transfer and aquaculture adoption would be to overlook what is arguably one of the most important and underexplored questions in aquaculture research: when, how, and for what reasons do farmers adopt innovations? The scarcity of evidence on the social dynamics that shape the relationship between sustainable aquaculture innovations and income, nutrition, and food security outcomes has been identified as a critical gap in contemporary aquaculture research [16].

To address this gap, we apply diffusion of innovation theory to uncover the social dynamics that shape the spread of aquaculture innovations. Specifically, we ask: *what factors influence the diffusion of aquaculture innovation from farmer to farmer in the absence of formal extension services?* We investigate this question empirically through the case of inland tilapia aquaculture in Solomon Islands. We aim to move beyond normative, pro-innovation impact assessments, which assume the utility of innovations and measure the total number of adopters, towards understanding the underlying processes responsible for adoption and non-adoption [11]. We focus on three potentially influential factors: (i) socio-economic characteristics of adopters; (ii) the role of opinion leaders in the adoption-decision process; and (iii) characteristics of the innovation. Ultimately, we aim to contribute to better understandings of the adoption decision process and to provide practical guidance for research, extension, and policy relating to the adoption of sustainable aquaculture.

## 2. Diffusion of Innovation: A Conceptual Framework

Diffusion of innovation theory seeks to explain how, why, and at what rate new ideas spread through a population [17–19]. A diffusion of innovation lens allows examination of why some innovations spread more quickly than others (and why some are rejected or fail to scale), what characteristics of individuals or communities make them likely to adopt an innovation, and the relative importance of innovation design and communication pathways in promoting adoption. In this context, an innovation is broadly defined as an idea or practice that potential adopters perceive to be new [18]. Innovations studied under this framework range from new products or technologies to social policy innovations. In this paper, we defined tilapia aquaculture as an innovation based on the premise that inland pond aquaculture is a new livelihood activity (e.g., not traditionally practiced) in Solomon Islands [20].

Five characteristics of innovations are said to influence the rate at which an innovation is adopted: (1) relative advantage; (2) compatibility; (3) complexity; (4) trialability; and (5) observability [18]. Importantly, the decision to adopt (and thus the rate of diffusion) is based upon potential adopters' subjective perceptions, rather than objective evidence. *Relative advantage* describes the degree to which an innovation is perceived to be better than the idea or practice it supersedes. The greater the perceived relative advantage of an innovation, the more rapid its rate of adoption is likely to be. *Compatibility* describes the degree to which an innovation is perceived to be consistent with the existing values, past experience and needs of potential adopters. Innovations that are incompatible with sociocultural values or beliefs, existing norms or practices will not be adopted as readily. *Complexity* is the degree to which an innovation is perceived as difficult to understand and to use. Innovations that are simpler to use and understand are adopted more rapidly than those that require the adopter to develop new skills and understanding. *Trialability* is the degree to which an innovation may be experimented with on a limited basis. Trialing provides information that reduces uncertainty about the relative advantage of the innovation; thus, innovations that are trialable represent less risk to adopters, and are more likely to be adopted. Finally, *observability* is the extent to which the results or benefits of using an innovation are visible to potential adopters. Like trialability, observability reduces uncertainty about the relative advantage of an innovation. Observability also enhances the prospects of 'over the fence' learning, which stimulates discussion about the innovation amongst potential adopters, thus increasing rates of diffusion.

Decision making about an innovation is not an immediate event; rather, it is a process that involves a series of steps over time [18]. Diffusion scholars describe the sequence of stages that an individual experiences while deciding whether or not to adopt an innovation as the innovation-decision process. The innovation-decision process can be divided into five states (Figure 1).

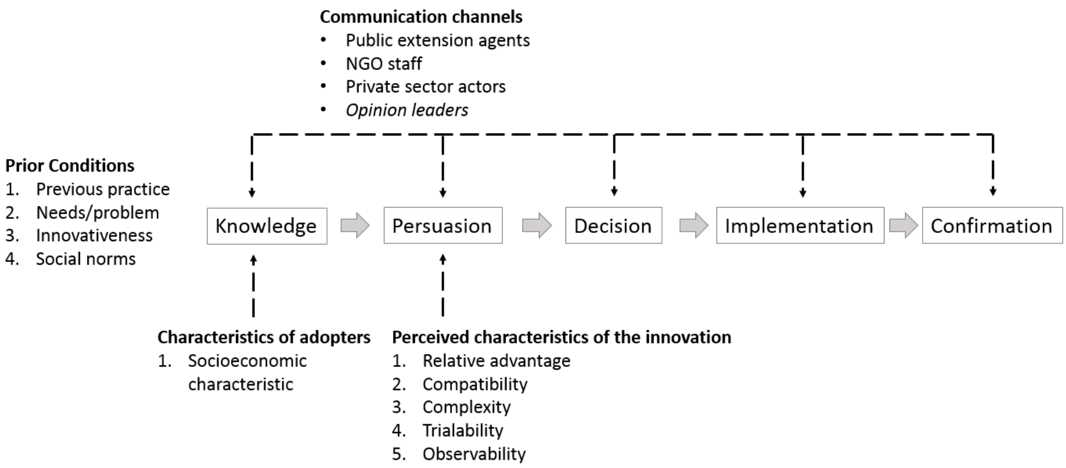


**Figure 1.** The innovation-decision process and the influence of various communication channels (adapted from [18]).

During the *knowledge stage*, an individual becomes aware of the existence of an innovation. Knowledge about an innovation is classified into three types: (i) 'awareness-knowledge' involves knowing that an innovation exists; (ii) 'how-to knowledge' consists of information necessary to use an innovation correctly (e.g., how to dig a pond); and (iii) 'principles-knowledge' consists of information about the underlying function of how an innovation works (e.g., understanding reproductive biology of tilapia) [18]. In the *persuasion stage*, an individual forms a preferential or oppositional attitude towards an innovation by evaluating the benefits and trade-offs of possible adoption. In the *decision stage*, the commitments that lead to the adoption or rejection of an innovation are made. Typically, individuals do not adopt an innovation without first testing it to determine its utility. Trial of an innovation can be facilitated through the distribution of free samples, such as a new seed variety or juvenile fish for aquaculture [18]. Deployment of innovation happens in the *implementation stage*. In the *confirmation stage*, an individual searches for validation about their decision to adopt or not-adopt an innovation.

Diffusion scholars posit that a population can be broken down into five different segments based on their propensity to adopt a particular innovation: innovators, early adopters, early majorities, late majorities, and laggards [18]. Research aimed at characterizing early adopters has demonstrated that socio-economic characteristics such as age, gender, and income, can influence the adoption of innovations. For example, illiteracy has been identified as a constraint in the uptake of aquaculture technology in India [21].

The adoption of new products or behaviors involves the management of risk and uncertainty. During the persuasion stage (Figure 1), personal networks and discussions with key individuals become more important in influencing an individual's decision to adopt [22]. *Change agents* are typically professionals with tertiary training in a technical field who influence potential adopters' innovation-decisions [18]. In agricultural systems, change agents have traditionally been government extension agents or project staff. The support of change agents has been identified as a strong determinant of the adoption and diffusion of aquaculture innovations [14,23].

In contrast to change agents, *opinion leaders* are not formally trained (e.g., university degree) and are members of the social systems in which they exert their influence. Opinion leaders are at the centre of interpersonal communication networks [24]. They often have exposure to social networks beyond their immediate family or community, have somewhat higher socio-economic status, and are more innovative than other members of their community [18]. These attributes make opinion leaders highly influential in the adoption decision of their peers. Opinion leaders are often trained by extension agents or project staff. The assumption is that opinion leaders will act as role models to their peers and are therefore important determinants of rapid and sustain uptake of innovations [18].

Taken together, the characteristics of an innovation, the innovation-decision process, the characteristics of potential adopters, and the influence of opinion leaders provide a sound conceptual framework for understanding how and why innovations spread through social groups.

## 3. Solomon Islands Aquaculture Context

By 2030, Solomon Islands is one of sixteen Pacific Island countries projected to become unable to meet its national fish consumption requirements through small-scale fisheries alone [25]. To address this anticipated deficit, the Government of Solomon Islands has identified aquaculture as a priority food security strategy [26].

For land-based aquaculture, two species that are already present in Solomon Islands have been identified as suitable: milkfish (*Chanos chanos)* and Mozambique tilapia (*Oreochromismossambicus*). *O. mossambicus* was introduced into Solomon Islands by the national government in 1957 and has since established feral populations in most suitable fresh and estuarine water bodies throughout the country. While concern rightly circulates about the negative impacts of introduced tilapia species on native biodiversity [27,28], the fact that *O. mossambicus* is already well established in Solomon Islands means there are no significant concerns about its intensification through small-scale farming for food security objectives [20,29].

Despite its widespread availability, *O. mossambicus* is considered ill-suited for commercial aquaculture due to its slow growth rate and early sexual maturity, which lead to stunting and low productivity [29]. The national aquaculture strategy recognises the limitations of *O. mossambicus* and the need for more research on its potential role for food security [20]. It is important to be clear that future ambitions for the role of tilapia in meeting fish supply gaps were based on an assumption that Nile tilapia (*Oreochromis niloticus*), a more productive species of tilapia, would be introduced by the Solomon Islands Government [20]. At the time of writing, a risk assessment for *O. niloticus* had been completed but no decision had been made by the Government on the importation. Therefore, current tilapia aquaculture initiatives proceed with what has been characterized as the "wrong" species of tilapia [29].

This research was conducted as a follow on to the "Developing Inland Aquaculture in Solomon Islands" project, a four year partnership (2011–2015) between a group of farmers in Malaita Province, WorldFish, the Ministry of Fisheries and Marine Resources, and the Secretariat of the Pacific Community. The Developing Inland Aquaculture project employed a participatory approach to develop and test local tilapia aquaculture techniques [30]. Project staff initially identified three farmers who met the criteria to act as opinion leaders: they were highly connected and innovative members of their communities who had requested assistance from WorldFish in fish farming for a number of years. Throughout the course of the project, the number of opinion leaders grew and was capped at twenty due to project capacity. Project staff and opinion leaders co-developed five contextually relevant technical recommendations designed to maximize production from *O. mossambicus*: (i) maintain water depth of 1–1.5 m; (ii) fertilization with animal manure; (iii) feed twice daily with local ingredients; (iv) <10 fish $m^2$ stocking density; and (v) regular harvesting of fish >10 cm long at intervals of 3–4 months [30]. The recommendations were then tested through on-farm-trials over a 34 month period (Figure 2).


**Figure 2.** Panel figure depicting small-scale tilapia aquaculture in Malaita, Solomon Islands (clockwise from top left): (**a**) opinion leader assisting with technical recommendations; (**b**) typical backyard pond; (**c**) cooking tilapia with cabbage and coconut milk; and (**d**) a meal of *O. mossambicus* and potato (photos: WorldFish).

As the "Developing Inland Aquaculture in Solomon Islands" project proceeded, other people began to demonstrate interest in tilapia aquaculture and dug ponds. Yet, providing direct support was beyond the capacity of the project. To address demand, informational material about tilapia aquaculture, tailored to the Malaita context, was collaboratively developed and distributed by opinion leaders to other interested farmers in their networks (Supplementary Materials S1–S3). The purpose of the informational materials was to facilitate the diffusion of tilapia aquaculture. This paper builds on the "Developing Inland Aquaculture in Solomon Islands" project, by exploring how tilapia aquaculture spread from opinion leaders to other farmers in the region in the absence of direct project or government extension support.

## 4. Materials and Methods

### *4.1. Study Site*

The study site, Radefasu Ward in Malaita Province, was purposefully selected in order to study the spread of tilapia aquaculture after the "Developing Inland Aquaculture in Solomon Islands" project had ended. Malaita Province ranks lowest in Solomon Islands on the Human Development Index and highest on the Human Poverty Index [31]. It is an island, characterised by high geographic and cultural diversity. The inland population historically traded garden produce for marine fish from the coastal population. However, access to marine fish is becoming increasing limited in the highlands due to rising demand for fish, increasing fuel costs, limited tarmacked road access, and declining marine fish supply [32].

### 4.2. Data Collection and Analysis

Between March and June 2015, we conducted semi-structured interviews with farmers who had adopted and not-adopted tilapia aquaculture. Interviews were structured in three sections. The first covered farmers' socio-economic characteristics. Second, farmers were asked to describe when and how they had learned about tilapia aquaculture. Third, farmers were asked to explain why they decided to adopt or not to adopt tilapia aquaculture and describe how their decision has impacted their households. We interviewed 16 adopters and 12 non-adopters. This represented 14% of the potential adopter population, which compares favourably with results from previous studies in Solomon Islands [33]. Total potential adopter population ($n$ = 203) was calculated based on the total number of highland (>5 km from the coastline) households in the Ward [34,35]. Sampling of farmers was based on a nonprobability sampling design [36]. Farmers were purposefully identified by WorldFish staff and subsequently via snowball sampling since a complete list of tilapia farmers, required for probability sampling, was not available. All respondents were male. Interviews were conducted in Solomon Islands' Pijin and typically lasted between 45 and 60 min.

Qualitative analysis was conducted using deductive coding [37]. We read the transcripts repeatedly to gain familiarity. Data were then analysed thematically, using the characteristics of innovations and the innovation-decision making process as a guide [18]. Data continued to be analysed until no new themes emerged. Participation in farmers' workshops, participant observation, and ongoing monitoring of on-farm trials enabled us to validate and triangulate our findings. All names used in the manuscript are pseudonyms.

## 5. Results

In Malaita between 2011 and 2015, the "Developing Inland Aquaculture in Solomon Islands" provided direct support to 20 farmers to implement inland tilapia aquaculture. From these initial farmers, tilapia aquaculture has begun to spread throughout the Province. Here, we discuss the factors that shaped the diffusion of tilapia aquaculture to farmers who did not receive direct project support. In particular, we focus on three explanatory variables: (i) socio-economic characteristics of adopters and non-adopters; (ii) the role of opinion leaders in the innovation-decision process; and (iii) characteristics of the innovation.

### 5.1. Socio-Economic Characteristics of Adopters

While variability within socio-economic characteristics was high (Table 1), age of household head and household income, and number of livelihoods, provided some predictive capacity for adoption. Households with a monthly income above the median value (USD 226) were more than twice (2.2 times) as likely to be adopters as those with lower incomes. Where the head of the household was aged above the median (35 years), households were over twice (2.2 times) as likely to be adopters, while eight of the 12 non-adopters were in the first tercile for age (age < 31). Households with above the median scores for both age and income were all adopters, although this combination of characteristics only describes 5 (31%) of the 16 adopter households. The 10 households reporting four or more livelihoods (not including tilapia aquaculture), were 1.8 times more likely to be adopters than those with 3 or fewer livelihoods. Among adopters, 81% (13 of 16) had at least one of the characteristics of above median income, above median age, or 4 or more livelihoods; only 33% of non-adopters (4 of 12) were within any of these groupings. All respondents reported having adequate access to land and water supply. Access to land and water were, therefore, not considered as influential variables in this case.

**Table 1.** Mean socio-economic characteristics of farmers surveyed in Malaita, Solomon Islands.

| Socio-Economic Characteristic | Adopters (*n* = 16) | Non-Adopters (*n* = 12) |
|---|---|---|
| Age (years) | 43 (±15) [1] | 32 (±11) |
| Married (%) | 94 | 92 |
| Literate (%) | 56 | 58 |
| Household size (number) | 5 (±2) | 6 (±1) |
| No. of livelihoods | 3 (±1) | 3 (±1) |
| Education (% with secondary schooling) | 19 | 15 |
| Monthly income (USD) | 843 (±1331) | 150 (±117) |

[1] Figures in brackets indicate standard deviation.

## *5.2. The Innovation-Decision Process*

### 5.2.1. Knowledge Stage

Up to a decade before the "Developing Inland Aquaculture in Solomon Islands" project, awareness of tilapia aquaculture had begun to spread in Malaita. Some farmers developed the idea independently, after seeing wild-caught tilapia for sale at the market. Others became aware of tilapia aquaculture through various development projects. Regardless of how farmers had been exposed to tilapia farming, interest in inland aquaculture was growing. Between 2012 and 2013, WorldFish and the Ministry of Fisheries and Marine Resources received more than 160 enquiries from farmers across the country looking for advice about developing tilapia ponds [33].

During the "Developing Inland Aquaculture in Solomon Islands" project, awareness-knowledge about tilapia aquaculture continued to spread through various communication channels (Table 2). Opinion leaders were the most frequent conduit for accessing information; 69 and 92 percent of adopters and non-adopters respectively reported receiving information from opinion leaders, who spread awareness and how-to information through word of mouth and by distributing printed informational materials to farmers. Yet, many farmers indicated that a lack of 'principles-knowledge' limited their capacity to produce tilapia. For example, one farmer said, "*we just do things the 'village way'—dig a pond, stock seed inside and feed the fish. That's all, nothing more. We don't have enough knowledge on tilapia aquaculture*" (Adopter 16).

**Table 2.** Communication modalities reported by interview respondents as methods through which they received information regarding tilapia aquaculture.

| Information Source | Adopters, % (*n* = 16) | Non-Adopters, % (*n* = 12) |
|---|---|---|
| Opinion leaders (word of mouth) | 69 [11] [1] | 92 [11] |
| Information pamphlets [2] | 38 [6] | 42 [5] |
| Look and learn visits | 25 [4] | 17 [2] |
| Family (word of mouth) | 24 [4] | 25 [3] |
| Independent trial and error | 13 [2] | 0 [0] |

[1] Number in brackets indicated number of respondents; [2] See Supplementary Materials S1–S3 for informational materials provided to farmers.

### 5.2.2. Persuasion Stage

After becoming aware of tilapia aquaculture, farmers gathered information about potential advantages and challenges through their social networks. Three quarters of farmers were swayed by opinion leaders. One farmer explained, "*George talks on the importance of tilapia aquaculture to our lives and its benefit to our communities. He also points out that it is a fresh water fish and easy to farm*" (Adopter 5). The remaining quarter of adopters were convinced about the potential benefits of tilapia farming through observing family members with ponds. During the persuasion stage, many non-adopters were waiting until they could observe the outcome of other farmers' ponds. As one farmer described, *"I am waiting on my brother and father who have just started tilapia aquaculture to see if it is successful, then it will motivate me to start mine"* (Non-adopter 1).

#### 5.2.3. Decision Stage

The decision to engage in tilapia farming was often based on direct advice from opinion leaders. When asked why he decided to try tilapia aquaculture, one adopter explained:

" ... because I was convinced and it stole my interest. Looking at George at the stage of selling fish from his pond made me try it out. George also helped me provide seed stock for my pond. My goal is to make plenty of ponds so I can sell my fish". (Adopter 4)

Another influential factor in the decision to adopt was the potential provision of fresh fish:

"I've seen pictures of fish ponds from one of the pamphlets that was given to me by George. The other thing that motivates me is that I want to eat fish and farming it meant I get to eat it when it's ready". (Adopter 5)

Finally, seven adopters cited the potential to earn income from the sale of tilapia as a motivating factor in their decision to engage in tilapia aquaculture.

The most common cited reason for non-adoption was commitment to other livelihood activities (Table 3). While all farmers had some awareness knowledge of tilapia farming, many farmers indicated that lack of 'how-to' or 'principles-knowledge' led to their decision not to engage. Several farmers indicated that fear of theft reduced their willingness to engage: *"I was busy with other activities, hence have no time to construct and start my pond. Also, stealing is a problem in our village, making me hesitant to start a tilapia pond"* (Non-adopter 3).

**Table 3.** Reasons for non-adoption of tilapia aquaculture.

| Barrier | No. of Times Barrier Was Cited |
|---|---|
| Busy/other commitments/no time | 8 |
| Lack of tools | 6 |
| Lack of information (e.g., construction, stocking, feeding) | 4 |
| Waiting to see if others are successful | 2 |
| Waiting for a market outlet | 2 |
| Interested in other species (e.g., eel, prawn, other tilapia) | 2 |
| Lack of money for labour | 1 |
| Concerned about theft | 1 |
| Negative previous experience with agricultural innovation | 1 |
| Written information inaccessible due to illiteracy | 1 |
| Waiting on fry | 1 |

In many cases, inadequate access to tools require for building ponds and harvesting fish also influenced farmers' decision not to engage despite an interest in adopting:

"My main problem of not to decide farming tilapia is I have not enough tools, such as crowbar or spades, and not enough information as well as to managing the survival of the tilapia fish". (Non-adopter 5)

#### 5.2.4. Implementation Stage

Of the sixteen adopters surveyed, eleven had tilapia in their ponds. The five farmers without tilapia indicated that they were waiting on fry. Nine of the farmers with tilapia received fry from an opinion leader, the other two from a family member or friend. Of the eleven farmers with stocked ponds, only four had harvested fish. Fish length and harvesting intervals were consistent with the technical recommendations developed and disseminated by opinion leaders (Table 4).

**Table 4.** Tilapia harvesting details in Malaita, Solomon Islands.

| Variable | Mean |
|---|---|
| Age of pond (months) | 7.5 |
| Number of harvests | 1.8 |
| Number of fish per harvest | 24.3 |
| Harvested fish length (cm) | 13.5 |

Farmers with stocked ponds, who had not yet harvested their fish, provided a variety of reasons for not harvesting, including: waiting for fish to grow ($n$ = 2); fish were stolen ($n$ = 2); stockpiling fish for a big harvest ($n$ = 2); enjoying the aesthetic quality of the pond and not wanting to harvest fish ($n$ = 1) and waiting until females start reproducing ($n$ = 1).

Only one farmer modified the aquaculture technique he learned from the informational brochure: he constructed a bamboo fence around the pond to exclude children and potential predators such as toads or frogs. Several farmers indicated that they had not begun experimenting with their ponds, because aquaculture was a relatively new livelihood activity, but that they planned on adapting their ponds in the future.

### *5.3. Characteristics of the Innovation*

#### 5.3.1. Relative Advantage

The most commonly cited advantage of tilapia aquaculture was increased access to fish. One farmer described that inland people often hike 15 km to the coast to buy fish, a trip that can take up to five hours. Another farmer explained he felt that tilapia aquaculture "*will make life easier for us, people living in the interior far from the coast, to eat fish whenever we want to*" (Adopter 5). In addition to providing a source of fish closer to home, tilapia represent a more reliable source of protein, "*not like in open oceans where a person is unsure of whether he will catch fish or not*" (Adopter 8).

A second advantage of tilapia aquaculture was the relative affordability in comparison to marine fish. Marine fish can be prohibitively expensive. Backyard ponds can eliminate this cost. One farmer explained that he chose to begin tilapia aquaculture "*so that at any time I need to catch and eat fish I just go and collect it without any restrictions or cost*" (Adopter 2). In comparison to farming and marine fishing, farmers noted that tilapia aquaculture requires relatively less time and labour. One farmer pointed out that since building his tilapia pond he spends "*less time fishing. Before I spent the whole night fishing. Now I spend only a few minutes to harvest*" (Adopter 12).

Yet, only four of the fifteen surveyed farmers had harvested fish from their ponds suggesting that at the time of writing the anticipated advantages may have been exceeding the realized benefits. For example, a farmer who built his pond one year prior to the survey explained, "*though positive impacts are not yet observed, there's still hope that one day this will have very positive impact on our lives and interest is still maintained*" (Adopter 1).

#### 5.3.2. Compatibility

Some farmers perceived tilapia aquaculture as compatible with their other livelihood activities. For example, one farmer explained that he already engaged in husbandry of pigs, poultry, and cattle therefore tilapia aquaculture felt like a natural continuation of these practices. For other farmers, tilapia aquaculture was seen as incompatible with several dimensions of their lives.

First, tilapia farming was perceived as incompatible with social norms. One farmer explained that tilapia aquaculture represented an alternative livelihood for him, rather than a complimentary one: "*at the moment gardening is very important to me and my family as it is the source of food and income. If I go into tilapia aquaculture what are the possibilities that it will take the place of gardening and provide for my family*?" (Non-adopter 4). He went on to express concern about his lack of familiarity with tilapia aquaculture: "*it is a new thing to us, so we are not sure and have no idea about its pros and cons and how we are going to* *benefit from it*". Moreover, while farmers were advised by opinion leaders to harvest their fish every three months to prevent overcrowding and stunting, many farmers were not harvesting their fish for a variety of reasons including the desire to "stockpile" fish for one big sale. This disjuncture may be indicative of an incompatibility between natural resource harvesting norms in Solomon Islands (e.g., based on amassing resources for a social event or fundraising) and tilapia harvesting requirements.

Second, the production limitations of *O. mossambicus* are incompatible with farmers' aspirations to produce tilapia for sale. Several farmers indicated that their main motivation for adopting tilapia farming was to sell fish for income, yet *O. mossambicus* is characterised by slow growth, early sexual maturity, and stunting, meaning they will not grow to marketable size and may not be suitable for commercial objectives.

Third, the absence of broader institutional support presents barriers for many farmers. Farmers cited the lack of fry, feed, public extension services, financial support, and market outlet as barriers for the adoption of aquaculture. Many farmers in Malaita had built ponds, but were waiting for fingerlings from an opinion leader. Without a national hatchery (which is not warranted for *O. mossambicus* given the species' limited potential for aquaculture), fry are difficult to obtain. In addition, many farmers reported that the lack of material resources, including tools (e.g., spade, crow bars), pond materials (e.g., pipes), or loans to purchase these materials, as a barrier to adoption.

#### 5.3.3. Complexity

The majority of adopters found pond management to be quite complex. While building and stocking a pond was relatively simple, many farmers indicated they needed more training regarding tilapia production. Farmers raised questions regarding water quality, fish feed, spawning, breeding, heat tolerance, growth rates, and stocking density. Some farmers indicated that they could manage their pond for subsistence production, but production for sale represented a challenge: "*the whole point of my tilapia was just for subsistence purposes, I wasn't eager to learn or know more. But now I want more advice on pond construction and management*". Non-adopters explained that even pond construction could be quite complex. "*I've seen Henry's pond, but I'm not sure of how the pond is constructed, that includes its depth, height, width, and the suitable site to construct the pond*".

#### 5.3.4. Trialability

In order to experiment with tilapia aquaculture, a farmer must have access to a pond. Yet, building a fish pond requires a relatively large investment of time and labour, reducing the trialability of tilapia aquaculture. Many non-adopters reported that they were reluctant to invest in pond construction before they were confident the technique would produce marketable fish. In addition, some farmers expressed interest in experimenting with faster growing species of tilapia or other types of pond aquaculture (e.g., eels, prawn) but were unable to access other aquatic species for trials. Finally, one non-adopter explained his reluctance to experiment with tilapia aquaculture was based on past experience of failed farming techniques that have been introduced by outside agencies.

#### 5.3.5. Observability

Half of the adopters learned about tilapia farming through direct observation. One farmer reported, "I got information from a cousin who also has a pond and saw how interesting it is. The whole tilapia husbandry practice—digging, feeding, and harvesting—seemed like a good practice to be engaged in. Especially for those of us who live inland and have little access to fish" (Adopter 13). This type of over the fence learning facilitated the diffusion of tilapia aquaculture.

## 6. Discussion

Small-scale aquaculture has been widely heralded as a means for sustainably addressing the growing global food security challenge [7,38]. Yet, recent innovations in aquaculture production (e.g., in breeding, feed, and management) have not translated into comparable contributions to food and livelihoods at the scale necessary to meet the future demand for fish [39]. This is particularly so in regions such as the Pacific, where aquaculture still represents a fraction of fish production. This paper set out to explore the influence of social dynamics on the adoption of tilapia aquaculture in the absence of extension services. Three main conclusions emerge from our research with implications for policy-makers, practitioners, and researchers.

First, adopters were typically older, wealthier, and had more diverse livelihoods than non-adopters. This result suggests that without sustained mechanisms designed to support marginalized individuals and households, the adoption of aquaculture innovations may be inaccessible to the poorest households. This raises important questions about whether the impacts of innovations are widely shared by all members of rural communities or whether powerful actors, such as local elites, are able to capture most of the benefits [16,40]. Critics of diffusion of innovation theory have argued that extension agents commonly target those who need it least, for example by paying disproportionate attention to opinion leaders who are by definition of higher socio-economic status [41]. Further, opinion leaders tend to be influential only in a specific segment of a community, often on those who are most similar to themselves [11]. These concerns highlight the need for research that prioritizes marginalized or resource-poor individuals and groups (e.g., [42]) and identifies mechanisms for including these groups in agricultural innovation research and practice [30].

Second, our results suggest that opinion leaders can effectively spread basic knowledge (awareness and how-to), but may lack the capacity to communicate principles-knowledge. For example, the majority of farmers surveyed possessed adequate information to effectively construct a tilapia pond. Yet, the majority of those who had stocked their ponds harvested too infrequently, leading to overcrowding, stunted growth, and reduced contributions to household food consumption [30]. This challenge suggests that while the concept of tilapia aquaculture is relatively intuitive, production and management of tilapia ponds is complex. The complexity of tilapia aquaculture, in combination with limited principles-knowledge, restricts farmers' ability to experiment and innovate. Even the development of low-input aquaculture innovations is often restricted to technical aquaculture institutions [43]. Yet, farmers' ability to experiment and innovate is crucial is order to achieve growth and impact through agricultural practices and to adapt innovation to local contexts [8]. To compensate for the lack of extension capacity, the government of Solomon Islands has identified the potential role of NGOs or private actors for supporting the development of small-scale aquaculture [20]. In developing countries, where state extension capacity is lacking, multi-stakeholder partnerships, between public, private, and civil actors, might provide an effective channel through which to provide the contextually relevant, long term support required to support the spread of agricultural innovations through remote communities [44,45].

Third, our research suggests that efforts to foster the spread of aquaculture innovations will be most effective when they engage with the broader social and institutional contexts [42]. First, an incompatibility between social harvesting norms and technical harvesting recommendations may be limiting the benefits of tilapia aquaculture. Traditionally, closed areas have been implemented by communities in order to stockpile resources for harvest in response to social needs, such as the death of prominent community member or a need for cash [34]. Similarly, some tilapia farmers were postponing their harvest in order to stockpile tilapia. This schedule runs counter to the technical management recommendations to harvest every three months and leads to stunting and low pond productivity [30]. Next, expectations for the benefits of an agricultural innovation must be aligned with the ecological potential of the innovation. In Solomon Islands, many farmers adopted tilapia farming with the objectives of selling their fish; yet, production for sale is incompatible with the slow growth and small maximum size of *O. mossambicus*. Finally, we reiterate the concern that much diffusion of innovation research places a large emphasis on individual explanatory variables, while broader system influences are often overlooked [46]. Our results suggest that limited infrastructure and institutional support for small-scale aquaculture at the provincial and national scale in Solomon Islands, limits the potential for spread at smaller scales. Many studies have demonstrated that aquaculture development requires an intermediate level of social and economic capital to succeed and if approached as a small-scale enterprise without broader support, is unlikely to contribute to local food security benefits [47].

These implications provide the basis for further empirical research. First, agricultural innovations are not inherently good or value free, but are complex social-ecological processes with differential social impacts [16]. Future research should explore how the costs and benefits of aquaculture innovations are distributed within and between households and communities. Building on this idea is the recognition that change never occurs alone. Evaluation of whether and how the introduction of technical innovations creates changes in social contexts represents an important research frontier. For example, future research might query how the introduction of tilapia farming influences household gendered dynamics, material interests, or practices of food production and consumption.

Taken together, our conclusions highlight some insights for practice aimed at supporting sustainable aquaculture, particularly in the Pacific context. The first involves directing specific attention to the poorest individuals and groups. While it is often appropriate and necessary to work with active, socially connected farmers, diffusion through these communication channels may support relatively affluent individuals. If this is the case, aquaculture programs may need to include explicit efforts to support opportunities for poor households to engage with knowledge-sharing activities, and adopt and experiment with novel farming techniques. The second insight involves the support of rural farmers through multiple channels and actors, including local opinion leaders, NGOs, public and private actors. The success of new agricultural practices is dependent on nuanced principles-knowledge and the capacity to experiment and innovate [13]. In the absence of public extension support services, farmers are often challenged to acquire complex principles-knowledge, which opinion leaders alone may not have the capacity to communicate effectively. Increasingly, international research organizations (such as the CGIAR) NGOs, and private sector actors may play an important role as knowledge and network brokers [48]. Ultimately, however, it is likely that publicly funded programs will be required to ensure long-term support for sustainable agricultural innovations. The third insight situates aquaculture innovations within complex, interacting social, ecological, and institutional contexts across scales. Sustainable aquaculture innovation is not just about adopting new technologies; it also requires reorganization of markets, labour, land tenure, and distribution of benefits [22]. When woven together, these insights should lead to more nuanced understanding of the social dynamics shaping the adoption of small-scale aquaculture innovations, ultimately increasing their potential contributions to more sustainable and food secure futures.

**Supplementary Materials:** The following are available online at www.mdpi.com/2071-1050/9/1/126/s1, Informational material for farmers S1: Tilapia farming in Solomon Islands, Informational material for farmers S2: How to construct and maintain ponds for fish farming, Informational material for farmers S3: Backyard tilapia farming: Manual for simple Mozambique tilapia ponds in Solomon Islands.

**Acknowledgments:** We gratefully acknowledge farmers in Malaita, Solomon Islands for their participation in this research. This work was supported by the Australian Centre for International Agricultural Research (ACIAR projects FIS/2010/057 and FIS/2012/074) and the CGIAR Research Program on Aquatic Agricultural Systems. We would also like to acknowledge the support of the Australian Research Council.

**Author Contributions:** Jessica Blythe, Reuben Sulu, Rebecca Weeks, Anne-Maree Schwarz, and Michael Phillips conceived and designed the study; Reuben Sulu and Daykin Harohau conducted the surveys; Jessica Blythe and David Mills analyzed the data; Jessica Blythe, Daykin Harohau, Rebecca Weeks, and David Mills wrote the paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

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