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Original Article

Turtles, TEDs, tuna, dolphins, and diffusion of innovations: key drivers of adoption of bycatch reduction devices

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Fisheries extension programmes frequently fail to secure mandatory or voluntary adoption of bycatch reduction devices and techniques. Approaches for improving the outcomes of extension programmes are often based on ad hoc assessments and do not consider human behaviour or change theories. This paper offers an in-depth analysis of extension activities that led to various adoption outcomes in two prominent bycatch case studies in the United States: turtle excluder devices in shrimp trawl fisheries and dolphin bycatch in the tuna purse seine fishery. Using a grounded theory approach to text analysis of interviews and documents, I examine five periods of voluntary or mandatory adoption efforts. I explain the outcomes through the lens of diffusion of innovation theory. The most effective extension programme involved informative and persuasive efforts, enforced regulations, and commercially practical bycatch reduction devices. Voluntary adoption occurred under exceptional circumstances of public and political pressure and a device that offered substantial benefits to the adopter. The two periods of successful adoption applied the most core principles of diffusion theory. This paper concludes with recommendations for how change agents can apply diffusion theory to future fisheries extension programmes to improve the adoption of bycatch reduction devices.

Keywords: BRD, bycatch reduction technology, discards, sea turtles, technology transfer, TED, uptake.

Introduction

The incidental catch of non-target species (i.e. bycatch) in commercial fishing gear has contributed to the decline of populations of fish, marine mammals, sea turtles, and sea birds (Spotila *et al.*, 2000; Lewison *et al.*, 2004; Read *et al.*, 2006; Lewison and Crowder, 2007; Croxall *et al.*, 2012; Pauly and Zeller, 2016). To alleviate this problem, people and organizations worldwide have developed numerous bycatch reduction devices (BRDs) and techniques for fishing gear (Watson and Kerstetter, 2006; Werner *et al.*, 2006; Swimmer *et al.*, 2020; Kennelly and Broadhurst, 2021). Yet, the inability to secure widespread, long-term, and proper use of bycatch reduction devices and techniques by fishers is a significant hurdle in addressing the bycatch problem and protecting imperiled species (Lewison *et al.*, 2003; Jenkins, 2006; Cox *et al.*, 2007).

Fisheries extension programmes promote the adoption of bycatch reduction devices and techniques, often in response to a regulatory mandate or hoping to spur voluntary adoption. Voluntary adoption programmes rarely succeed (Jenkins, 2006; Eayrs and Pol, 2019). Typically, extension programmes that precipitate from a mandate focus on education about regulations and the target catch and bycatch results from BRD testing. However, this approach also frequently fails to secure widespread adoption (Jenkins, 2006; Cox *et al.*, 2007) because some policymakers and managers erroneously believe persuasion is unnecessary once they pass mandatory use regulations. They think that a law negated the need for individual adoption decisions.

Some fisheries change agents and researchers have proposed to improve the outcomes of BRD extension programmes with approaches that emphasize early fisher engagement in developing, evaluating, and promoting the use of BRDs through varied modes of communication and incentives (Hall *et al.*, 2000; Hall and Mainprize, 2005; Jenkins, 2006; Hall *et al.*, 2007; Johnson and van Densen, 2007; Campbell and Cornwell, 2008; Jenkins, 2010c; Jenkins *et al.*, 2022; Tookes *et al.*, 2022). Change agent knowledge of these proposed approaches still did not lead to widespread adoption of fishing gear innovations (Eayrs and Pol, 2019; Jenkins *et al.*, 2022). Most of these proposed approaches are derived from post hoc consideration of lived experiences with bycatch reduction initiatives (Cox *et al.*, 2007). Few of them are based on empirical studies, leading to assumptions about the adoption process that are not grounded in rigorous evidence or theory (Campbell and Cornwell, 2008). Recently, studies have explored the adoption of BRDs through the lens of relevant theories such as change management (Hall *et al.*, 2007; Eayrs, 2022). But few fisheries change agents are knowledgeable about theories of change or the adoption of innovations (Eayrs and Pol, 2019).

In this paper, I offer an in-depth analysis of extension activities that led to various BRD adoption outcomes in two prominent bycatch case studies in the United States: turtle excluder devices (TEDs) in shrimp trawl fisheries and dolphin bycatch in the tuna purse seine fishery. I delineated the case studies into five periods of voluntary or mandatory BRD use and different extension approaches. For each extension period, I deconstruct the extension programmes, categorize the extension activities, and correlate evidence of adoption. I then examine and explain these outcomes through the lens of diffusion of innovation theory. I conclude by making empirically supported recommendations for how change agents could apply the diffusion of innovation theory to future fisheries extension to improve the adoption of BRDs.

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Theoretical framework

The diffusion of innovation theory presents an insightful framework for studying the adoption of BRDs. Diffusion research began with the work of Gabriel Tarde, who offered observations on "why, given one hundred different innovations conceived at the same time,…ten will spread abroad while ninety will be forgotten" (Tarde, 1969). Rogers (2003) is recognized as the seminal reference on the diffusion of innovations and synthesizes >5000 publications, most of which offer empirical evidence supporting the principles of diffusion theory. In the 1980s and 1990s, a few researchers explored the diffusion of innovations in fisheries (Acheson and Reidman, 1982; Levine and McCay, 1987; Dewees and Hawkes, 1988; Moberg and Dyer, 1994). Recently, there has been a renewed interest in studying the application of diffusion theory to fisheries, especially for achieving conservation objectives (Mbaru and Barnes, 2017; Mascia and Mills, 2018; MacKeracher *et al*., 2019; Song *et al*., 2019; Tookes *et al*., 2022).

Diffusion is "the process by which an innovation is communicated through certain channels over time among members of a social system" (Rogers, 2003). Thus, the four key elements in diffusion theory are innovation, communication channels, time, and the social system. An innovation is "an idea, practice, or object that is perceived as new" by the potential adopter (Rogers, 2003). A communication channel is how messages are transferred among people, such as through mass media and interpersonal communication. Mass media is any form of mass communication to a large audience, while interpersonal communication is a targeted exchange between a few people. Time is considered in terms of how long it takes an individual to move through the innovation-decision process described below and the rate at which an entire target population adopts an innovation. A social system is the combination of people, entities, external influences (e.g. media, politics, organizational structures, governmental mandates), and internal influences (e.g. the strength of social relationships, distance from influential members of the social network) that interact and impact how decisions are made and how innovations diffuse.

In diffusion of innovations theory, adoption arises as part of the five-stage innovation-decision process: knowledge, persuasion, decision, implementation, and confirmation (Figure 1). *Knowledge* occurs when the potential adopter is first exposed to an innovation and gains some understanding of how it functions. Mass media often facilitate this exposure and increase awareness. *Persuasion* happens when the potential adopter's interest in an innovation motivates them to seek additional information, which leads them to form an opinion about the innovation. Innovation negativism can occur at this stage when a negative experience with one innovation dissuades the adoption of future innovations. Interpersonal communications often facilitate persuasion. *Decision* occurs when the potential adopter actively chooses whether to adopt an innovation. *Implementation* happens when the adopter puts an innovation to use, which may trigger the adopter to seek more information about the innovation. Reinvention, a departure by the adopter from the originally promoted version or application of an innovation, can arise at this stage. *Confirmation* occurs when the adopter seeks reinforcement of a previous innovation-decision or reverses a prior innovation-decision in response to conflicting information. (Rogers, 2003). Discontinuance can happen at the confirmation stage. There are two types of discontinuance: replacement and disenchantment. Replacement occurs when adopters stop using an innovation because they have adopted another innovation that better suits their needs and purposes. Disenchantment occurs when adopters change their opinion of an innovation.

There are three types of innovation-decisions: optional, collective, and authority. An optional innovation-decision is when an individual chooses to adopt or reject an innovation independently from the decisions of the other system members. A collective innovation-decision is when members of a system choose by consensus to adopt or reject an innovation. An authority innovation-decision is when a few individuals in a system who possess power, status, or technical expertize choose to adopt or reject an innovation for everyone (e.g. a government mandate). Under this regime, the individual member has little or no influence in the system and overtly has no choice but to implement the decision. However, individuals may circumvent authority decisions during implementation, especially when enforcement is lacking (Rogers, 2003).

The most influential roles in the adoption rate are those of opinion leaders and change agents. Opinion leadership is "the degree to which an individual is able to influence other individuals' attitudes or overt behaviour informally in a desired way with relative frequency" (Rogers, 2003). Opinion leadership is earned and kept by competence, accessibility, and conformity. When the social system is oriented toward change, opinion leaders are innovative, but when the system's norms are opposed to change, opinion leaders are not innovative (Rogers, 2003).

A change agent is "an individual who influences clients' innovation-decisions in a direction deemed desirable by a change agency" (Rogers, 2003). The success of a change agent is positively related to eight factors: (1) the extent of effort in contacting clients, (2) a client orientation rather than a change agent orientation, (3) the degree to which the diffusion programme is compatible with clients' needs, (4) empathy with clients, (5) sharing a lot in common with clients, (6) credibility in the clients' eyes, (7) the extent to which the change agent works through opinion leaders, and (8) increasing clients' ability to evaluate innovations (Rogers, 2003).

The characteristics of the innovation also influence the decision about whether to adopt it. Adoption is positively related to an innovation's (1) compatibility with adopters' needs, (2) relative advantage offered, (3) trialability, and (4) observability while in use. Adoption is negatively related to (5) the complexity of an innovation (Rogers, 2003).

In this paper, I discuss the TED and tuna-dolphin case studies through the lens of diffusion theory. Specifically, I focus on the principles of diffusion over which change agencies (e.g. fisheries extension agencies) have some degree of control and thus are aspects that change agencies can directly apply to improve their extension programmes. These principles of diffusion are communication channels, social systems, the five characteristics of innovations that influence adoption, the eight factors related to change agent success, and extension efforts that are appropriate for the four stages of the innovation-decision process. I concentrate on the knowledge, persuasion, implementation, and confirmation stages but exclude the decision stage. I exclude the decision stage because it focuses on the actual moment of choice at which a potential adopter decides whether to adopt. It is difficult for an extension programme to influence the decision stage beyond the earlier efforts in the innovation-decision process. I exclude the key el-

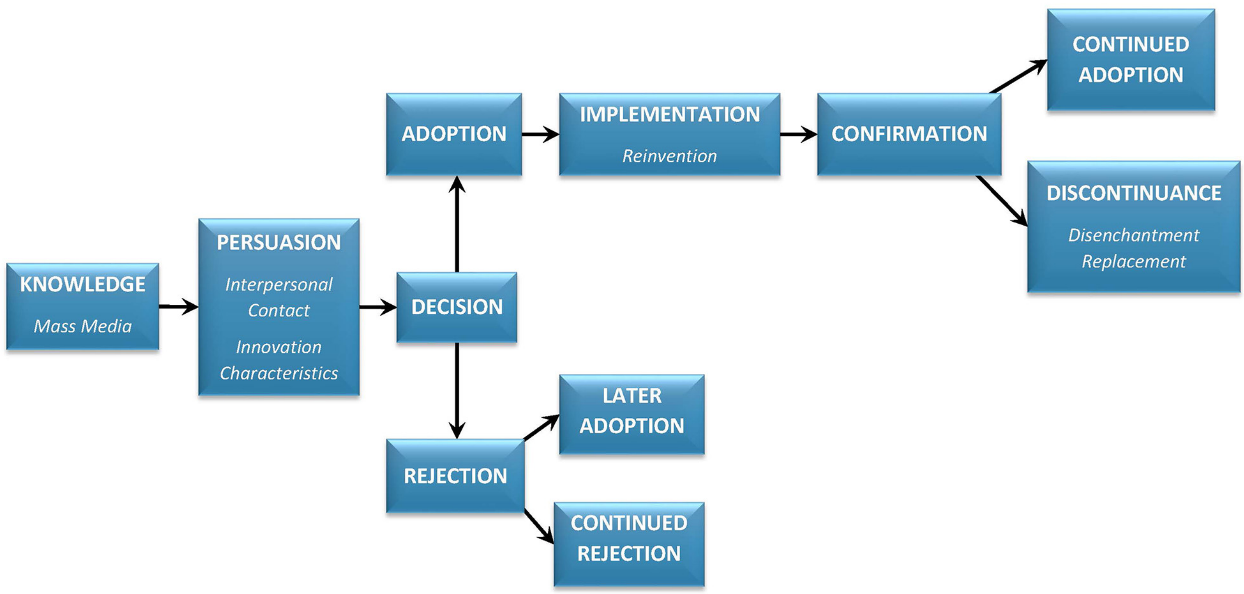

Figure 1. Innovation-decision process.

ement of time because change agents cannot actively control it. However, change agents need to acknowledge and account for how time impacts the diffusion of an innovation (Eayrs, 2022). Finally, I address the key element of innovation through the five characteristics of innovations that influence adoption.

Methods

This research focused on arguably the most well-known and well-documented case studies of bycatch reduction devices in the United States (Jenkins, 2006; Jenkins, 2007; Jenkins, 2010a; Jenkins, 2010c; Jenkins, 2012; Jenkins, 2015; Tookes *et al.*, 2022). I bound each case study within the geography of the fishery and within the best-documented time period for detailed examination of the case, from the creation of the BRD to widespread promotion efforts. The TED case study spans from 1976—when research began to reduce sea turtle bycatch—to 1998, the last year of TED development before significant changes in TED regulations. The tuna-dolphin case study examines the years between 1964—when dolphin bycatch was first brought to the government's attention—and 1981, the last year that a dolphin conservation technology development programme existed within the US government. I conducted this research in all eight commercial shrimping states in the southeast United States (North Carolina, South Carolina, Georgia, Alabama, Florida, Mississippi, Louisiana, and Texas), as well as in California, the base of the tuna purse seine fishing fleet, and Washington, a centre for the development of dolphin BRDs.

I gathered data for this study by conducting interviews, analysing documents, and examining examples of BRDs. I conducted 49 on-site, semi-structured, and unstructured interviews. The sample population consisted of representatives from stakeholders, including federal and state policymakers and managers, scientists, BRD inventors, change agents, the fishing industry, and environmental organizations. I initially established a sample frame using a purposive sample of prominent individuals frequently mentioned in the literature on the study (Orbach, 1977; Joseph and Greenough, 1979; Maril, 1983; Coe *et al.*, 1984; National Research Council, 1990; NRC, 1992; Joseph, 1994; Maril, 1995; Durrenberger, 1996; Margavio and Forsyth, 1996; Maiolo, 2004). I followed this with a snowball sample until I reached information saturation (Bernard, 2002). I also collected and analysed 695 documents, including government reports, research records, workshop reports, memos, personal letters, videos, and pamphlets (Supplementary Materials 1 and 2). I analysed the text of the interviews and documents using a grounded theory approach and an iterative process of coding and hypothesis testing to identify themes (Strauss and Corbin, 1998). I triangulated the findings with multiple sources of evidence.

Technology transfer was nominally the extension method in these case studies, but actual extension practices did not conform to this model. Diffusion of innovations theory, while not intentionally applied by change agents, was more explanatory of the relationship between extension efforts and adoption. The presence of certain principles of diffusion theory is qualitatively correlated with adoption. These principles were innovation characteristics, change agent factors, and stage-appropriate extension efforts during the innovation-decision process (Figure 1). These innovation characteristics and change agent factors were beneficial for case study analysis to provide a detailed discussion of influential variables and explain contextualized outcomes.

Based on the qualitative analysis and drawing on diffusion theory, I identified four influential variables that explain whether or not widespread adoption with consistent and proper use of an innovation occurred in each period of the case studies. While all the principles of diffusion considered are relevant to whether adoption occurred, these four variables were especially explanatory, facilitated comparative analysis between cases, and led to more generalizable findings. These four variables are: informative efforts, persuasive efforts, regulations and enforcement, and practical bycatch reduction devices and techniques.

Given the complexity of the extension efforts, I analysed them by deconstructing the efforts into types of extension activities, such as pamphlet distribution, on-board

Extension Period	Informative Efforts	Persuasive Efforts	Regulations & Enforcement	Practical BRD/Technique	Widespread, Proper, Consistent, Adoption
TED Voluntary Use	✓	✓			✗
TED Mandatory Use	✓		✓	✓	✗
Voluntary Skipper Training Workshops	✓	✓		✓	✓
Mandatory Skipper Training Workshops	✓		✓	✓	✗
Expert Skippers Panel & NMFS Extension Group	✓	✓	✓	✓	✓

Figure 2. Overview of extension variables and outcomes for each extension period.

demonstrations, or workshops. I categorized extension activities as either informative or persuasive, which respectively align with the "knowledge" and "persuasion" stages of the innovation-decision process (Rogers, 2003). Informative and persuasive efforts refer to both the nature of the content and the intention of an extension effort. Informative efforts facilitate potential adopters to gain awareness and increase their knowledge of an innovation. Persuasive efforts enable potential adopters to form an opinion about an innovation. I also considered for these factors whether there were stage-appropriate extension efforts (e.g. mass communication versus interpersonal communication) during the "knowledge" and "persuasion" stages of the innovation-decision process.

Regulations and enforcement were the most salient component of the social system (a key element of diffusion theory) in these case studies, as they proved to have the most explanatory value, and their presence correlated most with adoption than other components of the social system. Other components, such as politics and peer pressure, were relevant to idiosyncratic aspects of the case studies, and I will lightly discuss them below. For a more detailed discussion of the politics in each case and how it influenced the development of BRDs and their adoption, please see these other publications (Brotmann, 1999; Bache, 2002; DeSombre and Barkin, 2002; Jenkins, 2006; Jenkins, 2007; Jenkins, 2010b; Jenkins, 2015).

The final variable is whether a BRD or bycatch reduction technique is practical for commercial use. This variable heavily incorporates two innovation characteristics correlated with adoption: relative advantage and compatibility with clients' needs. It also includes the innovation characteristic that perceived complexity negatively correlates with adoption. In short, a commercially practical BRD offered notable benefits to fishers, was compatible with their existing boats, gear, and fishing practices, and did not overly complicate the fishing process.

For each extension period, I constructed extension equations that depict the presence of these four explanatory variables and whether widespread, proper, and consistent adoption occurred. The adoption outcome in the equations coincides with the implementation stage of the innovation-decision process. I chose this point because most of the available data in the case studies was on the initial use of an innovation rather than the continuation or confirmation of the adoption decision. I compared these extension equations and other findings to tenets of diffusion theory to explain why the extension activities in each period led to specific adoption outcomes.

Findings and discussion

Across the two case studies, two periods of extension resulted in widespread, proper, consistent adoption and use of BRDs (Figure 2). These were the voluntary skipper training workshops period and the Expert Skippers' Panel and NMFS Extension Group period in the tuna-dolphin case study. These two periods were also when extension activities aligned with all five characteristics of innovations that influence successful adoption and all eight factors positively related to change agent success (Figure 3). In the following sections, I will discuss the specifics of each extension period, show how assemblages of different extension activities and variables led to different outcomes, and further explain these outcomes through the lens of diffusion of innovation theory.

TED case study

Case study summary

In 1973, Congress passed the Endangered Species Act, which listed several sea turtle species. Consequently, the bycatch of sea turtles became a management issue for the United States' shrimp trawl fishery. At this time, NOAA Fisheries was known as the US National Marine Fisheries Service (NMFS). NMFS has responsibility for managing marine fisheries and protecting sea turtles in the United States. To fulfil this responsibility, NMFS began research to invent a device to reduce sea turtle bycatch. Eventually, NMFS adapted a device created by the shrimping industry called the jellyball shooter, a metal grid that shunted cannonball jellyfish out of the net. NMFS built on this idea, adding a sturdier grid and a large metal frame to create the NMFS TED. The NMFS TED was 97% effective

			Extension Period				
			TED Voluntary Use	TED Mandatory Use	Voluntary Skipper Training Workshops	Mandatory Skipper Training Workshops	Expert Skippers Panel & NMFS Extension Group
Principles of Diffusion Theory	Innovation Characteristics	Compatibility With Clients' Needs		✓	✓	✓	✓
		Relative Advantage			✓	✓	✓
		Trialability	✓		✓		✓
		Observability While In Use	✓		✓		✓
		Low Perceived Complexity	✓	✓	✓		✓
	Change Agent Factors	Effort Contacting Clients			✓	✓	✓
		Client Orientation			✓		✓
		Diffusion Program's Compatibility With Clients' Needs			✓		✓
		Empathy With Clients			✓		✓
		Commonality With Clients			✓		✓
		Credibility To Clients			✓		✓
		Works Through Opinion Leaders	✓		✓		✓
		Increasing Clients' Ability To Evaluate Innovations	✓		✓		✓
Total # of Diffusion Principles Met			**5**	**2**	**13**	**3**	**13**
Widespread, Proper, Consistent Adoption			✗	✗	✓	✗	✓

Figure 3. Overview of key principles of diffusion theory fulfilled by each extension period.

in allowing sea turtles to escape, but it weighed almost 100 lbs. and was an unwieldy one square metre (Jenkins, 2012). In time, shrimpers, gear manufacturers, and the NMFS developed a variety of TEDs that were more manageable to use and were just as effective in removing turtles (Margavio and Forsyth, 1996; Jenkins, 2006).

In the TED case study, there were many overlapping extension efforts from NMFS, Sea Grant, state agencies, industry groups, and environmental groups (Jenkins, 2006). However, NMFS and Sea Grant efforts were the most numerous and far-reaching. Sea Grant is a US change agency charged with transferring new fishing technologies to the fishing industry and educating the industry about new regulations. In the TED case, Sea Grant agents engaged with shrimpers, who had begun developing new TEDs independently. Sea Grant led the effort to test industry-invented TEDs and support their development. Sea Grant also interacted with NMFS about the continued refinement of NMFS-invented TEDs. Eventually, Sea Grant, especially Georgia Sea Grant, helped develop more collaborative TED research between NMFS and shrimpers (Jenkins, 2006; Tookes *et al.*, 2022).

The analysis of this case will focus on two eras of extension: the federally sponsored voluntary use programme from 1981 to 1985 and the federally mandated use of TEDs starting in 1989. These extension efforts aimed to convince the shrimping fleet, which numbered in the tens of thousands of vessels, to adopt TEDs. This effort was challenging because independent captains owned most shrimping vessels. So, change agents needed to individually convince each captain/owner of the importance of adopting TEDs.

informative efforts + persuasive efforts + impractical TED = low adoption

Figure 4. TED voluntary use extension equation.

		Examples of Evidence
Variables	Informative Efforts	Mass media extension efforts (magazine article, newsletters, and technical memorandums) promoted TED awareness. Industry groups, Sea Grant, and NMFS held informative meetings and workshops.
	Persuasive Efforts	Persuasive efforts included: workshops, technical assistance, gear trials as part of cooperative testing programs, TED giveaways, conversations, an economic study of the benefits of TEDs, a film on the development, effectiveness, and advantages of TEDs, and onboard TED demonstrations.
	Impractical TED	During the voluntary use period, the only TED certified for use was the NMFS TED. Many shrimpers complained that it was large, cumbersome, and unsafe (Kitner, 1987). Shrimpers expressed concerns over shrimp loss, fish bycatch reduction, and safety.
Outcome	Low Adoption	Five years after the start of the voluntary use program, at best, 5%, but more likely far less, of shrimpers were using a TED even part-time. The reasons for low levels of TED adoption were the unavailability of TEDs, the cost of TEDs, the lack of TED manufacturers, and concerns that TEDs were impractical and unsafe. Those who received free TEDs comprised the majority of TED adopters. However, most of these shrimpers did not adopt them as intended but used them periodically to exclude trash when the water was full of debris or jellyfish (Kitner, 1987).

Figure 5. Supporting evidence for the TED voluntary use extension equation.

TED voluntary use period

In 1982, NMFS started a voluntary use programme to encourage the adoption of the NMFS TED. A group called the TED Voluntary Use Committee was formed to advise this programme. NMFS, Sea Grant, industry, and environmental groups were jointly involved in the committee, co-chaired by an industry and environmental leader. In 1983, the Committee agreed that within three years, most southeastern US shrimpers should be using TEDs, areas and times of critical importance to sea turtles should be identified as soon as possible, and TED usage should be 100% in areas of critical importance. Over the next two years, levels of voluntary use remained low (Margavio and Forsyth, 1996). Thus, in 1985, the cooperative spirit between parties began to fail, and the voluntary use programme effectively ended that year. A key point of tension was that the environmental groups believed that industry leaders should have pushed their constituents to adopt TEDs. In contrast, industry leaders felt they were at or beyond the limit of change that their constituents were ready to tolerate. Subsequently, some industry leaders involved with the Voluntary Use Committee lost their leadership positions with shrimper associations (Jenkins, 2006). During this period, because the available TEDs were commercially impractical, adoption was low despite the use of informative and persuasive extension efforts (Figures 4 and 5).

Most extension efforts during the voluntary use period were informative and directed at large audiences through publications and group meetings. These extension efforts were affordable and wide-reaching, thus effectively promoting TED awareness but not widespread adoption. Change agents focused their extension efforts on industry organizations, but most shrimpers did not belong to an industry group. Thus, there was little direct communication between the extension agencies and individual shrimpers.

Also, Sea Grant agents believed that TEDs were contrary to the desires of their clients (i.e. shrimpers), so the agents initially did not want to advocate for the device. Therefore, Sea Grant held informative workshops and advised and assisted individual shrimpers, upon request, on TED installation and use. Sea Grant's initial efforts skipped from the knowledge stage directly to the implementation stage of the innovation-decision process, neglecting persuasive efforts that would have moved shrimpers towards the decision stage of the diffusion process by reducing uncertainty.

The few persuasive efforts that did occur mainly were onboard TED demonstrations. These demonstrations were when change agents often touted the benefits of TEDs, e.g. finfish and jellyfish bycatch reduction, and when shrimpers could interact closely with the gear and have their specific questions answered. Persuasive efforts were few due to budget constraints and an initial lack of willing change agents.

The extension efforts during the voluntary use period promoted TED awareness but not widespread adoption. The low levels of persuasive efforts likely inhibited adoption. A survey of shrimpers showed that they would consider adopting TEDs if they had personal instruction and assistance installing, tuning, and using the device (Kitner, 1987). This holds with the generality that personal interactions are more important than mass media (i.e. informative efforts) during the persuasion stage of the adoption process (Rogers, 2003). This also high-

Principles of Diffusion Theory			Examples of Evidence
	Innovation Characteristics	Trialability	Free TEDs through giveaway programs allowed shrimpers to try out TEDs with no upfront cost.
		Observability While In Use	Free TEDs through giveaway programs allowed shrimpers to observe the impact of TED on their catch and fishing process.
		Low Complexity	TED design was simple and derived from an existing industry device for removing jellyfish from a shrimp trawl.
	Change Agent Factors	Works Through Opinion Leaders	The industry leaders in the Voluntary Use Committee were opinion leaders. But working through them did not further adoption because the extension efforts pressured them to push for rapid adoption in a system resistant to change. Thus, the opinion leaders were change-oriented in a social system opposed to change; this reduced their conformity, which is one of the three ways that opinion leadership is earned and kept.
		Increasing Clients' Ability To Evaluate Innovations	Free TEDs through giveaway programs allowed shrimpers to evaluate TEDs more easily within the context of their shrimping practices.

Figure 6. Supporting evidence of principles of diffusion fulfilled by TED voluntary use extension efforts.

lights that extension efforts must continue beyond adoption to include the implementation stage. Even if the persuasive efforts were greater, it likely would not have increased adoption because the technology was not commercially acceptable. TED experts gathered at a TED workshop to review the status of the TED programme reached a similar conclusion:

> The efforts of marine extension agents (Sea Grant Advisory Service) throughout the southeast region have produced a high level of TED visibility and encouraged limited trials of the devices by many shrimpers. However, the historic reluctance of fishermen to adopt gear regarded as not useful or productive and the poor construction and/or performance of many TED units to date have actually created a credibility gap between the agents and their constituents, leading to a probable further reduction of voluntary TED acceptance by the industry.

The extension efforts during the TED voluntary use period aligned with three characteristics of innovations that influence successful adoption and two factors positively related to change agent success (Figure 6). But these extension efforts did not yield widespread adoption of TEDs.

For the small percentage of shrimpers that did adopt TEDs, most received free TEDs through giveaway programmes that distributed only hundreds of TEDs to a fishery estimated to have 10000s shrimp boats (Jenkins, 2006). However, these adopters often discontinued using TEDs, and many never chose to adopt (Moberg and Dyer, 1994). There are three possible explanations for this discontinuance and low adoption: innovation negativism, disenchantment, and a lack of user involvement in the innovation process. These three reasons link back to the NMFS TED being commercially impractical. Innovation negativism was possibly present in shrimpers familiar with a high rate of shrimp loss while using jellyball shooters and thus likely assumed a similar loss using TEDs.

The shrimpers that stopped using TEDs or only used them intermittently engaged in discontinuance due to disenchantment. In the early years of the TED case study, the manufacturing, installation, tuning, and maintenance of TEDs were poor and inconsistent (Margavio and Forsyth, 1996; Jenkins, 2006). These problems could have resulted in a negative experience that caused disenchantment.

Another reason for poor adoption was the lack of industry involvement in inventing the NMFS TED. Diffusion studies show that the speed of adoption and receptiveness to innovations is aided when users initially develop the innovation (Rogers, 2003; Tookes *et al.*, 2022). Conversely, adoption and receptiveness are inhibited when users are not allowed to re-invent an innovation developed elsewhere (Rogers, 2003). Shrimpers perceived the NMFS TED as having been created in a government "back room" and then forced on them. NMFS did not initially support shrimpers' efforts to modify the NMFS TED or create other designs. This type of reinvention typically occurs during the implementation stage. So, these innovative shrimpers who modified or reinvented TEDs had already adopted TEDs to some degree. But their adoption decisions were not confirmed because they were not supported in changing the device to suit their needs.

TED mandatory use period

NMFS promulgated mandatory TED use regulations in 1987 that required the use of TEDs by all shrimpers in all waters at all times. After years of amendments to and varying enforcement of the regulations, they became fully and consistently effective in 1994. The penalties for not complying with the regulations included seizing a vessel's shrimp catch and fines. The mandatory TED use regulations significantly boosted the adoption rate compared to the voluntary use period. Still, many shrimpers tried to find loopholes to avoid implementing the regulations (Moberg and Dyer, 1994). The extension equation for mandatory use (Figure 7) thus yields inconsistent adoption, even though by this time, shrimpers and gear manufacturers had developed TEDs that were more practical for commercial use (Jenkins, 2010c) (Figure 8).

informative efforts + enforcement + practical TEDs = inconsistent adoption

Figure 7. TED mandatory use extension equation.

		Examples of Evidence
Variables	Informative Efforts	Extension efforts were primarily informative, focusing only on the specifics of TED regulations and how shrimpers can comply with the new regulations, not why they should comply.
	Enforcement	Hefty penalties for non-compliance increased adoption. For example, in Texas, the government initially issued only warnings for noncompliance, and TED adoption was relatively low. Next, the government charged shrimpers with civil violations for non-compliance, resulting in no or light penalties, and TED adoption was about fifty percent. Then, the government began charging shrimpers with criminal offenses that could result in seizure of catch, and $25,000 fines and compliance increased to eighty percent (Jenkins, 2006).
	Practical TED	Fishing industry-invented TEDs were lighter, easier to handle, and viewed as safer by shrimpers. These TEDs were modified to address local concerns such as shrimp loss, bycatch reduction, valuable flatfish retention, and clog reduction due to trash-filled waters. These were also devices that local gear manufacturers or shrimpers could build and repair themselves, thus increasing availability and reducing costs (Jenkins, 2010c).
Outcome	Inconsistent Adoption	A survey found that 37% of North Carolina shrimpers were looking for loopholes in the proposed regulations. Others said they would not start to use TEDs until enforcement officers caught them without one. One shrimper suggested tying off the net ahead of the TED, thereby complying with the law but "beating the system" (Kitner, 1987).

Figure 8. Supporting evidence for the TED mandatory use extension equation.

Notably, there was a lack of persuasive efforts during this period. There are several possible reasons for this. Given limited staffing, extension agencies may have chosen to abandon costly persuasive efforts and focus on informing constituents about the new regulations. Also, as controversy heightened over pending regulations, some shrimpers refused to participate in persuasive efforts such as on-board TED demonstrations. This was the case in Alabama in response to Alabama Sea Grant extension efforts. But the most consistent reason arising from interviews and documents was that many management and extension agencies believed that the federal mandate for TED use negated shrimpers' individual adoption decisions. They thought regulations, enforcement, and penalties were sufficient to drive adoption, even when adopters were unpersuaded that TEDs were necessary. As discussed below, this belief proved to be false.

Although the management and extension processes did not explicitly recognize the individual adoption decision, they did manipulate it through enforcement. Enforcement increased the costs (e.g. risks of penalties) of non-compliance and swayed the cost-benefit analysis (i.e. the compliance equation) in favour of compliance. However, even with the possibility of stiff penalties and increased enforcement patrols, some shrimpers continued not to comply (Moberg and Dyer, 1994; Margavio and Forsyth, 1996). They created the appearance of compliance by installing disabled TEDs. Even though enforcement officers are trained to recognize the common ways to disable TEDs, innovative shrimpers intent on non-compliance still have the upper hand. Short turnover times with enforcement officers inhibited them from building the expertize to identify new means of false compliance.

Under mandatory use laws, the government forced shrimpers to adopt TEDs, so many did not truly adopt TEDs based on their merits. They had not made an individual adoption decision in which they were persuaded of the benefits of TEDs, and thus they were not committed to compliance (Moberg and Dyer, 1994).

These issues highlight that enforcement is not a substitute for, nor can it assure, committed adoption. Every day, people break the law, for example, by speeding or jaywalking, because they decide that breaking the law is more beneficial than following it. They implicitly contemplate the compliance equation (Figure 9).

For example, the benefits of using TEDs, such as reduced time spent sorting shrimp from bycatch, less trash (i.e. garbage and natural debris) in the net, and higher shrimp quality, would be weighed against the costs of the TED, the loss of catch, the likelihood of being caught, and the potential penalty for noncompliance. In a shrimper's mind, this equation might become (Figure 10):

Unfortunately, the extension efforts during the mandatory use period did not account for individual adoption

benefits of compliance – costs of compliance
≥ or ≤
benefits of noncompliance – costs of noncompliance

Figure 9. Compliance equation.

(reduced trash + less sorting time + better shrimp quality) – (cost of TEDs + loss of shrimp)
≥ or ≤
retention of shrimp – (probability of citation X penalty for violation)

Figure 10. Example of a possible compliance equation for shrimpers.

decisions or the shrimper's compliance equation. Due to the over-reliance on regulations and enforcement to sway adoption decisions, extension efforts aligned with only two characteristics of innovations that influence successful adoption and none of the factors positively related to change agent success (Figure 11).

According to diffusion theory, the mandatory TED use period is an example of an authority's innovation-decision (Rogers, 2003). The federal government used its authority to make a blanket adoption decision for the entire shrimping industry. Many individual shrimpers had not been personally persuaded about the need for and utility of TEDs, so some tried to find loopholes to avoid implementing the regulations (Moberg and Dyer, 1994). This illustrates that regulations and enforcement are not a substitute for persuasion, nor can they assure committed adoption.

One notable benefit of the extension activities during this period was that the focus on compliance with TED regulations aligned with the knowledge and implementation stages of the innovation-decision process. So, for those shrimpers that had made a personal decision to adopt TEDs (i.e. an optional innovation-decision), the compliance information aided them in the implementation stage, when they would have sought additional information on how to use TEDs.

Tuna-dolphin case study

Case study summary

The problem of dolphin bycatch in the tuna purse seine fishery was pivotal in the history of marine conservation in the United States. Fishermen set the purse seine around floating objects, free-swimming tuna schools, or pods of dolphins at the surface to capture tuna (McNeely, 1961; Orbach, 1977). Setting on dolphin pods yields the largest yellowfin tuna (NRC, 1992) and the least amount of unwanted fish catch; however, bycatch of dolphins can be extremely high. "Problem sets" caused most dolphin mortality and occurred during poor weather or water conditions or when there was a major equipment failure. The net collapses or canopies during problem sets, trapping and entangling dolphins. Public outrage over the deaths of perhaps hundreds of thousands of dolphins in tuna purse seines helped pass the US Marine Mammal Protection Act (MMPA) in 1972 (Hall, 1998), which required that the tuna industry reduce dolphin bycatch to levels "approaching zero". Additionally, the public's demand for "dolphin-safe tuna" placed economic pressure on the industry to address the bycatch problem.

In 1969, the US Bureau of Commercial Fisheries (which soon became NMFS) began a research programme devoted to the tuna-dolphin problem. In response to the drafting of the MMPA, NMFS set goals for a two-phase programme. Phase one was focused on improving the status quo approach to tuna fishing and was to immediately develop and transfer methods and gear that would reduce dolphin mortality. Phase two was to design a new fishing system allowing tuna harvest without capturing dolphins. From the beginning, NMFS collaborated with the industry, primarily through the American Tunaboat Association (ATA), first by seeking to spread operational changes (i.e. techniques) and gear refinements (i.e. BRDs) used by a few fishers to the whole fishery and later by involving fishers in the testing of new technology (Coe *et al.*, 1984). NMFS thoroughly evaluated numerous devices and operational changes to reduce bycatch, and fishers originated some of the most important ones. Three bycatch reduction devices and techniques were the most effective in reducing dolphin mortality: (1) the backdown method, which entails reversing the ship to partially sink the net and allow the dolphins to escape; (2) the Medina panel, a section of small mesh that prevents dolphin entanglement in the net as they escape; and (3) the use of hand rescue procedures using rescue rafts. Other bycatch reduction devices and techniques employed in especially problematic situations were anti-torque cables to prevent the net from rolling and forming canopies that could entrap dolphins and speedboats towing on the net to keep it from collapsing. These bycatch reduction devices and techniques successfully reduced dolphin mortality to only 2600 individuals in 1996 (Coe *et al.*, 1984; Hall, 1998).

The tuna-dolphin case had three extension periods: voluntary use, mandatory skipper training workshops, the Expert Skippers' Panel, and the NMFS Extension Group. The latter two periods occurred during the era of mandatory use, but there was no distinct separation between the periods. Instead, the activities of the Expert Skippers' Panel and NMFS Extension Group added to and overshadowed the continuing activities of the mandatory skipper training workshops.

Voluntary use period

During the voluntary use period, the Medina panel and the backdown method were available and practical for commercial use. For over a decade, some tunaboats had been using

			Examples of Evidence
Principles of Diffusion Theory	Innovation Characteristics	Compatibility With Client's Needs	The shrimping industry created new TED designs addressing their concerns about catch loss, net clogging, and safety.
		Low Complexity	The new TEDs designed by the shrimping-industry design were simpler, with just the grid without a bulky frame used on the original NMFS TED.

Figure 11. Supporting evidence of principles of Diffusion fulfilled by TED mandatory use extension efforts.

the backdown method, which a fisherman created. Harold Medina, a highly successful skipper from a prominent fishing family, developed the Medina panel, which became the most essential technology for reducing dolphin bycatch in purse seines. Medina experimented with and refined the panel until he could use it in commercial conditions to achieve low dolphin mortality rates with minimal tuna catch loss. The simplicity of the Medina panel was such that it did not change the fishing process, and most fishermen could easily understand how it worked. Harold Medina also facilitated adoption by providing diagrams and instructions for panel installation (informative) and strongly recommending it to other fishermen (persuasive) (Barham *et al.*, 1977). The diagrams and instructions also aided the implementation stage of the innovation-decision process for those fishermen who had already decided to adopt the Medina panel and were just beginning to use it.

The ATA knew some industry members already used dolphin bycatch reduction devices and techniques. The major obstacle that the ATA had to overcome to spread these fishermens' ideas was trade secrecy. The culture of this fishery was to try to keep any innovation a secret to increase its competitive advantage. So, the ATA had a closed meeting with fishers to encourage sharing information, especially about the best way to perform the backdown method. This sharing of information was another way that the workshops supported the implementation stage of the innovation-decision process. From 1972 through 1974, the ATA formalized this idea by developing, organizing, and conducting at least eight voluntary skipper training workshops. The ATA held these workshops every few months, each attended by about forty skippers, representing almost half the fleet.

The ATA structured the voluntary skipper training workshops to facilitate information exchange. The workshops featured experienced and respected skippers and NMFS personnel as speakers. The workshops also formed working groups to discuss techniques to reduce dolphin mortality. The working groups offered intensive interactions and a conversational exchange of information that allowed the participants to move beyond a theoretical understanding of the backdown method—for example—to understanding how to apply the technique to their fishing vessel. Again, this supported the implementation stage. Also, as fishers continued using the backdown method, hearing the positive reports of others confirmed their decision to adopt it was a good decision, thus aiding the confirmation stage of the innovation-decision process. The ATA's strategy to address dolphin bycatch was to advocate for the adoption of—not just educate about—bycatch reduction devices and techniques, stating, "We…plan to vigorously sell [i.e. promote] this approach to the fleet in the coming months)".

NMFS leadership described the ATA's voluntary skipper training workshops as "efficient, informative, and participative [with a] give-and-take atmosphere". NMFS leaders believed that the trusting relationship between workshop attendees and the knowledgeable skippers who served as speakers was critical to the workshops' success, writing:

> Industry personnel, through mutual and cooperative effort, have become experienced in presenting and exchanging information for the purpose of their workshops. They have available the expertise, equipment, and materials necessary to operate an effective training programme. The fishermen are familiar with the instructors (some of whom are drawn from among the more successful and knowledgeable skippers) and trust the data put out in these workshops…[this] provide[s] the basis for obtaining the free exchange of ideas and experience by highly qualified fishermen and…provide[s] the trust factor that we believe is so essential.

The voluntary skipper training workshops resulted in an extension equation that successfully led to adoption (Figure 12). These workshops integrated informative and persuasive extension activities (Figure 13). During this period, most of the industry's ~100 boats voluntarily and rapidly adopted the Medina panel and learned how to perform the backdown method better. Also, in 1973, the industry voluntarily began using hand rescue procedures. Several canneries that owned fleets of tunaboats of about ten boats drove a notable amount of this adoption (Jenkins, 2006). So, by focusing on the leadership of canneries, the persuasion of a small group of people led to significant increases in adoption.

Notably, while adopting the Medina panel and the backdown method was voluntary, it occurred under pressure. The tuna industry had a two-year exemption (1972–1974) from the MMPA, so using bycatch reduction devices and techniques was not mandatory during this period. Still, there was substantial media and public attention on the bycatch of dolphins in the tuna industry, leading to public calls for reform ("Pity the Poor Porpoise", 1971). This motivated the industry to deflect criticism, and adopting the Medina panel and backdown method helped them do so.

The voluntary skipper training workshops also succeeded because they embodied the eight factors positively related to change agent success (Rogers, 2003). As presented in the ATA workshops, the Medina panel and the backdown method

informative efforts + persuasive efforts + practical BRDs & techniques = adoption

Figure 12. Voluntary skipper training workshops extension equation.

		Examples of Evidence
Variables	Informative Efforts	Workshop speakers gave updates on BRD prototypes and presentations on dolphin biology. Other components of the workshops were forming working groups to discuss techniques to reduce dolphin mortality and group leader presentations on the best backdown methods. The ATA was also the first to use film as an extension tool in this case study, showing and discussing films of prototype BRDs in action at workshops and producing a training film on dolphin bycatch reduction devices and techniques.
	Persuasive Efforts	The voluntary skipper training workshops included testimonials from captains about their experiences using dolphin BRDs. One such workshop in 1974 included skippers who tried the anti-torque cable and testified to its effectiveness. Based on exposure to the experimental gear during research, most of the participating fishers formed favorable opinions of anti-torque cable. So much so that some captains tried the anti-torque cable during commercial fishing trips and later reported that it performed excellently in preventing net rolling and canopies.
	Practical Bycatch Reduction Devices and Techniques	A commercially practical bycatch reduction device and technique existed in the form of the Medina panel and the backdown method. Both the Medina panel and backdown method saved considerable time from having to disentangle nets after "problem sets."
Outcome	Adoption	In 1972, before Congress passed the MMPA, 40-50% of the industry had voluntarily adopted the Medina panel. By 1973, but before the MMPA was enforced in the tuna fishery, 60-70% of the industry had adopted it (Jenkins, 2006).

Figure 13. Supporting evidence for the voluntary skipper training workshops extension equation.

fulfilled the five characteristics of an innovation that influence successful adoption (Figure 14).

Diffusion theory also offers insight into Medina's role as an opinion leader. Opinion leadership is earned and kept by competence, accessibility, and conformity (Rogers, 2003). Medina's highliner status spoke to his competence. As an active fisherman, he was as accessible as any other fisherman. As a member of an established family of tuna fishers, he conformed with other fishery members. When social systems are oriented toward change, opinion leaders tend to be more innovative, which Medina was. The tuna industry had experienced a voluntary major gear conversion just a decade earlier from hook and line to purse seines; thus, it was oriented to change (Orbach, 1977; Rogers, 2003; Jenkins, 2006). These qualities made Medina an innovative opinion leader in an industry that valued innovation. This combination was likely influential in adopting the Medina panel (Jenkins, 2010c).

Mandatory use era

In 1974, the mandatory use era began with the regulatory requirement that tuna fishers use the Medina panel and the backdown method. Even though most of the industry had voluntarily adopted these conservation strategies in previous years, the new regulations created inner turmoil as NMFS leaders struggled to agree on the best approach to addressing enforcement and compliance. The regulations also changed the prescribed mesh size of the Medina panel, which required the fishery to re-adopt the refined BRD. The regulations also required installing anti-torque cable and using speedboats to tow the net in every set. Moreover, at least one crewmember must have a certificate allowing participation in the fishery. A primary focus of this era was not just the adoption but the optimal execution of bycatch reduction techniques, such as the backdown method and towing on the net with speedboats.

Mandatory skipper training period

During this period, anti-torque cables and net towing became more commercially practical. Members of the industry and some NMFS personnel voiced concerns about the broad utility of anti-torque cable and said that constant net towing on every set was unnecessary and wasted fuel. NMFS responded to these concerns by only requiring the anti-torque cable on vessels with a history of a significant number of net roll-ups. Also, in 1975, NMFS issued a more liberal interpretation of the speedboat regulation that allowed skippers to judge when the threat of net collapse had passed and to cease towing.

Principles of Diffusion Theory			Examples of Evidence
Principles of Diffusion Theory	Innovation Characteristics	Compatibility With Client's Needs	The Medina panel and backdown method were compatible with fishers' need to reduce dolphin bycatch.
		Relative Advantage	The Medina panel and backdown method offered a relative advantage to standard gear and techniques by reducing time lost to untangling nets during problem sets.
		Trialability	Fishers could easily trial the backdown method because it did not require any new equipment.
		Observability While In Use	The use of film to record and later show gear trials increased observability.
		Low Complexity	The Medina panel was not complex in design. The working groups developed and explained best practices for the backdown method, reducing its perceived complexity.
	Change Agent Factors	Effort Contacting Clients	The ATA was in frequent contact with its members.
		Client Orientation	The ATA's purpose was to serve its membership's interests and needs. It was to fulfill this purpose that ATA became a change agency for the industry.
		Diffusion Program's Compatibility With Client's Needs	The ATA was intimately aware of the fishers' needs in terms of information about bycatch reduction and the logistics of delivering this information.
		Empathy With Client	The ATA was empathic to fishers by nature of its relationship to the fishery. Current and former tuna fishers managed the ATA, many of whom had close relatives active in the close-knit tuna fishery.
		Commonality With Clients	Because the ATA consisted of tuna fishers, there was a high commonality.
		Credibility To Client	Many retired highliners (i.e., skippers with high target catch rates) were actively involved with the ATA, so fishers extended their respect and credibility for these individuals to the ATA.
		Works Through Opinion Leaders	The ATA used experienced and respected skippers, who were also opinion leaders, as workshop instructors.
		Increasing Clients' Ability to Evaluate Innovations	The ATA used film, thus allowing many fishers who have not had to opportunity to participate in gear trials, to see the gear in action.

Figure 14. Supporting evidence of principles of diffusion fulfilled by the voluntary skipper training workshops extension efforts.

The new mandatory use regulations also gave NMFS a directive to implement a mandatory training programme for skippers. In 1975, NMFS created the programme for all certificate holders—about 225 fishers—using the ATA voluntary skipper training workshops as a model and contracted the ATA to administer the new programme. However, NMFS retained control and final decision-making power over how the ATA ran the workshops. Persuasive efforts are not included in this extension equation because NMFS excluded critical factors of the voluntary training workshops: creditable, expert speakers, and personalized discussions. Instead, the day-long training implemented boilerplate language that was not customized to the concerns of the individual fishermen present. Initially, none of the speakers were tuna fishers, and reports noted that fishers were reserved when faced with NMFS speakers. After two years of repeated internal and external suggestions, NMFS allowed the workshop to feature fishermen as speakers starting in 1977. Another concern was that the visual aids, such as films, were of poor production quality and underutilized.

In the mandatory workshops, participants did not learn how to use the bycatch reduction techniques properly, and others were not persuaded of the necessity of using them. An NMFS report stated:

> Some of our observers reported the necessity of showing skippers how to backdown or use rescuers. The few attempts to use speedboats to hold the net open were ineffective because crewmen did not understand the procedure. Thus, skipper training sessions should be improved. Detailed explanations, including slides or movies, on the right and wrong ways of following the regulations should be prepared. Aboard vessels training should be considered.

The extension equation for the period of mandatory skipper training workshops does not result in adoption (Figure 15). This period in the tuna-dolphin case study is similar to

informative efforts + enforcement + practical BRDs & techniques = improper adoption

Figure 15. Mandatory skipper training workshops extension equation.

		Examples of Evidence
Variables	Informative Efforts	The mandatory training workshops consisted of lectures on (1) the seriousness of the tuna-dolphin problem, (2) the status of the dolphin stocks, (3) the MMPA, (4) marine mammal regulations and advice on how to comply, (5) backdown method and established dolphin BRDs, (6) emerging bycatch reduction devices and techniques, and (7) the observer program.
	Enforcement	The enforcement regime was inadequate due to a lack of personnel and the vast and distant area in which the industry fishes. Inspectors could only conduct on-shore gear inspections for technologies that fishers could not easily modify at sea. For example, enforcement officers could assure that skippers had installed a Medina panel in their net but not that they used the backdown method at sea.
	Practical Bycatch Reduction Devices and Techniques	Commercially practical bycatch reduction devices and techniques, such as the Medina panel and backdown method, were already widely used. NMFS adjusted regulations to make the mandatory use of an anti-torque cable and towing on the net with speedboats more situation specific and thus more commercially practical.
Outcome	Improper Adoption	In the mandatory workshops, participants did not learn how to use the bycatch reduction techniques properly. Others were not persuaded of the necessity of using them, such as towing on the net with speedboats. Also, 1974 observer data revealed that some fishers did not backdown all dolphins out of the net and sometimes did not perform backdown.

Figure 16. Supporting evidence for the mandatory skipper training workshops extension equation.

the mandatory use period in the TED case study. NMFS made an authority innovation-decision and attempted to use informative extension efforts, regulations, and enforcement to pressure rather than persuade the adoption of conservation strategies (Figure 16).

The mandatory skipper training workshops only incorporated two of the five characteristics of innovations that influence successful adoption and one of the eight factors positively related to change agency success (Figure 17). However, there were internal and industry suggestions that NMFS did not extensively implement and that would have incorporated three other factors positively related to change agency success. Implementing the proposals to include skilled and respected skippers as speakers would have improved the change agent's credibility in the clients' eyes (factor 6) and the extent to which the change agent works through opinion leaders (factor 7). NMFS and industry documents pointed out the informative and persuasive value of visual graphics and the need to improve and increase visual aids, such as film. Visual aids helped fishers better understand the construction and function of BRDs, increasing their ability to evaluate the BRDs (factor 8). Implementing these recommendations could have made the mandatory skipper training workshops more effective and improved the skipper's understanding and ability to use the bycatch reduction devices and techniques.

Expert Skippers' panel and NMFS extension group period

In 1977, NMFS implemented regulations requiring the ATA to form an Expert Skippers' Panel to identify and provide more personalized training to those skippers that needed it. NMFS supplied the Panel with copies of observer logs for review of the dolphin mortality and compliance of individual skippers. The Panel either made recommendations to NMFS on how to address the problem or took action by meeting with the poorly performing skipper. When the Panel met with a skipper with high dolphin morality, the skipper would describe his fishing process, and the panel members would give him individualized advice on reducing dolphin mortality. The Expert Skippers' Panel improved skippers' skill levels, resulting in a decrease in dolphin mortality. According to one Panel member, during his tenure, no skipper needed a second meeting with the Panel to address bycatch reduction. Also, many interviewees specifically noted the influential efforts of the Expert Skippers' Panel in improving skippers' skill levels.

The Expert Skippers' Panel also reviewed the data on problem sets. The Panel found that problem sets were only 4% of total sets, but they accounted for 56% of the dolphin mortality. Almost 75% of these sets had a canopy form in the net (Jenkins, 2006). The Panel recommended that NMFS send a

Principles of Diffusion Theory			Examples of Evidence
	Innovation Characteristics	Compatibility With Client's Needs	The Medina panel and backdown method were compatible with fishers' need to reduce dolphin bycatch. Refined regulations made anti-torque cable and speedboat towing on nets more situation specific and thus better aligned with fishers' needs.
		Relative Advantage	The Medina panel and backdown method offered a relative advantage to standard gear and techniques by reducing time lost to untangling nets during problem sets.
	Change Agent Factors	Effort Contacting Clients	NMFS informed all certificate holders about the mandatory workshops.

Figure 17. Supporting evidence of principles of diffusion fulfilled by the mandatory skipper training workshops extension efforts.

informative & persuasive efforts + enforcement + practical BRDs & techniques = adoption

Figure 18. Expert Skippers' Panel and NMFS extension group extension equation.

memo to all skippers to warn them of the causes of canopies and how to prevent them. The tuna industry also published guidelines on how to properly use dolphin bycatch reduction devices and techniques (Botsford *et al*., 1997).

Also in 1977, NMFS expanded its extension efforts. That year, NMFS and the industry agreed to prioritize extension, especially meeting with fishers on the docks to introduce and encourage the use of bycatch reduction devices and techniques. Dockside extension was an effective tool because the fleet consisted of only ~100 vessels that were geographically concentrated when in port. Subsequently, NMFS established an extension group to disseminate information on bycatch reduction. The primary responsibility of the extension group, which it successfully fulfilled, was to ensure proper construction, installation, and operation of the super apron that recent regulations mandated all vessels use (Coe *et al*., 1984). The super apron evolved from the Medina panel, further reducing dolphin entanglement.

The NMFS extension group also engaged in informative BRD extension efforts via radio broadcasts. Shrewdly, they coupled the announcements with weather reports that fishermen listened to religiously. NMFS created a solid reason for fishers to tune into the announcements by including information critical to the fishery, such as the level of dolphin mortality and whether the industry was approaching its yearly limit.

The extension equation for the period of the Expert Skippers' Panel and NMFS extension group led to adoption (Figure 18). Increased enforcement also aided adoption. During this period, observer records became allowable grounds for enforcement and admissible evidence for prosecution (Figure 19). Furthermore, the frequency of sets involving net collapse declined by >60% due to improved fishers' skills in preventing them (Bratten and Hall, 1996). These improved performances show that these extension activities aided the implementation phase of the innovation-decision process. The extension efforts of the Expert Skippers' Panel and extension group aligned with all five innovation characteristics that influence successful adoption and incorporated all eight factors positively related to change agent success (Figure 20).

Within and cross-case comparative discussion and recommendations

In comparing across each extension period, certain variables and principles of diffusion correlated consistently with successful adoption. These qualitative correlations indicate practices that future extension efforts should consider applying. The most effective extension periods for yielding widespread, consistent, and proper adoption of a BRD included informative efforts, persuasive efforts, regulations, enforcement, and practical bycatch reduction devices or techniques (Figure 21).

The one variable shared by all five extension periods was informative efforts, revealing that informative efforts are something that BRD extension programmes do reliably and competently. However, informative efforts are a necessary but insufficient condition for securing adoption; other extension efforts are needed in concert.

Juxtaposing the successful voluntary adoption of the Medina panel and the backdown method with the unsuccessful efforts to secure voluntary adoption of TEDs shows that voluntary adoption occurred when the stakes were high and the potential benefits were substantial and obvious. These benefits are often associated with the BRD being commercially practical, which is a necessary but insufficient condition in the effective extension equation. Voluntary adoption was successful for the Medina panel due to charismatic opinion leaders, clear benefits from the technology, large potential consequences, and focused public pressure. This rare constellation of conditions shows that voluntary adoption is possible but not often probable. For example, the looming threat of regulations in combination with other factors was insufficient to drive adoption during the TED voluntary use period. The threat of regulations is especially insufficient to drive adoption if fishers believe they could evade law enforcement or that penalties would be minor (Margavio and Forsyth, 1996; Jenkins, 2006).

Surveying across three periods of mandatory use programmes revealed that regulations, enforcement, and penalties are not necessary or sufficient conditions for adoption. The

		Examples of Evidence
Variables	Informative Efforts	The Expert Skippers' Panel recommended that a memo be sent to all skippers to warn them of the causes of canopies and how to prevent them. In 1979, the tuna industry published a booklet of guidelines developed by the Panel to instruct fishers on how to make a normal set while using dolphin bycatch reduction devices and techniques (Botsford, 1997). The NMFS extension group broadcasted via radio suggestions for how to improve the effective use of dolphin bycatch reduction devices and techniques (Coe, 1984).
	Persuasive Efforts	The Expert Skippers' Panel harnessed the cache of its members (skippers with low dolphin mortality) to motivate other captains through coaching and accountability to reduce their dolphin mortality by improving their use of bycatch reduction devices and techniques. The NMFS extension group installed various dolphin BRDs and helped troubleshoot problems with these BRDs. They also tried to persuade fishers of the benefits of the super apron by holding daylong at-sea demonstrations. Furthermore, the extension group reviewed observer reports for high mortality rates and gear problems and then met with captains to discuss the issues informally (Coe et al., 1984).
	Enforcement	Based on observer records, non-compliant skippers could receive a Notice of Violation. This would trigger a mitigation and prosecution process overseen by NMFS and advised by the Expert Skippers' Panel. Possible penalties include fines and suspension of certificates needed to legally fish.
	Practical Bycatch Reduction Devices and Techniques	As an evolution from the Medina panel, the super apron was also commercially practical.
Outcome	Adoption	By this period, most of the industry had adopted the mandated bycatch reduction devices and techniques, but dolphin mortality was still above the MMPA standard of "approaching zero." Interviewees credited the further reduction in mortality to the increased skill of skippers in using the BRDs and techniques due to training by the Expert Skippers' Panel.

Figure 19. Supporting evidence for Expert Skippers' Panel and NMFS extension group extension equation.

exception that kept this condition from being necessary was the voluntary adoption of the Medina Panel during the tuna-dolphin voluntary use period. However, intense public pressure and scrutiny notably served as a type of censure that can carry informal but substantive penalties. Even though regulations and enforcement are not absolutely necessary for BRD adoption, this factor is frequently present in cases of successful adoptions.

Levels of adoption and proper use of BRDs fluxed with levels of enforcement (Moberg and Dyer, 1994; Margavio and Forsyth, 1996; Lewison *et al.*, 2003; Jenkins, 2006). If the level of enforcement, chances of being caught in violation, and penalties were high, shrimpers said they would be more likely to use TEDs. This is consistent with other studies that have shown that levels of enforcement influence compliance (Anderson and Lee, 1986; Furlong, 1991; Hatcher and Gordon, 2005). However, maintaining this high level of enforcement requires substantial human and financial resources that can be difficult to sustain over time (Sutinen and Andersen, 1985). Effort should be made to appropriately enforce regulations on the use of BRDs, including investing in an adequate number of enforcement officers. These officers should be sufficiently trained to recognize proper BRD installation and use. They also should have long-term assignments to build expertize in the workings of the fishery and identify new ways of circumventing the implementation of the regulations (Furlong, 1991).

While not necessary conditions, regulations, enforcement, and penalties play an important role under authority innovation-decisions (i.e. when a few individuals in a system who possess power, status, or technical expertize decide for all group members whether to adopt or reject an innovation). Under authority innovation-decisions, individuals whose adoption decision was made for them are incentivized to constantly weigh the perceived risk and reward of compliance (Moberg and Dyer, 1994; Margavio and Forsyth, 1996). If fishers perceived the risk of non-compliance as low, they tended to disregard the law; if they perceived the risk as high, they

Principles of Diffusion Theory			Examples of Evidence
Principles of Diffusion Theory	Innovation Characteristics	Compatibility With Client's Needs	The gear assistance through the NMFS extension group helped make the innovation more compatible with existing fishing gear and processes.
		Relative Advantage	As an evolution of the Medina panel, the super apron continued to reduce time lost to untangling nets during disaster sets.
		Trialability	The sea trials of the super apron increased trialability.
		Observability While In Use	The sea trials of the super apron increased observability.
		Low Complexity	The diagrams and instructions in the manual produced by the Expert Skippers' Panel probably helped reduce the perceived complexity of the bycatch reduction devices and techniques and increased fishers' confidence and competence in using them.
	Change Agent Factors	Effort Contacting Clients	The effort to contact skippers with high dolphin bycatch was through a personal invitation to meet individually with the Expert Skippers Panel. The NMFS extension group's use of radio and dockside visits increased the extent of effort in contacting clients.
		Client Orientation	The Expert Skippers' Panel personalized guidance to each individual. The troubleshooting and gear assistance the NMFS extension group offered fishers was client-oriented.
		Diffusion Program's Compatibility With Client's Needs	The Expert Skippers' Panel tailored its advice to address the specific problems of each individual. The NMFS extension group's activities, especially dock-side visits and gear assistance, directly addressed individual fishers' questions and needs.
		Empathy With Client	As tuna fishers themselves, the experts on the Panel were sensitive to their clients' needs and perceptions. The panel took the role of coach and encourager.
		Commonality With Clients	The experts on the Panel were active tuna fishers just like the clients.
		Credibility To Client	The experts on the Panel were successful, skillful, and well-respected fishers.
		Works Through Opinion Leaders	The experts on the Panel were successful, skillful, and well-respected fishers and thus were opinion leaders.
		Increasing Clients' Ability To Evaluate Innovations	The manuals produced by the Panel increased fishers' ability to evaluate innovations. The sea trials of the super apron conducted by the NMFS extension group increased fishers' ability to evaluate BRDs by allowing more fishers to experience the gear in action and see the gear's effectiveness when used skillfully.

Figure 20. Supporting evidence of principles of diffusion fulfilled by Expert Skippers' Panel and NMFS extension group extension efforts.

informative & persuasive efforts + enforcement + practical BRDs & techniques = adoption

Figure 21. Effective extension equation.

followed the law (Lewison *et al.*, 2003). Similarly, other scholars have found that the adoption decision is governed by the capital cost of the innovation, perceived savings, certainty of savings, dissatisfaction with the current circumstances, efforts and skills needed to install the innovation, attitude, and lifestyle compatibility (Darley and Beniger, 1981). The preceding examples are, in essence, the variables in a compliance equation. In authority innovation-decisions, incompatibilities with the preceding variables or perceived high cost of compliance can lead to inconsistent and improper adoption.

Potential adopters also based their adoption decisions on perceived advantages and compatibility (Acheson and Reidman, 1982; Vollink *et al.*, 2002). They weigh perceived risks, benefits, costs, and gains in current and anticipated future conditions when deciding to adopt an innovation (Levine and McCay, 1987). The decision to adopt is more complex than whether it is mandatory, so extension programmes must address all the concerns that significantly impact the adoption decision. Change agents should continue to address adopters' concerns after the initial adoption decision to help prevent discontinuance due to disenchantment (Rogers, 2003).

Whether voluntary or mandatory (authority innovation-decision), extension programmes should always involve persuasive efforts to ensure proper and prolonged adoption. Fishers who adopt under optional or collective innovation-decisions will have found the innovation meritorious for adoption. Thus, these fishermen will have made a personal adoption decision and will likely persist in that adoption choice if the merits of the BRD are maintained. Even if fishers adopt under an authority innovation-decision, they can still move to an optional or collective innovation-decision. This happened in the TED case. In later years, many shrimpers said they would continue to use TEDs without enforcement because of the trash excluded, the higher quality of shrimp, the less damage to nets, and the time saved sorting the catch (Tookes *et al.*, 2022).

Persuasive efforts were present in both successful adoption periods, indicating that this is a necessary but insufficient condition. The Voluntary Skipper training workshops persuaded adopters of the value of using the Medina panel regardless of regulations. Further, the Expert Skippers' Panel revealed that sharing authority with the regulated user group encouraged fishers to self-monitor and govern. This shared governance improved bycatch reduction practices and reduced dolphin mortality through positive peer pressure. Persuasive efforts in the TED case were insufficient because they were coupled with an impractical TED and the number of persuasive efforts was small compared to the fishery's size. Making persuasive efforts in large fisheries is resource-intensive because of the need for interpersonal communication. Thus, it is important to stimulate peer-to-peer sharing and diffusion in these instances, even if it means releasing some control of the messaging (Jenkins, 2010c).

Widespread, long-term, and proper adoption of BRDs occurred during extension periods that employed (albeit unintentionally) more principles of diffusion theory. Past fisheries and diffusion theory research has shown that for each innovation, a different assemblage of variables led to successful adoption (Dewees and Hawkes, 1988). This may explain why extension periods were more successful when they employed more principles of diffusion. They covered more bases and were more likely to include the critical variables for adopting the specific BRD.

Thus, extension programmes should strive to apply as many principles of diffusion theory as possible. They should promote the adoption of BRDs that display the five characteristics associated with successful adoption. The BRD should (1) be compatible with fishers' needs, (2) offer a relative advantage, (3) be able to be tried on a trial basis, (4) be observable while in use, and (5) not be complex (Rogers, 2003). Change agents should have as many as possible of the eight factors that affect the adoption rate of innovations. A successful change agent should (1) put great effort into contacting fishers, (2) be oriented to the fishers' needs, (3) apply an extension programme that is compatible with the client's needs (e.g. time, location, type of extension activity), (4) be empathic with the fishers, (5) share a lot in common with the fishers (e.g. life experience relevant to the social workings of the fishery), (6) be credible to the fishers (e.g. experience as a commercial fisher), (7) work extensively through opinion leaders, and (8) increase the fishers' ability to evaluate innovations (e.g. use of high-quality videos and on-board, hands-on demonstrations) (Rogers, 2003).

Principles that arose as particularly important in these case studies were trialability, observability, relative advantage, and change agent factors related to client-orientation and engagement. In keeping with a client-orientation, change agents should ask fishermen what they perceive as the relative advantages of a BRD rather than promoting a pre-determined list of benefits (Dewees and Hawkes, 1988). Notably, a relative advantage is associated with a commercially practical BRD. Trialability and observability support and amplify the impact of relative advantage by making this advantage more evident to potential adopters.

Trial periods offer fishers an opportunity to experiment with the BRD and ease concerns about potential negative impacts of the technology. One type of trial useful in these case studies was giving away free BRDs, but this can be prohibitively expensive. Another alternative that NMFS and Sea Grant employed was cooperative testing with fishers. This allowed fishermen to use the gear and have input into the development process. In the TED case, the novelty of this cooperative work spurred the involved fishers to share this experience with other fishers, diffusing information about the technology throughout the fishery. A third alternative is onboard demonstrations, in which change agents temporarily install the BRD on a fisherman's boat, showing the fisherman how it functions and its benefits.

Observability is also important for the diffusion of BRDs. Fishers want to know how a BRD works and how it might affect their fishing practices, but the ocean is not conducive to direct observation due to turbidity, turbulence, and depth. Repeatedly, in both case studies, fishers responded positively to visual presentations, especially videos, of data and gear designs. Despite their popularity, videos were underutilized and poorly produced, with the primary appeal being the novel visual information they offered. Future extension efforts should invest more in videos as an extension tool, maximizing the videos' appeal, educational value, and persuasive power.

Having a change agency and change agent with a substantial client focus rather than a problem or programme focus is a necessary condition for adoption. Often extension programmes, such as the TED voluntary use period and tuna-dolphin mandatory skipper training periods, focus on solving a bycatch problem or executing a bycatch reduction programme. This problem or programme focus guides activity choices based on what is best for the extension programme. But it is critical to remember and centre on the fact that the client's adoption decision will ultimately determine if the problem is solved or the programme is successful. This may mean that an extension activity that is best for the client may only be good or acceptable in terms of a programme or problem. This is a short-term trade-off for long-term gain. Diffusion theory, other research (Tookes *et al.*, 2022), and these case studies show that prioritizing clients' needs and having a client focus are more likely to ultimately lead to successful adoption (Rogers, 2003). Client-orientation is often facilitated and demonstrated by personal contact and follow-up with fishers, which also builds trust. However, fisheries extension agents need formal methods of extension and, preferably, commercial fishing experience to feel equipped to engage in interpersonal extension activities (Eayrs and Pol, 2019; Jenkins *et al*., 2022).

BRD extension programmes should incorporate extension efforts targeting the stages of the innovation-decision process, and the type of effort should be appropriately aligned with the stage. Extension efforts during the knowledge stage should leverage mass media (e.g. newsletters, fisheries association meetings, radio) to raise awareness. Interpersonal contact (e.g. conversations, dockside visits, and onboard demonstrations) is more critical during the persuasion stage.

Many BRD extension programmes do not have an explicit goal, but when they do, the focus is on the initial adoption decision (Jenkins *et al*., 2022). Adoption is a process, not an event, so continued contact is essential to inform proper use and confirm continued adoption. All the extension periods in these case studies had extension efforts focused on the proper installation and use of a BRD. Still, not all these efforts were timed correctly to occur during the implementation stage of the innovation-decision process. So, extension programmes should conduct implementation activities after persuasive efforts have led to a successful adoption decision.

Implementation is also the stage when reinvention can occur, increasing a sense of ownership and the innovation's compatibility with the client's needs (Rogers, 2003; Tookes *et al*., 2022). During the case studies, change agencies sometimes resisted or did not support reinvention. However, rather than resisting reinvention, change agencies should guide reinvention by setting reasonable parameters to maintain the core functions and performance of a BRD. Also, if resources allow, change agencies should actively support reinvention and base criteria for allocating support for reinvention on the innovation's promise, not the innovator's pedigree or credentials (Jenkins, 2007; Jenkins, 2010c).

Change agencies must be aware of the necessity for confirmation to perpetuate long-term BRD use. The only extension period where extension efforts aligned with confirmation was the voluntary skipper training workshops. The working groups and testimonials allowed for interpersonal communication that affirmed adopters' choices. Future BRD extension efforts should establish forums for adopters to share their experiences with BRDs and have their adoption choices confirmed.

Conclusion

This paper examines two of the most prominent and well-documented case studies of BRDs in the United States: the introduction of TEDs in the shrimp trawl fishery and dolphin bycatch reduction devices and techniques in the tuna purse seine fishery. The final period in the tuna-dolphin case yielded the most effective extension equation for achieving widespread adoption. While widespread adoption was also achieved during the voluntary skipper training workshop period, this adoption occurred under exceptional and not readily reproducible circumstances of public and political pressure. It also involved a BRD and bycatch reduction technique that substantially benefited the adopter. Also, these two successful extension periods notably applied all the core principles of diffusion theory.

To implement the effective extension equation, change agents should use a combination of informative and persuasive efforts to advance fishers through the innovation-decision process to the point of continued adoption. The change agents should maximize the eight factors positively related to success: effort contacting fishers; fisher orientation; extension programme compatibility with fishers' needs; empathy, credibility, and commonality with fishers; working through opinion leaders; and increasing fishers' ability to evaluate BRDs. The opinion leaders should be competent, accessible, conform to industry norms, and reflect the industry's attitude towards change. Regulations on using BRDs help achieve widespread adoption. They should be enforced, but extension efforts should encourage individual adoption decisions and be mindful of the compliance equation (i.e. risk versus reward of compliance). Bycatch reduction devices and techniques should be commercially practical and embody the characteristics of the innovation that are positively related to adoption: compatibility, relative advantage, trialability, observability, and simplicity.

The effective extension equation is a successful approach to achieving adoption, supported by empirically derived diffusion theory principles (Rogers, 2003). Many of these principles align with the strategies proposed by fisheries change agents and researchers striving to improve BRD adoption through early fisher engagement in creating, testing, and promoting BRDs and different ways of communicating (Hall *et al*., 2000; Hall and Mainprize, 2005; Jenkins, 2006; Hall *et al*., 2007; Johnson and van Densen, 2007; Campbell and Cornwell, 2008; Jenkins, 2010c; Steins *et al*., 2022; Tookes *et al*., 2022). Applying these principles is not a guarantee or recipe for successful adoption, and change agencies must address other factors such as emotion and sentiment when designing extension programmes (Jenkins, 2015; Eayrs and Pol, 2019). However, diffusion theory lays a solid foundation for beginning to create an extension programme that is primed for success.

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Supplementary material

The following supplementary material is available at *ICESJMS* online: (1) a bibliography of all documents analysed for the TED case; (2) a bibliography of all documents analysed for the tuna-dolphin case; and (3) additional supporting quotes for the findings.

Conflicts of interest

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Author contributions

Conceptualization, formal analysis, funding acquisition, investigation, methodology, project administration, resources, visualization, writing—the original draft; writing—review and editing; validation and data curation.

Data availability

The interview data underlying this article cannot be shared publicly due to protecting the privacy of individuals that participated in the study. Government documents underlying this article are in the public domain and may be available in the physical archives of the respective government agencies. The data will be shared on reasonable request of the corresponding author.

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