UNIVERSITÉ DU QUÉBEC À MONTRÉAL

LE RÔLE DES RÉSEAUX SOCIAUX DANS LA DIFFUSION D'INNOVATIONS PRÉVENTIVES COMPLEXES DANS LE CADRE D'UNE RECHERCHE PARTICIPATIVE POUR RÉDUIRE L'EXPOSITION AU MERCURE EN AMAZONIE

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RESUMÉ

Les approches écosystémiques à la santé humaine ont défini un nouveau paradigme de recherche-action basé sur la reconnaissance des interactions complexes entre la santé des populations humaines et les facteurs sociaux, environnementaux, économiques et politiques Ces approches se basent sur la recherche scientifique avec l'objectif de promouvoir l'action en développant des solutions intégrées visant à améliorer la santé des populations et la qualité des écosystèmes. Transdisciplinarité, équité entre les groupes sociaux, prise en considération du genre, participation communautaire, traduction des résultats de la recherche en politiques publiques sont parmi les principes, toujours en évolution, qui guident les projets qui s'appuient sur ces approches.

L'application de ces principes a suscité un questionnement sur les bases théoriques et méthodologiques sur lesquelles s'appuyer pour que les populations soient en mesure de s'approprier les connaissances générées au cours de la recherche. L'analyse des réseaux sociaux, en tant que paradigme et méthode, a été choisie pour répondre à ce questionnement. Il s'agit d'une perspective de recherche qui met en évidence la structure sociale à partir des liens qui existent entre les entités sociales.

Les recherches ont été réalisées dans le cadre d'un projet basé sur les approches écosystémiques de la santé, appelé Caruso. Les recherche menées entre 1994 et 2005 au sein de ce projet ont permis à des chercheurs et chercheuses brésiliens et canadiens de déboucher sur une compréhension nouvelle de la dynamique de la circulation du mercure dans les écosystèmes et des effets du mercure sur la santé humaine, ainsi que de mettre en place une série d'interventions participatives pour réduire l'exposition au mercure et améliorer la qualité de vie des populations riveraines.

L'objectif principal de la présente thèse est d'étudier les rôles des réseaux sociaux dans la circulation des informations et dans la mise en place de solutions participatives pour améliorer la santé humaine et la qualité de vie au niveau d'une communauté d'Amazonie brésilienne dont les habitants sont exposés au mercure en conséquence de l'utilisation traditionnelle des sols pour l'agriculture de subsistance. Cinq chapitres contribuent à atteindre cet objectif.

Le premier chapitre introduit l'analyse des réseaux sociaux en tant qu'outil et que paradigme innovateur pour étudier, évaluer et promouvoir la prise en compte du genre, de l'équité entre les groupes sociaux et de la participation communautaire au sein des recherches basées sur les approches écosystémiques.

Le deuxième chapitre met en évidence l'importance de prendre le genre en considération dans les recherches qui s'appuient sur les approches écosystémiques, afin de comprendre le rôle différencié des hommes et des femmes dans le développement de solutions participatives pour améliorer la santé humaine. Il présente une analyse du rôle de la communication interpersonnelle entre les hommes et les femmes de la communauté de Brasilia Legal au niveau des changements de comportement alimentaire pour diminuer l'exposition au mercure. Cette analyse s'appuie sur la théorie de la diffusion des innovations

et considère la consommation préférentielle des poissons les moins contaminés par le mercure comme une innovation préventive de santé. Les résultats montrent qu'une proportion élevée des habitants de la communauté a changé son comportement alimentaire, malgré que les caractéristiques de cette innovation ne soient pas favorables à son adoption. L'étude du réseau de discussion sur le mercure met en évidence l'importance de la discussion sur le mercure entre les hommes et les femmes, ainsi que le rôle des femmes leaders d'opinion au sein de la communauté et des épouses au sein des couples dans la promotion des changements alimentaires pour réduire l'exposition au mercure.

Le troisième chapitre met en évidence l'importance d'impliquer l'ensemble des acteurs locaux dans le développement de la recherche et propose une approche basée sur l'analyse des réseaux sociaux pour analyser l'équité entre les divers groupes sociaux en relation avec les processus participatifs. À partir d'une analyse de l'évolution de la participation de la communauté au long des différentes phases du projet Caruso, ce chapitre analyse les facteurs qui favorisent ou sont au contraire une barrière à l'implication des membres de la communauté de Brasilia Legal au sein du processus de recherche. La caractérisation de la participation des divers groupes sociaux au sein du réseau de discussion sur le mercure met en évidence une participation inégale en fonction de l'éducation, de la religion, du genre, du quartier et des activités de subsistance de la population du village. Les résultats de cette recherche permettent de proposer des stratégies participatives pour promouvoir l'équité de participation entre les villageois de Brasília Legal au sein du projet Caruso.

Le quatrième chapitre se tourne vers la question de la durabilité de la mobilisation communautaire lorsque le projet de recherche participative prend fin. Il analyse le potentiel de participation à long terme de la communauté de Brasilia Legal dans les discussions au sujet du mercure et de la santé en relation avec le développement de solutions adaptées à l'évolution des contextes environnementaux et sociaux. L'analyse de la structure et de la robustesse du réseau de discussion sur le mercure dans la communauté permet de mettre en évidence le potentiel de durabilité du processus de communication au sein de la communauté. Cependant, les résultats jettent aussi la lumière sur le rôle clé d'une seule personne qui a collaboré intensément avec les chercheurs et chercheuses dès le début du projet, ce qui laisse entrevoir un risque pour le futur au cas où cette personne viendrait à quitter le village ou à abandonner ses activités dans le domaine de la santé. Une approche en deux étapes, basée sur l'identification des personnes clé et sur l'analyse de la robustesse des réseaux d'échanges d'information, est proposée afin d'augmenter l'efficacité et la durabilité des projets participatifs de promotion de la santé.

Le cinquième chapitre se penche sur les relations entre l'organisation sociale et la disponibilité, l'accès et la mobilisation des ressources communautaires pour améliorer la qualité de vie. L'analyse de la structure sociale de la communauté de Brasilia Legal suite à l'intégration des relations formées de liens forts d'amitié, de travail et de parenté a permis de mettre en évidence une nouvelle structure de réseaux : un petit monde de liens forts. Il s'agit d'une structure qui n'avait jamais été révélée jusqu'à ce jour dans les réseaux construits en utilisant une seule dimension sociale, mais qui émerge quand plusieurs relations sociales sont prises en considération simultanément. Les propriétés structurelles et fonctionnelles de ce réseau permettent de mettre en évidence les mécanismes sociaux qui peuvent être associés à

la disponibilité, l'accès et la mobilisation d'une série de ressources communautaires qui sont partagées et mises à profit pour améliorer la qualité de vie des villageois. Trois exemples illustrent comment cette organisation sociale en réseau permet d'assurer la sécurité alimentaire en garantissant une ample distribution des ressources de pêche, de promouvoir la santé collective par le biais d'intenses échanges de plantes médicinales et de stimuler la diffusion des comportements alimentaires permettant de diminuer l'exposition au mercure. Cependant, d'autres exemples indiquent que cette structure sociale pourrait également être associée à une fermeture de la communauté sur elle même, limitant l'établissement de relations au delà de ses frontières et la privant ainsi de diverses ressources et opportunités.

Mots clés : Réseaux sociaux, Amazonie, approches écosystémiques à la santé humaine, mercure, participation sociale.

INTRODUCTION GÉNÉRALE

Les approches écosystémiques à la santé humaine ont défini un nouveau paradigme de recherche-action basé sur la reconnaissance des interactions complexes entre la santé des populations humaines et des facteurs sociaux, environnementaux, économiques et politiques (Forget et Lebel, 1999; Lebel, 2003; De Plaen et Kilelu, 2004). Ces approches se basent sur la recherche scientifique avec l'objectif de promouvoir l'action en développant des solutions intégrées visant à améliorer la santé des populations et la qualité des écosystèmes. Transdisciplinarité, équité entre les groupes sociaux, prise en considération du genre, participation communautaire, traduction des résultats de la recherche en politiques publiques sont parmi les principes, toujours en évolution, qui guident les projets qui s'appuient sur ces approches.

L'application de ces principes a suscité un questionnement sur les bases théoriques et méthodologiques sur lesquelles s'appuyer pour que les populations soient en mesure de s'approprier les connaissances générées au cours de la recherche. Les modèles linéaires de communication où les résultats des recherches sont transmis aux populations locales doivent être repensés pour permettre un dialogue entre scientifiques et communautés qui, ensemble, vont définir les priorités de recherches, développer les études et mettre en place des solutions. En effet, l'approche participative permet de remplacer le flux d'information directionnel entre les donneurs (chercheurs, agents d'intervention) et les receveurs (populations locales) par la construction d'un savoir collectif où les deux groupes apprennent simultanément (Bordenave, 1976; Freire, 1971). Selon le modèle de communication par convergence proposé par Rogers et Kincaid (1981), la communication est un échange continu impliquant simultanément les différents partenaires engagés dans le processus avec l'objectif de se comprendre réciproquement, de progresser dans les connaissances et de déboucher sur des actions concrètes. Dans le cadre de la recherche participative, ce sont les chercheurs et chercheuses et les populations qui sont impliqués dans le processus de communication.

La participation des communautés a également pour objectif la construction de solutions adaptées aux réalités locales et qui aient le potentiel d'évoluer dans une perspective à long terme qui dépasse amplement la durée du projet de recherche. Pour permettre la

construction collective de connaissances et garantir la continuité et l'adaptation des solutions mises en œuvre durant le projet de recherche, les membres des communautés dialoguent, échangent des informations, négocient, collaborent. Ce sont ces interactions sociales entre les membres d'une communauté impliquée dans un projet basé sur l'approche écosystémique qui constitue le cœur des recherches de la présente thèse. L'approche méthodologique choisie est l'analyse des réseaux sociaux qui est une perspective de recherche qui met en évidence la structure sociale à partir des liens qui existent entre les entités sociales (Moreno, 1960; Scott, 2000; Wasserman et Faust, 1994).

Un réseau est composé d'un ensemble d'entités, appelée nœuds, connectées par un ensemble de relations, appelées liens. Un réseau social est un ensemble d'entités sociales (individu, groupe, communauté, etc.) connectées entre elles par un ensemble de relations sociales (amitié, parenté, travail, discussion, collaboration, etc.). L'analyse des réseaux sociaux met en rapport le comportement des entités sociales et les caractéristiques et la configuration de la structure des relations sociales (Wasserman et Faust, 1994; Saint-Charles et Mongeau, 2005, Scott, 2000). Elle se base sur l'étude de deux types de variables. Les variables de composition sont définies au niveau de l'entité sociale comme le genre, l'âge, le travail d'un individu ou la taille, la religion, la localisation géographique d'une communauté. Les variables relationnelles sont définies au niveau d'une paire d'entités sociales et caractérisent le type de relation entre celles-ci. L'amitié (Fararo et Sunshine, 1964), les collaborations scientifiques (Newman, 2001), les relations sexuelles (Bearman, Moody et Stovel, 2002; Liljeros, Edling, Amaral, Stanley et Aberg, 2001), la communication par courriel (Ebel, Mielsch et Bornholdt, 2002), les conseils dans les organisations (Saint-Charles et Mongeau, 2005) et les relations entre collègues (Bernard, Kilworth, Evans, McCarty et Selley, 1988; Csányi et Szendroi, 2003) sont parmi les relations sociales qui ont été étudiées du point de vue de l'analyse des réseaux sociaux.

De nombreuses recherches ont montré que la structure des réseaux sociaux influence les processus de communication, les actions individuelles et collectives et la diffusion de nouvelles pratiques au sein des groupes et des communautés (Boulay et Valente, 1999; Coleman, Katz et Mengel, 1966; Granovetter, 1973; Granovetter, 1978; Kincaid, 2000; Rogers et Kincaid, 1981; Rogers, 1995; Saint-Charles et Mongeau, 2009; Valente, 1995;

Valente et al., 1997; Watts, 2003). D'autres recherches ont également montré que l'analyse de réseaux peut être mise à profit pour comprendre comment rejoindre les individus qui sont les plus isolés au sein des communautés (Boulay et Valente, 1999; Kincaid, 2004; Rogers, 1995; Saint-Charles et Mongeau, 2005; Valente, 1995), ainsi que pour favoriser les interventions en santé dans la mesure où elle permet d'identifier et d'impliquer certains individus ou groupes sociaux, capable d'agir comme multiplicateurs, pour promouvoir la diffusion des informations et des pratiques (Ball et al., 1998; Bond et al., 1999; Kegler et al. 2003; Rogers, 1995; Valente et Saba, 1998; Valente et Davis, 1999).

Au sein de la présente thèse, nous utiliserons l'analyse des réseaux sociaux, en tant que paradigme et méthode, pour étudier les rôles différenciés des hommes et des femmes, l'équité entre les groupes sociaux, la participation à long terme des populations et l'organisation communautaire dans les échanges d'information et la mise en place de solutions pour améliorer la santé humaine au sein d'un projet basé sur les approches écosystémiques de la santé, appelé Caruso.

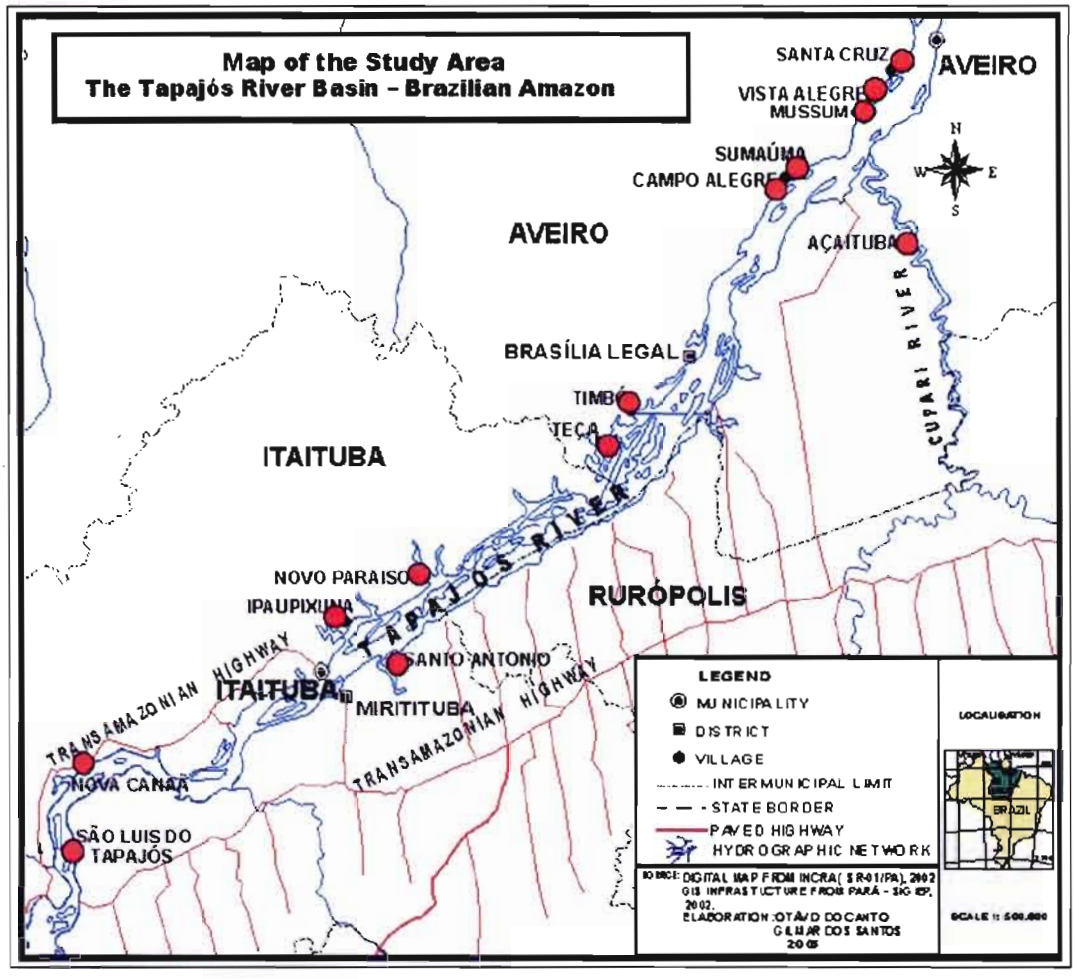
1. Le projet Caruso

À partir de 1994, dans le cadre du projet Caruso, des chercheurs et chercheuses brésiliens et canadiens ont formé une équipe interdisciplinaire pour étudier la question du mercure, dans la région de la rivière Tapajós, en Amazonie brésilienne (voir figure 1.1).

L'utilisation d'une approche écosystémique de la santé a permis à ces études de déboucher sur une compréhension nouvelle de la dynamique de la circulation du mercure dans les écosystèmes et des effets du mercure sur la santé humaine, ainsi que de mettre en place une série d'interventions participatives pour réduire l'exposition au mercure et améliorer la qualité de vie des populations riveraines. Les études, qui se sont déroulées entre 1994 et 2005 peuvent être présentées en trois sections qui se chevauchent chronologiquement. La première section, fruit des recherches réalisées au long des 11 années du projet, présente les principales découvertes scientifiques qui ont permis de mettre en évidence les sources de contamination par le mercure, l'accumulation du polluant dans la chaîne trophique et les effets de l'exposition sur la santé des populations riveraines. La

deuxième section expose brièvement les résultats de l'intervention participative qui a été menée, entre 1998 et 2001, au niveau local dans le but de diminuer l'exposition humaine de la communauté de Brasília Legal. La troisième section présente la phase de régionalisation du projet où diverses communautés du Tapajós ont été impliquées et qui a été réalisée à partir de l'année 2002.

Figure 1.1. Carte de la région d'étude



Les cercles rouges indiquent les communautés où les recherches du projet Caruso ont été réalisées.

1.1. Section 1 : Les découvertes scientifiques (1994-2005)

1.1.1. Une nouvelle source de contamination par le mercure : l'érosion des sols

Les principaux sites d'orpaillages, où le mercure est utilisé pour séparer l'or des sédiments, dans la région du Bas-Tapajós se situent en amont de la ville d'Itaitúba (voir Figure 1.1.). Dans le but de mettre en évidence l'impact des activités minières artisanales sur la contamination de la rivière Tapajós par le mercure, des échantillons d'eau, de sédiment et de sol ont été collectés près des sites d'orpaillages et à intervalles réguliers, en aval, jusqu'à une distance de plusieurs centaines de kilomètres. Les résultats ont montré que les niveaux de mercure étaient relativement constants tout au long de la rivière, ce qui suggère l'existence d'une autre source majeure de contamination par le mercure, indépendante des activités minières (Roulet et al, 1998a).

L'analyse des sédiments du lit de la rivière a permis de mettre en évidence que les couches les plus récentes contenaient jusqu'à trois fois plus de mercure que les couches déposées il y a plus de 40 ans, même à une distance de 400 km des régions d'orpaillage (Roulet et al, 1998a). De plus, l'analyse des profils de sols sur les berges de la rivière a révélé l'existence de concentrations relativement élevées de mercure jusqu'à 1 mètre de profondeur. Ces découvertes ont conduit à la conclusion que l'érosion des sols, suite à la déforestation, est responsable du transfert de mercure vers les écosystèmes aquatiques du Tapajós (Farella et al, 2001; Roulet et al, 1998a, 1998b, 1999, 2000a, 2000b, 2001a, 2001b).

1.1.2. L'entrée et l'accumulation du mercure dans la chaîne alimentaire aquatique

D'autres études ont montré que les conditions climatiques et l'abondance de sites naturels comme les plaines d'inondation et les prairies flottantes à macrophytes dans la région du Tapajós créent des conditions favorables au processus de méthylation du mercure et accélèrent son entrée dans la chaîne alimentaire (Guimarães et al, 2000a, 2000b). Les analyses des concentrations de mercure dans les espèces de poissons les plus couramment pêchées par les populations riveraines du Tapajós ont mis en évidence l'accumulation du

polluant dans la chaîne alimentaire (Lebel et al, 1997; Sampaio da Silva et al, 2005). En effet, les concentrations augmentent progressivement des poissons herbivores aux poissons omnivores, puis carnivores, étant, en général, maximales pour les individus des espèces carnivores âgés et de grande taille (Lebel et al., 1997; Sampaio da Silva et al., 2005).

1.1.3. L'alimentation, l'exposition au mercure et les effets sur la santé humaine

Une étude détaillée sur le régime alimentaire de la population de plusieurs villages de pêcheurs installés sur les rives du Tapajós a permis d'établir une étroite relation entre la consommation de poissons et les niveaux de mercure mesurés dans les cheveux (Lebel et al., 1997; Dolbec et al., 2001). Des études longitudinales ont mis en évidence une variation sinusoïdale des concentrations de mercure dans les cheveux en fonction du temps. Elle est à mettre en parallèle avec les variations de la consommation de poissons, entre les saisons sèches et humides qui elles mêmes reflètent l'évolution temporelle et cyclique de la disponibilité de poisson en fonction des caractéristiques des cycles de vie de chaque espèce (Lebel et al., 1997; Sampaio da Silva et al., 2005; Dolbec et al., 2001). Dans l'étude réalisée dans la région de Brasília Legal, les poissons carnivores sont prédominants dans l'alimentation des habitants durant la saison des pluies, période de l'année durant laquelle les concentrations en mercure mesurées dans les cheveux sont maximales (Lebel et al., 1997).

Une enquête alimentaire, menée avec les femmes du village de Brasília Legal sur un an, a permis de mettre en évidence que les villageois ont accès à une grande variété d'aliments, provenant aussi bien de la rivière, des potagers que de la forêt (Passos et al., 2003a). La composition du régime varie en fonction des saisons, reflétant la disponibilité des aliments. Les personnes qui ont accès au poulet et à la viande ont des niveaux plus bas de mercure. De plus, pour une même consommation de poissons, l'ingestion de fruits est associée à une diminution des concentrations de mercure dans les cheveux des villageois de Brasília Legal (Passos et al., 2003b, Passos et al., 2007).

En parallèle avec les mesures des niveaux de mercure, des tests neurocomportementaux ont été appliqués pour évaluer l'impact de l'exposition sur la santé. Les résultats ont montré une forte relation entre l'exposition au mercure et un déficit au

niveau de la coordination motrice et de certaines fonctions visuelles, à des niveaux d'exposition nettement en dessous du seuil qui était considéré critique pour l'apparition d'effets sur la santé humaine (Lebel et al., 1998; Dolbec et al., 2000; Mergler et Lebel, 2001). De plus, les niveaux de mercure dans les cheveux des villageois sont associés à l'existence de troubles cellulaires (Amorim et al., 2000) et cardiovasculaires (Fillion et al., 2006). Ces résultats démontrent qu'une exposition au méthylmercure à faible dose, mais chronique, a un impact significatif sur la santé et le bien-être des populations riveraines du Tapajós (Mergler et al., 2007; Passos et Mergler, 2008).

1.2. Section 2 : Recherche et intervention participatives à l'échelle locale: Brasília Legal (1998 – 2001)

Les résultats scientifiques ont permis de mettre sur pied une stratégie d'intervention basée sur les habitudes alimentaires afin de contrôler l'exposition au mercure tout en garantissant une alimentation équilibrée et sur les pratiques de pêche afin que les poissons dont les niveaux de mercure sont les plus bas soient préférentiellement disponibles pour la consommation des populations riveraines. Ces stratégies ont été appliquées au niveau local dans la région du village de Brasília Legal.

La stratégie d'intervention participative s'est appuyée sur l'analyse des représentations sociales de la population et sur les intérêts et les connaissances spécifiques de certains groupes clés pour construire de nouveaux savoirs issus de la collaboration entre les chercheurs et la communauté : l'alimentation auprès du groupe des mères de famille, la pêche auprès du groupe des pêcheurs professionnels, ainsi que la santé auprès du groupe formé par les sages femmes et l'infirmière. Les pêcheurs ont participé à l'élaboration d'affiches qui permettent de distinguer les espèces de poissons sur base de leur niveau de mercure grâce à un jeu de couleur et qui ont été distribuées dans chaque maison : poissons rouges: haut niveau; oranges: niveau moyen; verts: bas niveau de mercure. Un message positif a été proposé afin de stimuler la consommation de poissons herbivores qui sont les moins contaminés : « mangez plus de poisson qui ne mangent pas les autres poissons ».

L'intervention participative menée à Brasília Legal a permis de réduire considérablement les niveaux de mercure chez les habitants du village, tout en maintenant la consommation de cet aliment riche en nutriments (Mergler et al., 2001). La comparaison du régime alimentaire et de l'exposition au mercure auprès d'un groupe de 43 personnes, en 1995 et 2000, a montré qu'elles continuaient à manger les mêmes quantités de poissons, mais que la proportion des poissons non carnivores consommés avait augmenté, avec pour conséquence, une diminution de 35% des niveaux de mercure dans les cheveux.

La réduction de l'exposition au mercure à Brasília Legal est la conséquence de changements survenus à différents niveaux au sein de la communauté: sélection différentielle des poissons pour la consommation locale et pour la vente par les pêcheurs et choix des poissons les moins contaminés pour l'alimentation de la famille par les femmes.

1.3. Section 3 : Recherche et intervention participatives à l'échelle régionale : l'ensemble des communautés riveraines du Bas-Tapajós (2002 – 2005)

Le succès des recherches menées entre 1994 et 2001, tant au niveau scientifique qu'au niveau social, a conduit à l'élaboration et au financement d'une nouvelle phase du projet Caruso dont l'objectif principal est d'étendre au niveau régional les processus de recherche participative et d'intervention. L'objectif principal de cette phase est de réduire l'exposition au mercure et les sources de contamination, au niveau d'une quinzaine de villages échelonnés sur 200 km le long de rives du Tapajós entre les villages de São Luís do Tapajós et de Aveiro, en s'appuyant à la fois sur les résultats des recherches qui ont été menées dans la région de Brasília Legal et sur de nouvelles études mettant en évidence la diversité des écosystèmes et des communautés au long de la rivière.

À partir de 2002, il était prévu que soient réalisées une série d'études à l'échelle régionale, articulées autour de cinq axes de recherche participative portant respectivement: 1) sur le cycle du mercure dans les écosystèmes aquatiques et les pratiques de pêches, 2) sur les régimes alimentaires, l'exposition au mercure et la santé, 3) sur les modes de vie et l'utilisation du territoire, 4) sur les représentations sociales, 5) le rôle des réseaux sociaux dans le contexte de la recherche participative.

Le volet basé sur l'analyse des réseaux sociaux a été introduite pour répondre à diverses questions soulevées au cours des recherches menées entre 1994 et 2001. Les hommes et les femmes des communautés jouent-ils des rôles différenciés au sein du processus de recherche participatif et de la mise en place de solutions pour diminuer l'exposition au mercure? L'ensemble des groupes sociaux sont-ils impliqués de forme au sein de ces processus? Quelles sont les perspectives de durabilité des solutions mises en place en fonction de l'évolution des contextes sociaux et environnementaux qui touche la région?

Dans la mesure où l'analyse des réseaux sociaux constituait une thématique nouvelle qui n'avait pas été abordée au cours des phases antérieures du projet Caruso, les recherches du volet 5 de la phase III, qui font l'objet de la présente thèse, n'ont pas été menées à l'échelle régionale. Une étude approfondie au niveau local s'est montré être essentielle avant qu'il ne soit possible d'analyser le rôle des réseaux sociaux à l'échelle régionale. Les recherches menées dans le cadre du volet 5 ont donc été menées au niveau de la communauté de Brasilia Legal (Figure 1.1). Elles ont permis une compréhension approfondie des interactions sociales associées au processus participatif au niveau communautaire et s'intègrent aux études réalisées à l'échelle locale. Elles ont été aussi le point de départ de la mise sur pied diverses recherches qui sont en cours et incluent la problématique des réseaux sociaux à l'échelle régionale (PLUPH - Poor land use and poor health: primary prevention of human health through sound land-use for small-scale farmers of the humid tropics, 2007-2011 : Projet de recherche financé par le Programme de partenariat Teasdale-Corti de recherche en santé mondiale).

2. Objectif principal

L'objectif principal de la présente thèse est d'étudier les rôles des réseaux sociaux dans la circulation des informations et dans la mise en place de solutions participatives pour améliorer la santé humaine et la qualité de vie au niveau d'une communauté d'Amazonie brésilienne dont les habitants sont exposés au mercure en conséquence de l'utilisation traditionnelle des sols pour l'agriculture de subsistance. Cinq chapitres contribuent à atteindre cet objectif. Le premier chapitre introduit l'application de l'analyse des réseaux sociaux au sein des recherches basées sur les approches écosystémiques, tandis que les chapitres 2 à 5

abordent l'étude, l'évaluation et la promotion de 1. la prise en compte des rôles différenciés des hommes et des femmes, 2. l'équité entre les groupes sociaux, 3. la participation communautaire à long terme et 4. l'organisation communautaire, en relation avec la circulation des informations et le développement des solutions pour diminuer l'exposition au mercure au sein du projet Caruso

3. Description des chapitres

Les cinq chapitres de la thèse sont présentés sous la forme d'article.

Chapitre 1

Le premier chapitre introduit l'analyse des réseaux sociaux en tant qu'outil et que paradigme innovateur pour étudier, évaluer et promouvoir la prise en compte du genre, de l'équité entre les groupes sociaux et de la participation communautaire au sein des recherches basées sur les approches écosystémiques. La présentation de l'approche est illustrée par certains des résultats qui seront approfondis dans les chapitres 2 à 5. Le réseaux de discussion sur le mercure entre les villageois de la communauté de Brasilia Legal, construit à partir de données recueillies auprès de 158 personnes en 2001, est utilisé pour mettre en évidence les rôles différenciés des hommes et des femmes dans l'adoption des nouveaux comportements basés sur le choix des poissons les moins contaminés par le mercure afin de diminuer l'exposition au contaminant. Ce même réseau est utilisé pour caractériser l'équité de participation entre les groupes sociaux de la communauté, en identifiant les facteurs qui favorisent ou sont une barrière à leur implication dans les discussions sur le mercure. La comparaison des réseaux de discussion sur le mercure de deux autres communautés riveraines du Tapajós, Mussum et Açaituba, a permis de mettre en évidence l'importance d'une participation qui implique la majorité de villageois, pour promouvoir les solutions pour diminuer l'exposition au mercure.

Chapitre 2

Le deuxième chapitre met en évidence l'importance de prendre le genre en considération dans les recherches qui s'appuient sur les approches écosystémiques, afin de

comprendre le rôle différencié des hommes et des femmes dans le développement de solutions participatives pour améliorer la santé humaine. Il présente une analyse du rôle de la communication interpersonnelle entre les hommes et les femmes de la communauté de Brasilia Legal au niveau des changements de comportement alimentaire pour diminuer l'exposition au mercure. Cette analyse s'appuie sur la théorie de la diffusion des innovations et considère la consommation préférentielle des poissons les moins contaminés par le mercure comme une innovation préventive de santé. Les résultats montrent qu'une proportion élevée des habitants de la communauté a changé son comportement alimentaire, malgré que les caractéristiques de cette innovation ne soient pas favorables à son adoption. L'étude du réseau de discussion sur le mercure met en évidence l'importance de la discussion sur le mercure entre les hommes et les femmes, ainsi que le rôle des femmes leaders d'opinion au sein de la communauté et des épouses au sein des couples dans la promotion des changements alimentaires pour réduire l'exposition au mercure.

Chapitre 3

Le troisième chapitre met en évidence l'importance d'impliquer l'ensemble des acteurs locaux dans le développement de la recherche et propose une approche basée sur l'analyse des réseaux sociaux pour analyser l'équité entre les divers groupes sociaux en relation avec les processus participatifs. À partir d'une analyse de l'évolution de la participation de la communauté au long des différentes phases du projet Caruso, ce chapitre analyse les facteurs qui favorisent ou sont au contraire une barrière à l'implication des membres de la communauté de Brasilia Legal au sein du processus de recherche. La caractérisation de la participation des divers groupes sociaux au sein du réseau de discussion sur le mercure met en évidence une participation inégale en fonction de l'éducation, de la religion, du genre, du quartier et des activités de subsistance de la population du village. Les résultats de cette recherche permettent de proposer des stratégies participatives pour promouvoir l'équité de participation entre les villageois de Brasília Legal au sein du projet Caruso.

Chapitre 4

Le quatrième chapitre se tourne vers la question de la durabilité de la mobilisation communautaire lorsque le projet de recherche participative prend fin. Il analyse le potentiel de participation à long terme de la communauté de Brasilia Legal dans les discussions au sujet du mercure et de la santé en relation avec le développement de solutions adaptées à l'évolution des contextes environnementaux et sociaux. L'analyse de la structure et de la robustesse du réseau de discussion sur le mercure dans la communauté permet de mettre en évidence le potentiel de durabilité du processus de communication au sein de la communauté. Cependant, les résultats jettent aussi la lumière sur le rôle clé d'une seule personne qui a collaboré intensément avec les chercheurs et chercheuses dès le début du projet, ce qui laisse entrevoir un risque pour le futur au cas où cette personne viendrait à quitter le village ou à abandonner ses activités dans le domaine de la santé. Une approche en deux étapes, basée sur l'identification des personnes clé et sur l'analyse de la robustesse des réseaux d'échanges d'information, est proposée afin d'augmenter l'efficacité et la durabilité des projets participatifs de promotion de la santé.

Chapitre 5

Le cinquième chapitre se penche sur les relations entre l'organisation sociale et la disponibilité, l'accès et la mobilisation des ressources communautaires pour améliorer la qualité de vie. L'analyse de la structure sociale de la communauté de Brasilia Legal suite à l'intégration des relations formées de liens forts d'amitié, de travail et de parenté a permis de mettre en évidence une nouvelle structure de réseaux : un petit monde de liens forts. Il s'agit d'une structure qui n'avait jamais été révélée jusqu'à ce jour dans les réseaux construits en utilisant une seule dimension sociale, mais qui émerge quand plusieurs relations sociales sont prises en considération simultanément. Les propriétés structurelles et fonctionnelles de ce réseau permettent de mettre en évidence les mécanismes sociaux qui peuvent être associés à la disponibilité, l'accès et la mobilisation d'une série de ressources communautaires qui sont partagées et mises à profit pour améliorer la qualité de vie des villageois. Trois exemples illustrent comment cette organisation sociale en réseau permet d'assurer la sécurité alimentaire en garantissant une ample distribution des ressources de pêche, de promouvoir la

santé collective par le biais d'intenses échanges de plantes médicinales et de stimuler la diffusion des comportements alimentaires permettant de diminuer l'exposition au mercure. Cependant, d'autres exemples indiquent que cette structure sociale pourrait également être associée à une fermeture de la communauté sur elle même, limitant l'établissement de relations au delà de ses frontières et la privant ainsi de diverses ressources et opportunités.

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CHAPITRE 1

COMMUNITY NETWORK ANALYSIS FOR ADDRESSING GENDER, EQUITY AND PARTICIPATION IN ECOHEALTH RESEARCH

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Abstract

Transdisciplinarity, gender analysis, social equity and participation are the methodological pillars of the Ecohealth approach, whose main goal is to improve human health and well-being while simultaneously maintaining a healthy ecosystem. In the present study, social network analysis is presented as an innovative tool to address gender, equity and community participation in Ecohealth research, by drawing upon experiences and results from the Caruso project which studies environmental dynamics and health effects of mercury in the Brazilian Amazon with the objective to reduce mercury exposure. As a participatory research tool, social network analysis is used to analyse the relationships between community action to reduce mercury exposure and 1. the distinctive roles of men and women; 2. the involvement of the different social groups and 3. the patterns of community participation. As a participatory development tool, social network analysis can contribute to the promotion of gender and social equity as well as local participation.

Introduction

The main goal of the Ecohealth approach, is to improve human health and well-being while simultaneously maintaining a healthy ecosystem (Forget & Lebel, 2001; De Plaen & Kilelu, 2004). Transdisciplinarity, gender analysis, social equity and participation are the essential methodological pillars of the approach which focuses on the analysis of the complex relationships between environmental, economic, social and cultural factors and human health (Lebel, 2003).

Gender analysis involves taking into account that men and women's particular tasks and responsibilities are associated to differences in their utilization of environment resources, with respect to risk exposure and in their respective role in the community. Equity acknowledges the importance of working with the various social groups to ensure the sharing of the development outcomes between the different community members. Participation of the communities in the research process is essential to ensure the local ownership of the research

results and to make the communities responsible for the building of solutions that are adapted to socio-cultural contexts, meet population needs and are effective on the long-term.

In the present article, social network analysis (Wasserman & Faust, 1994) is presented as an innovative tool to address gender, equity and participation in transdisciplinary Ecohealth research, by drawing upon experiences and results from the Caruso project whose main objective is to study the environmental dynamics and the health effects of mercury in the Brazilian Amazon and to build solutions with the communities to reduce mercury exposure.

Social network analysis and transdisciplinarity in the Caruso project

Results from the first phase of the Caruso project (1994-1997) showed that deforestation resulting from "slash-and-burn" agricultural practices leads to widespread mercury contamination of aquatic ecosystems, affecting the health of a large number of fish-eating communities in the Tapajos region, Brazilian Amazon (Lebel et al., 1998; Lucotte et al., 2004; Roulet et al., 1999). In the second phase of the study (1998-2001) participatory actions, carried out in the Brasilia Legal community, have been successful in reducing human exposure and improve well being by promoting diet behaviour change toward the consumption of fish species which have low mercury levels (Lebel et al., 1997; Mergler et al., 2001). These results have been achieved though transdisciplinary research involving communities, decision-makers and specialists in the fields of biogeochemistry, aquatic ecology, toxicology, agriculture, human health, nutrition, anthropology and communication. In the third phase of the project (2002-2005), participatory research activities were scaled up to the regional level and included a new approach, social network analysis, which studies the relationships between the pattern of social interactions between people and individual behaviour (Wasserman & Faust, 1994).

The network approach allowed us to map discussion networks about mercury issues of several communities in order to answer key questions regarding gender, equity and participation in the Caruso project. How is diet behaviour change to reduce mercury exposure

affected by communication within and across gender? Is there equity in involvement of the different social groups regarding mercury issues? What are the relationships between the patterns of participation in the discussion networks and community action to reduce mercury exposure?

Material and methods

The study was carried out in three communities, situated on the banks of the Tapajos River, a major tributary of the Amazon River, Brazil. The Brasilia Legal community has been involved in the Caruso project since 1994, while Mussum and Açaituba communities were involved much more recently, in 2003. A map of the study region is available on the CARUSO project web site: http://www.unites.uqam.ca/gmf/caruso/caruso.htm. Data were collected in 2001 (Brasilia Legal) and 2005 (Mussum and Açaituba), using semi-structured face-to-face interviews which covered standard demographic characteristics, adoption of new diet behaviour to reduce mercury exposure and network questions. Strategy to maximize de size of our sample in Brasilia Legal (n=158) is presented in Mertens et al, 2005. All the villagers more than 14 years old present at the time of field trip were interviewed in the Mussum (n=130) and Açaituba (n=63) communities.

Interpersonal communication regarding the mercury issues was assessed by asking the respondents to name the individuals with whom they usually discuss about mercury issues. Network data were stored as an actor-by-actor matrix using the UCINET software (Borgatti et al., 2002) and then exported to the Netdraw software (Borgatti, 2002) to visualize the structure of the discussion networks.

Adoption of new diet behaviour was measured as a dichotomous variable as whether the respondent said that he/she has modified his/her fish consumption toward fish species which have low mercury levels with the objective to reduce mercury exposure and was able to explain how this change has been achieved.

Results

Gender: the role of men and women in mercury discussion networks

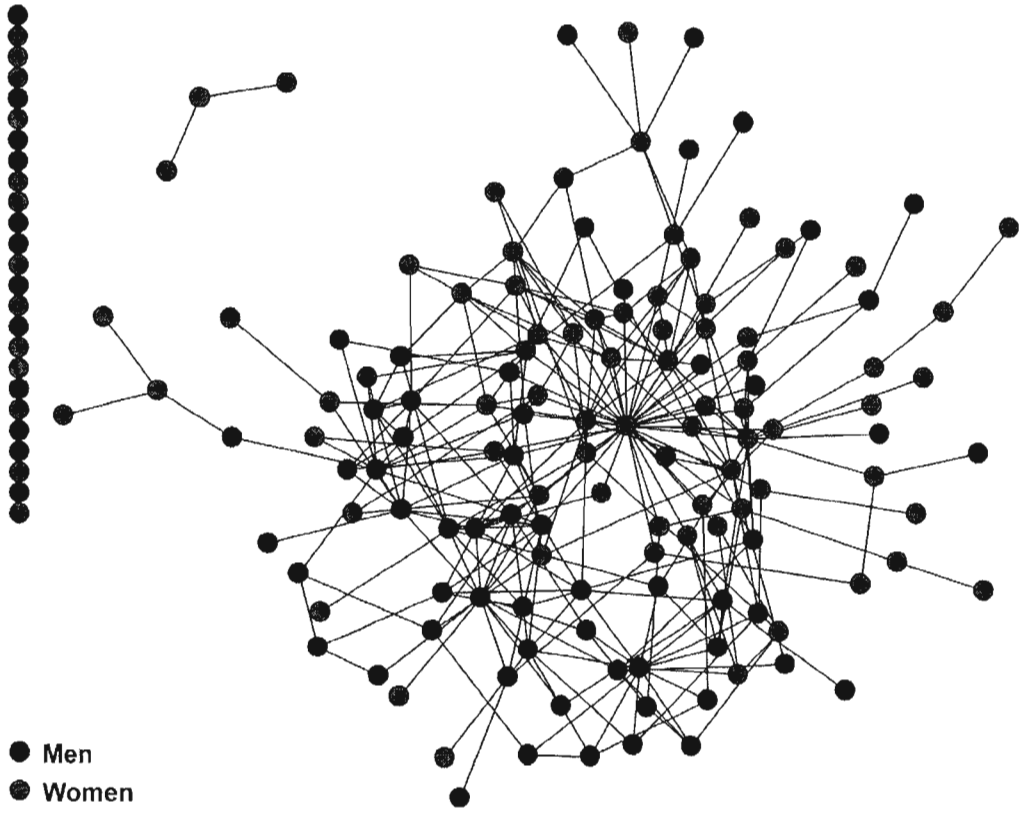
Figure 1 presents the distribution of men and women in the discussion network about mercury in the Brasília Legal village. Two individuals are considered as discussion partners and connected by a line if one or both reported discussing with the other about mercury issues. We used a series of logistic regression models to inquire about relationships between the number of men and/or women an individual is discussing mercury issues with and whether or not this individual has adopted new diet behaviour to reduce mercury exposure. The percentage of individuals who adopted new fish diet was not significantly different between men (54%) and women (58%). Although most of the discussion about mercury occurs within same gender groups - respectively 76% of the men and 81% of the women discuss mercury issues with same sex members – discussion across gender was identified as key to promote the adoption of new diet behaviours. At the community level, preferential consumption of less-contaminated fish was associated, for both men and women, with the discussion with other women, but not with other men. At the household level, men who considered their wife as a discussion partner were much more likely to change their behaviour than those who did not.

Equity: the involvement of social groups in mercury discussion networks

Equity in the involvement regarding mercury issues was addressed by performing a disaggregated analysis of the discussion patterns between the various social groups in the Brasilia Legal community (Mertens et al., 2005). Figure 2 illustrates how social groups can be differentiated in the mercury discussion network, using, as an example, subsistence activities to characterize the villagers. By calculating the mean number of discussion partners of social groups differentiated according to age, religious affiliation, education, socio-economical status and subsistence activities, we have been able to map the social factors that

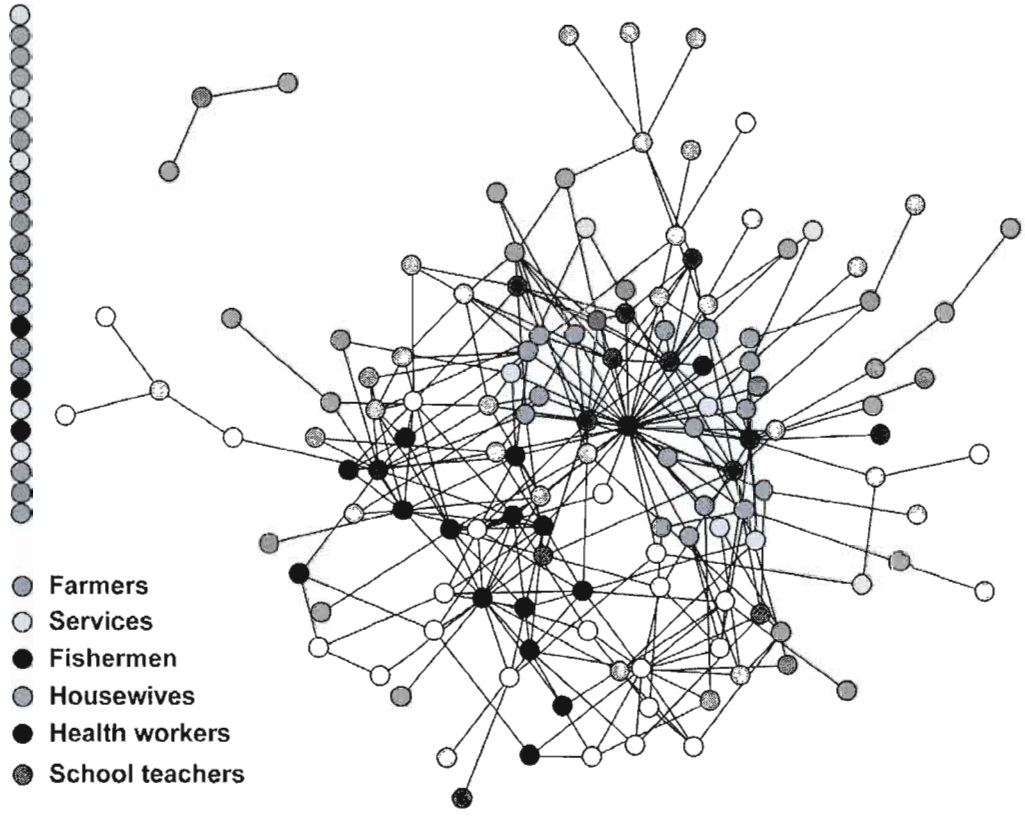
may facilitate or act as barrier to the involvement of the various social groups in discussions about mercury. Results are summarized in table 1.

Figure 1



Gender is used to differentiate between the villagers in the mercury discussion network from the Brasília Legal community. The network is composed of one main component of 130 individuals, one small component of three individuals and 25 isolates.

Figure 2



Subsistence activities are used to differentiate between the villagers in the mercury discussion network from the Brasília Legal community. The network is composed of one main component of 130 individuals, one small component of three individuals and 25 isolates.

Participation: community involvement patterns in mercury discussion networks

A higher level of adoption of new diet behaviour is observed in the Açaituba (29%) compared to the Mussum (20%) community. To inquire into a possible relationship between adoption level and community participation patterns in the discussions about mercury issues, we compared the networks of the two communities based on four structural properties.

Table 1

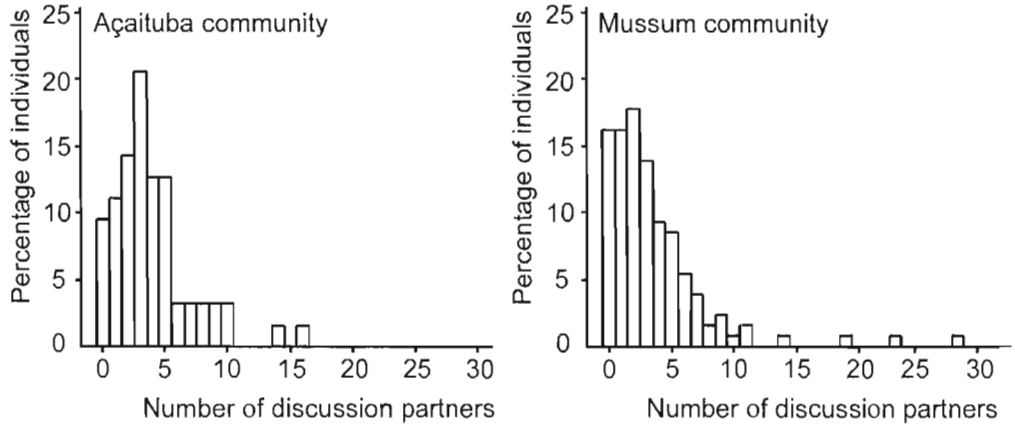
	Participation in the mercury discussion network	
Social factors used to differentiate between the villagers	High	Low
Age	31-50 years old	14-30 and 51-88 years old
Religious affiliation	Catholics	Evangelical or none
Education	More than 8 years of schooling, only for women	
Socio-economical status	No difference between groups	No difference between groups
Subsistence activities	Health workers, fishermen, school teachers	Farmers, housewives

Three of these properties exhibit similar characteristics in the discussion networks of the two communities. The mean number of discussion partners, which reveal the average level of participation in the communication process, is similar in the discussion networks of Açaituba (3.9) and Mussum (3,5). The degree of fragmentation of the network which is associated with the existence of distinct disconnected subgroups, follows the same pattern in the two communities, the majority of the respondents belonging to one main and relatively dense component comprising 87 and 84% of the individuals for Açaituba and Mussum, respectively. The mean distance between individuals (Wasserman & Faust, 1994), that is especially relevant for assessing the ability of people to communicate with each other, is similar in the main component of the discussion networks of Açaituba (3.0) and Mussum (3.3).

However, a fourth network property, the frequency distribution of the number of discussion partners, shows a different pattern in the two communities (figure 3). The discussion network of Mussum exhibits a heterogeneous distribution which reveals that the

majority of the individuals has none or a small number of discussion partners (64% of the individuals have 0 to 3 discussion partners), while some individuals discuss mercury issues with a very high number of villagers and can be considered as opinion leaders in the community. A homogeneous distribution characterizes the discussion network of Açaituba, indicating that the majority of the individuals has a number of discussion partners close to the mean value (61% of the individuals have 2 to 5 discussion partners) and consequently that only a few individuals do not discuss mercury issues and no individual has a very high number of discussion partners.

Figure 3



Frequency distributions of the number of discussion partners in the Açaituba and Mussum communities.

Discussion

Results demonstrate the importance of interpersonal communication between community members regarding the adoption of new diet behaviours to reduce mercury exposure. By sharing these results with communities, adapted actions can be carried out in order to achieve higher levels of adoption and a better health.

Promoting discussion across gender

The analysis of the distinctive role of men and women in the Brasilia Legal mercury discussion network illustrates the key role of women in promoting healthy changes in dietary habits and reveals the importance of stimulating discussion across gender both at the community and the family level. As an example, promoting discussion between spouses is one of the guidelines we have adopted in the workshops, carried out in 2005 in Brasilia Legal, where young couples were invited to debate health risks of foetus and young children in relation to mercury exposure.

Promoting equity of involvement between social groups

The results on the differential involvement of social groups in the Brasilia Legal community, allowed us to develop specific participatory activities to address the low level of participation of some groups and to promote equity by stimulating a balanced participation between the various segments of the village. In 2005, targeted activities involving farmers, people under 30 years old, school teachers and people attending evangelical churches have been carried out in Brasilia Legal to promote debates centered on the specific role of each group in the building of solutions to reduce the environmental and social impacts of mercury contamination.

Promoting horizontal participation

Although no causal relationship can be inferred between a higher level of adoption and a more homogeneous distribution in the frequency of discussion partners in Açaituba, compared to Mussum, the observed association suggests that involving most of the villagers in an inclusive and equitable discussion process is efficient in promoting social change. Results also suggest that researchers should not rely exclusively on community opinion leaders to stimulate the process of change in communities and should give emphasis to the strengthening of an horizontal process of participation which may facilitate the emergence of cooperation and the building of consensus.

Conclusion

It is a challenge for Ecohealth projects to develop methods for taking gender issues into consideration, for analysing and promoting social equity and for evaluating and stimulating participation. Social networks analysis is a promising methodological tool to be included in the Ecohealth approach to achieve these goals, as a way of developing a better understanding of the role of social structure to facilitate the promotion of environmental awareness and actions for improving health.

Transdisciplinarity in the Ecohealth approach aims at achieving the participation of researchers and communities, but also of decision-makers from the regional and national levels. In the next phase of the Caruso project, social network analysis will be used to map dialogue, collaboration and confidence networks between villagers of communities at the local level and between communities and stakeholders from government and civil society at the regional, state and federal levels. Analysing how community and multi-scale networks spread into and take advantage of the existing spaces for dialogue and channel for representation, will allow us to understand how the pilot activities at the community level might be scaled up spatially to the entire Amazon region and temporally to the longer-term after the end of the project.

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CHAPITRE 2

PARTICIPATORY RESEARCH, INTERPERSONAL COMMUNICATION AND ADOPTION OF A PREVENTIVE HEALTH INNOVATION TO REDUCE MERCURY EXPOSURE

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Cet article a été preparé en vue d'une soumission à Social Sciene and Medicine

Abstract

A social network study was conducted within the context of a participatory intervention in a Brazilian Amazonian village. Inhabitants of Brasilia Legal, a small village located on the left shore of the Tapajós river in the Brazilian Amazon, are exposed to methyl mercury through fish consumption. A participatory intervention based on dietary changes aimed at reducing mercury exposure from fish consumption was initiated in 1995. Comparison of diet and exposure of the same persons in 1995 and in 2000 showed that although they continued to eat the same quantity of fish, they had preferentially included less contaminated herbivorous fish in their diet. This resulted in a decrease in hair mercury levels of approximately 35%. In the present article, we conducted a network analysis in order to determine the influence of interpersonal communication on individual behavioural changes in fish consumption. Every household was visited and socio-demographic data, information about fish consumption and sociometric data on the communication network related to diet, health and mercury were collected for 85 women and 67 men. We were able to identify both male and female opinion leaders in the communication network. However, opinion leadership was associated with change in fish consumption only for women. Furthermore, results illustrate the influence of female opinion leaders at the community level and female spouses at the household level in promoting healthy changes in dietary habits to reduce mercury exposure. Preferential consumption of less-contaminated fish was associated with the presence of female communication partner – but not male – in the personal networks of both men and women. At the household level, men who considered their wife as a discussion partner were much more likely to change their behaviour than those who did not. These results convinced us to incorporate social networks analysis in our methodological approach not only as an after-the-fact analytical method but as a way of developing a better understanding of social networks which in turn should facilitate the promotion of environmental awareness and actions.

Introduction

Health prevention programs frequently rely on the promotion of change in individuals' behavior to attain their goal. This behavior change can be framed as a preventive innovation, defined as a new idea or behavior that an individual adopts at one point in time in order to lower the probability that some future unwanted event will occur (Rogers, 2003). Understanding the factors that influence adoption of new behavior, as well as their diffusion is key to program efficiency. Health programs based on an ecological framework, recognize that individuals make decisions not in social isolation, but in interaction with others and focus on the role of the social environment and inter-individual factors on the shaping of individuals health behavior (Luke & Harris, 2007; Merzel & D'Afflitti, 2003). Their effectiveness is increased by capitalizing on local communication networks which stimulate the involvement of community members to act as peer-educators and role model to increase awareness and promote behavior change (Valente & Pumpuang, 2007).

Dozens of studies have contributed to our understanding of how information and messages generated by government or organization-sponsored programs spread through communication networks and affect the adoption of new health behavior (Rogers, 2003; Luke & Harris, 2007; Valente & Fosados, 2006). This sizeable body of literature has demonstrated the association between interpersonal communication and the adoption of preventive health behavior in programs created, supported and/or implemented by a wide variety of organizations: governmental health communication campaigns or programs on family planning (Nepal: Boulay et al., 2002; Malaysia: Palmore et al., 1971; Korea: Palmore et al, 1976; Kenya: Behrman et al. 2002; Bangladesh: Kincaid, 2000), governmental community-based preventive cardiovascular program (Finland: Puska et al, 1986), peer education reproductive health program carried out by youth-serving organizations (Nigeria and Ghana: Brieger et al, 2001) or by nongovernmental organizations (Ghana: Wolf et al, 2000), paid non participatory research project on condom use (Latkin et al, 2003), coupled media campaign and focus group intervention to prevent HIV/AIDS transmission (Singhal & Rogers, 2003; Wohlfeiler, 1998), church-based intervention to reduce cardiovascular risk (Oexmann et al, 2001) and school-based tobacco prevention programs (USA: Valente et al, 2003).

However, to our knowledge, the role of local communication networks in promoting health behavior change in communities involved in participatory research projects has not been studied. Research can be defined as participatory when communities share power and control over the knowledge generation process, usually by integrating scientific and local perspectives and priorities (Cornwall & Jewkes, 1995). Through participatory approaches, new ideas and research results are generated through a mutual learning process and contribute to foster knowledge for local action. Consequently, in participatory health research, ideas and messages aimed at changing behavior are built into the partnership between researchers and communities rather than defined by an agency which is external to the community (governments, organizations, associations) and afterwards transmitted to communities using specific communication approaches like mass media campaign or peer intervention. We hypothesize that the involvement of communities' members in the participatory research favors interpersonal discussion about the health issues under investigation. These discussion processes may help to put the health issue on the community's agenda, allow for the re-interpretation of the problem, encourage community ownership of the preventive actions and promote the building and implementation of solutions adapted to social contexts (Valente & Fosados, 2006). The main objective of the present article is to analyze the relationships between community discussion processes generated through participatory research activities and individual health behavior change. We build on a case study, a participatory research project that was carried between 1994 and 2007 to investigate the role of human and environmental factors on mercury contamination of the aquatic ecosystems and on community health in the Brazilian Amazon.

The work presented here draws on the principles of diffusion networks theory, a perspective that considers that relations among actors and the patterns formed by these relations are important to understand changes in individual behaviors. We illustrate how this approach has been used to study the role of communication networks in the adoption of preventive health innovations in several contexts. Next, information regarding the case study is provided. We present the participatory research activities, carried out in one community, aimed at generating knowledge to reduce health risk associated to mercury exposure and analyze the possible contribution of these activities to the emergence of a discussion network

on mercury issues among the villagers. Change in diet behavior to reduce mercury exposure is presented as a preventive health innovation and its characteristics are discussed. The last section of the introduction presents how the analysis of the interpersonal communication patterns in the mercury discussion network can shed light on the understanding of the social processes associated to adoption of new diet behavior to reduce mercury exposure.

The role of diffusion networks in the adoption of preventive health innovations

Diffusion network theory provides a way to conceptualize the spread of the adoption of new behaviors within a population, taking into consideration both the characteristics of the potential adopters and the social influences through communication networks (Valente, 1995; Rogers & Kincaid, 1981). This theory brings together two conceptual frameworks: diffusion of innovation and social network analysis. The diffusion of innovation framework describes the mechanism in which an innovation, which is an idea, practice or object, perceived as new by individuals, spreads over time among the members of a community (Rogers, 2003). According to this perspective, a change in health behavior can be analyzed as the adoption of an innovation. Social network analysis, rather than analyzing actions of social actors in terms of their own characteristics, studies the relationships between individuals' behavior and the pattern of interactions between people (Scott, 2000). This perspective assumes that social interactions are not random and that individuals' behaviors are influenced by the interpersonal communication structure of the social environment (Wasserman & Faust, 1994; Valente, 1995).

Studies of reproductive health programs aimed at preventing unwanted pregnancy and/or HIV/AIDS infection have greatly contributed to the understanding of the role of diffusion networks in promoting the adoption of preventive health behaviors (for reviews see: Luke & Harris, 2007; Valente & Fosados, 2006; Neaigus, 1998). For instance, Behrman et al. (2002) showed that social networks have substantial effects on the adoption of new contraception methods in rural Kenya by providing information on family planning rather than influencing social norms. Using a probability sample of West Malaysian married women 15-44 years of age, Palmore et al. (1971) showed that women who had discussed family

planning with relatives, friends or neighbors were found to be further along in the family planning adoption process. In another study in Kenya, women and men who had discussed family planning with their network members were much more likely to be aware of and to be using modern contraceptive methods (Boulay & Valente, 1999). In another study on family planning, Stoebenau & Valente (2003) focus on the role of individuals acting as bridges between the health program and their community in prompting discussion and stimulating the spreading of information through local networks. They show that use of modern contraception methods, in a rural village of Madagascar, is associated with discussing family planning with agents responsible for community-based distribution of family planning services. In his review on network-based approaches to prevent HIV infection among injecting drug users, Neaigus (1998) shows HIV risk reduction when intervention targets the dyadic, personal or complete network levels.

Another set of studies has examined the role of opinions leaders in diffusion networks. Opinion leaders, who are frequently identified as individuals with a high number of connections in social networks, act as role models among their peers and may be especially effective in promoting preventive health behavior among members of their community (Rogers, 2003; Valente & Davis, 1999). In contexts where social norms favor change, opinion leaders have been show to adopt new behavior earlier than most people in the community (Rogers, 2003). Levy-Storms & Wallace (2003) show a positive association between being among the most well-connected women within church-based health communication networks and a higher likelihood of recent use as well as intention of future use of mammography screening to detect breast cancer in early stages. Pearlman et al., (2002) also found that adolescent peer leaders involved in HIV/AIDS outreach activities for youth, from nine communities from Massachusetts, had higher HIV/AIDS knowledge levels than adolescents from the comparison groups. Opinion leaders have also been actively identified and recruited by agencies that capitalize on their capacity to stimulate the process of change in communities, to accelerate diffusion and to help implementing and institutionalizing health programs (Valente & Pumpuang, 2007). Effectiveness in using opinion leaders to promote preventive health behavior has been reported in a wide variety of geographical and cultural contexts, including, among many others, a community-based preventive cardiovascular

program in Finland (Puska et al, 1986), HIV prevention in the injecting drug user community in the USA (Latkin, 1998), contraceptive use in Bangladesh (Kincaid, 2000), AIDS prevention and reproductive health program in Ghana (Wolf et al., 2000; Wolf & Bond, 2002) and tobacco prevention in schools in the USA (Valente et al., 2003).

Gender has also been shown to be an important variable in diffusion network approaches to health prevention. The relation between husband-wife discussion regarding family planning and adoption of contraceptive methods has been extensively studied (Becker, 1996). Men's unsupportive attitude toward family planning practices has been identified as a barrier to spousal communication (Bauni & Jarabi, 2000), while women's literacy and autonomy (Hogan et al, 1999) and women's higher socioeconomic position (Gage, 1995) are factors positively correlated with a higher likelihood to discuss family planning with husbands and with use contraceptive methods. Cross-sectional studies, in India (Mukherjee, 1975), Korea (Palmore et al, 1976), Bangladesh (Kincaid, 2000) and Nepal (Sharan & Valente, 2002) found that adoption of contraceptive methods was positively related to husband-wife communication regarding family planning. Furthermore, results from a longitudinal study were able to demonstrate a causal relationship between spousal communication and contraceptive use (Bawah, 2002). Reproductive health interventions that involve couples have also been shown to be more effective than those directed at only one sex (Becker, 1996). Some studies also focused on the relations between intra-couple communication and adoption of protective behavior against sexually transmitted diseases and revealed the critical importance of spouse dialogue to help preventing HIV transmission among couples in northern Vietnam (Go et al. 2006) and to facilitate the negotiation of strategies to limit the intrusion of AIDS in families of rural Malawi (Zulu & Chepngeno, 2003) Overall these studies agree that information, education and communication activities carried out by programs on reproductive health should promote spousal communication.

The studies described above, most of which focus on the analysis of family planning or HIV prevention programs, show that communication through social networks can influence adoption of preventive health innovation and illustrate the key role of opinion leaders' and of spousal communication in the diffusion process. The present study differs

from previous research on two main points: we analyze the adoption of new diet behavior to reduce mercury exposure, an innovation that has not been previously studied, and we focus on a discussion network which emerged through the involvement of the community in participatory research activities, rather than on interpersonal communication processes based on messages created by agents which are external to the community.

A participatory research to reduce mercury exposure

Methylmercury is a potent toxin mainly contained in higher trophic-level fish, as a result bioaccumulation and concentration in the aquatic food web (Mergler et al., 2007). Populations for whom fish is a dietary mainstay can be exposed to methylmercury at level that place a serious risk to their health. In 1994, researchers from Brazil and Canada initiated the CARUSO project in order to investigate ecological and human aspects of mercury contamination in the Brazilian Amazon. The project was based on the Ecosystem Approach to Human Health (Ecohealth), whose principles include transdiciplinarity, multistakeholder participation, social and gender equity and linkages between research and policies (Forget & Lebel, 2001; Lebel, 2003). This participatory approach, based on a dialogue between communities and researchers from different disciplines, was able to generate a new understanding regarding mercury contamination and exposure in the Amazon. Biogeochemical studies led to the discovery that Amazonian soils from the Tapajós region are rich in naturally occurring mercury (Roulet et al., 1998). Analysis of the ecological relationships between aquatic and terrestrial ecosystems showed that deforestation associated to "slash-and-burn" agricultural practices had caused intensive erosion of soils, resulting in widespread mercury contamination of the aquatic ecosystems (Farella et al, 2006; Roulet et al, 1999, 2000; Lucotte et al, 2004). Furthermore, climatic conditions and aquatic vegetation are also optimal for mercury methylation, speeding up the process of the incorporation, bioaccumulation and concentration of methylmercury into the aquatic food chain. (Guimarães et al., 2000). As a consequence, fish eating communities living along the Tapajós present a high level of mercury exposure and a variety of adverse health effects associated to methylmercury exposure from fish consumption (Lebel et al., 1998; Dolbec et al, 2000; Fillion et al., 2006; Passos and Mergler, 2008).

From the onset, a participatory approach was chosen by the researchers of the CARUSO project as an appropriate methodology to generate scientific knowledge as well as to design intervention strategies to reduce mercury exposure. Many of the research results depended on the participation of the villagers of the Brasilia Legal community. Mobilization of the community has been a continuous process, through participation in meetings and focus groups, where new ideas emerged which served to re-direct the research efforts and through collaboration with researchers in activities like the identification fish species in regards to mercury levels, the keeping of a daily food diary and the preparation of didactic material. Since the first contact with inhabitants from the Brasilia Legal community in 1994, the participatory research has gone through a number of stages associated with different types of participation of the villagers, following a trend of progressively deeper involvement of the community (Mertens et al, 2005). In 1998, researchers and community initiated a pilot project to reduce mercury exposure. Since villagers participated in all stages of the pilot project and shared some of the responsibilities with the researchers, participation can be defined as collaborative (Biggs, 1989). The objective of the pilot project was to promote changes in diet behavior that would maximize nutrition from fish consumption, which provides an essential source of proteins for riparian populations, while at the same time minimizing toxic risk, associated with mercury exposure.

The recommendations for diet behavior change were defined based on a process of integration of scientific results and local knowledge. Scientific research contributed to the discovery that mercury concentrations vary widely between fish species, the highest mercury levels being consistently found in piscivorous species, while the lowest were encountered in herbivorous species (Sampaio da Silva et al., 2005). Community knowledge regarding local ecosystems and fishing practices is used to take advantage of the very high fish biodiversity in the Tapajós region in order to choose between many different fish species for consumption and fishing activities are carried out in diverse locations surrounding the village. The collaboration between researchers and the community led to the preparation educational posters showing the status of mercury contamination in relation to the fish species and to the recommendation that all fish can be eaten, but diet should be directed towards more frequent

consumption of less contaminated fish species (Mertens et al., 2005). Thus, the preventive health innovation that is the focus of the present study is a change in diet behavior to reduce mercury exposure through the preferential consumption of less contaminated herbivorous fish. One important characteristic of this innovation is that it has been defined with the participation of community members, the very same people that are the potential adopters of the innovation.

Diet behavior change to reduce mercury exposure as a preventive health innovation

Five attributes of innovations - relative advantage, observability, compatibility, triability and simplicity - have been shown to positively influence adoption rates (Bertrand, 2004 ; Rogers, 2003; Tornatzky & Klein,1982). Since change in diet behavior to reduce mercury exposure has not previously been framed and studied as a preventive health innovation, we will first present how these five attributes can be used to characterize the innovation.

The relative advantage of the innovation - the degree to which it is considered as better than the idea it supersedes - is difficult to perceive by the population. Health impacts of mercury exposure are associated with long-term, non-specific signs and symptoms which go unnoticed in a population affected by numerous and more visible health problems like water-related infections and vector-borne diseases (Santos, 2001). For a poor family, struggling to survive, eating all kinds of available fish seems to offer the greater advantage, at least in the short-term.

The observability of the innovation - the degree to which the events resulting from its adoption are visible to others - is weak. Indeed, the health benefits which may result from orienting diet behavior toward less contaminated fish species are not readily observable by other villagers, nor are the changes in eating habits themselves. The outcome associated with adoption on the short-term is a decrease in hair mercury level, which is used as a bio-indicator of exposure in the analyses performed by the research team (Lebel et al., 1998). Observability of this possible outcome is low because information regarding hair mercury

level is provided individually and confidentially and is dependent upon the availability of scientific tools and expertise.

The compatibility of the innovation - the degree to which it is perceived as being consistent with existing values, past experiences and needs of potential adopters - varies across gender and between social groups. On the one hand, the innovation questions fishing practices and the use of fish as the main source of protein since it is based on the idea that some fish species contain more mercury and thus potentially harmful to health; on the other hand, the innovation is consistent with a traditional health practice which recommends to pregnant women and sick people to avoid the consumption of certain fish species called "reimoso" (Murrieta, 2001).

The trialability of the innovation - the degree to which it may be experimented on a trial basis - offers no specific difficulties. However, because of the long-term effects of mercury exposure, the advantages of the change in diet behavior cannot be evaluated following a short, temporary trial.

The simplicity of the innovation - the degree to which it is perceived as easy to understand and use - is low because mercury levels in fish vary according to fish species and developmental stage, environmental conditions and season (Sampaio da Silva et al. 2005, Lucotte et al., 2004). Furthermore, recent studies suggest that eating tropical fruits modulates the relationship between fish consumption and Hg exposure, further contributing to the complexity of the innovation (Passos et al, 2007).

In summary, the characteristics of the innovation appear to be highly unfavorable to achieve a change in diet behavior with a view to reducing mercury exposure in this community. However, community participation in the building of solution to reduce mercury exposure could have contributed favorably to the diffusion process. One possible way by which the participatory process may have contributed to the diffusion is by the generation of community interpersonal discussion about the topic helping to put mercury issues on the agenda and allowing the villagers to more easily relate the innovation to local realities

(Mertens et al., 2008). To analyze the possible relationships between interpersonal communication and change in diet behavior to reduce mercury exposure, we collected data on the level of adoption and on the discussion network regarding mercury issues in the Brasilia Legal village. Since other studies have shown that opinion leadership and communication between men and women play an important role in the diffusion of preventive health innovations, we focus on these two aspects in the analyses.

Data and methods

Population

Brasília Legal is situated on the banks of the Tapajós River, a major tributary to the Amazon River, Brazil. A map of the study region is available on the CARUSO project web site: http://www.unites.uqam.ca/gmf/caruso/caruso.htm. In September 2001, a meeting was held in the Brasilia Legal community to invite the villagers to participate in the present study. A complete mapping of the community, done in collaboration with the villagers, revealed that the village had a total of 110 households. Data were collected using semi-structured, face-to-face interviews privately at the home of the participants in October 2001. The interviews covered standard demographic characteristics, adoption of new diet behavior to reduce mercury exposure and network questions. In order to increase the likelihood of finding people at home and to maximize the size of our sample, each household was visited several times at different times of the day to invite the household heads (usually a couple) to participate in the interview. If the household heads were repeatedly absent after several visits, another person in the house was interviewed. This strategy allowed us to conduct the interview with a total of 158 persons (89 women and 69 men), from a total of 96 different households. People from the remaining 14 households could not be encountered either because they were not permanent members of the community, had moved recently or were temporarily absent for health or professional reasons.

Individual-level and network variables

Adoption of preventive health innovations has been shown to be associated with several individual-level characteristics (Valente et al., 1997, Rogers, 2003), including age, socioeconomic status and education, which will be analyzed here as control variables. Socioeconomic status was measured as an interval variable that was made up of the sum of the presence in the house of a radio, a television set, a television parabolic receptor, a well for drinking water, a bathroom inside the house and an electric generator. Educational level is the number of years of formal schooling. Adoption was measured as a dichotomous variable according to whether the respondent said that he/she had modified his/her fish consumption with the objective of reducing mercury exposure and was able to explain how this change had been achieved.

Interpersonal communication regarding the mercury issue was assessed by asking the respondents to name the individuals with whom they usually discuss mercury issues, whether in the context of health, diet or fishing. Our intention with the phrasing of the question was to preferentially select network partners with whom the respondent had substantial conversations about mercury and not merely casual talk. From a total of 363 nominations directed at individuals living in the village, 322 (89 %) were directed at individuals who had been interviewed and 41 (11 %) were directed at individuals who were not included in our sample. Network ties with individuals who could not be interviewed were dropped from the analysis since no information was available for these network partners.

Personal discussion network was defined as the set of people with whom an individual discussed mercury issues. Two individuals were considered discussion partners if one or both individuals reported discussing with the other. Personal networks were characterized for each individual, in order to identify the total number of discussion partners, as well as the number of men and women with whom mercury issues were discussed. Identification of individuals that may be considered community opinion leaders regarding mercury issues was made on the basis of the number of times the individual was nominated

as discussion partner. To identify opinion leaders among men and among women, we distinguished between nominations received from each.

Network data were stored as an actor-by-actor matrix using the UCINET software (Borgatti et al, 2002) and then exported to the Netdraw software (Borgatti, 2002) to visualize the structure of the discussion network as presented in Figure 1. We used logistic regression models to analyze the relationships between the individual-level and network variables and the dependent variable, the adoption of new diet behavior to reduce mercury exposure (Hosmer & Lemeshow, 2000).

Results

Characteristics of the population and adoption

Inhabitants of the Brasília Legal community mostly depend on agriculture and fishing activities both to generate income and to ensure family nutrition. Their diet is composed primarily of fish, rice and cassava flour (Passos et al., 2003). More than 80 % of the adult men fish for family consumption. Revenue from crops, livestock and fish sold on local markets is very low, opportunities for remunerated jobs are scarce and children and adolescents usually have to help their parents in their daily activities. This situation is reflected in the socio-demographic data presented in Table 1. Many families cannot afford to equip their house with most of the 6 items that were selected to evaluate socioeconomic level and more than 70 % of the respondents had no opportunity to study beyond primary school level.

More than half of the villagers (56%) declared having changed their diet behavior in order to reduce exposure. No statistically significant differences were found for age, socioeconomic, education and adoption distributions between men and women respondents who participated in the study (Chi Square).

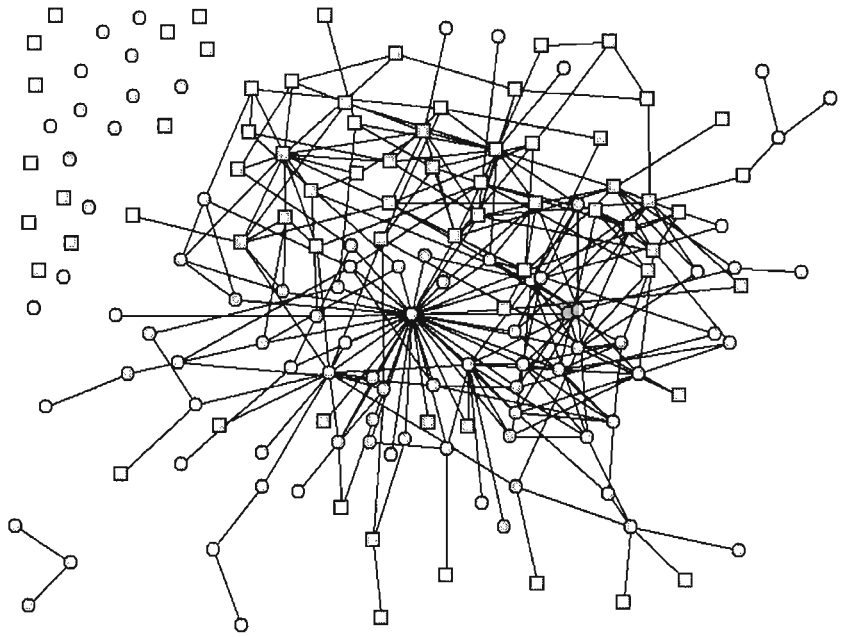
Table 1. Percentage distribution of male and female respondents, by age, socio-economic level and education

Individual-level characteristic	Women *(n=89)*	Men *(n=69)*
Age		
14-30	31.5	18.8
31-40	22.5	17.4
41-50	20.2	18.0
51-60	15.7	29.0
61-	10.1	15.9
Socio-economic level		
0	12.4	11.6
1	28.1	26.1
2	20.2	24.6
3	15.7	7.2
4	12.4	15.9
5	7.9	8.7
6	3.4	5.8
Education		
0	6.7	14.5
1-6 (primary)	65.2	71.0
7-11 (secondary)	28.1	14.5
Adoption		
Yes	58.4	53.6
No	41.6	46.4
Total	100.0	100.0

Interpersonal communication about mercury

Figure 1 presents the discussion network about mercury in Brasília Legal. The nodes depicted as black circles in the graph represent men, while white circles represent women. Arrows from one individual to another indicates that the first one nominated the second as discussion partner. The most striking characteristic of the discussion network is that the majority of the villagers belong to one main and relatively dense connected group comprising 130 members, including 73 women and 57 men. This observation shows that mercury is a discussion topic between most of the community members. However, a significant portion of villagers does not seem to be actively involved in discussion about mercury. Indeed, 25 individuals, who are isolated in the network, do not take part in the discussion and three villagers form a small discussion group disconnected from the main component of the network.

Figure 1



The discussion network about mercury in Brasília Legal (n=158)

Table 2a provides information on the pattern of interpersonal communication about mercury issues within and across gender. Personal discussion networks about mercury issues can be characterized both in terms of their size – number of discussion partners - and composition – whether these discussion partners are men or women. Although the number of discussion partners varies greatly from one individual to the other, on the average, men and women are equally likely to discuss mercury issues with someone from the community. Most of the discussion about mercury occurs within same gender groups. Indeed, men and women are over 3 times more likely to discuss mercury issues with same gender individuals than with individuals of the opposite gender.

Table 2: Interpersonal communication and opinion leadership about mercury issues by gender

	Women (n=89)		**Men** (n=69)	
	Mean	Range	Mean	Range
a) Interpersonal communication				
Total number of discussion partners	**3.5**	0-40	**3.6**	0-15
Number of women as discussion partners	**2.9**	0-33	**0.9**	0-5
Number of men as discussion partners	**0.6**	0-7	**2.8**	0-12
b) Opinion leadership				
Number of nominations	**2.1**	0-34	**2.0**	0-13
Number of nominations from women	**1.7**	0-30	**0.4**	0-3
Number of nominations from men	**0.4**	0-4	**1.5**	0-10

Adoption and interpersonal communication about mercury

Table 3 shows a series of logistic regression models to investigate the potential relationships between the characteristics of the respondents, the size and composition of their personal discussion network and adoption of new diet behavior to reduce mercury exposure. In Model 1, we examine the association between adoption and three individual-level characteristics: socio-economic status, education and age. No statistically significant relations were observed for men. However, women with higher education level are more likely to adopt the innovation: each additional year of schooling was associated with a 50% increase in the likelihood that the respondent had changed her diet to reduce mercury exposure.

Model 2 and 3, which were adjusted for the individual-level variables included in Model 1, examined the association between adoption and the size and gender composition of men and women's personal networks. Adjusted Model 2 reveals that, for both men and women, the number of discussion partners on mercury issues is associated with an increased likelihood to have adopted new diet behavior. Adjusted Model 3 shows that, for women, the likelihood of behavioral change is associated with both more men and women in their discussion network. However, for men the likelihood of adoption is associated only with the number of women as discussion partners, showing no statistically significant relationship with the number of men in the personal network.

Adoption and opinion leadership

The number of nominations received in social networks has frequently been used as an indicator of opinion leadership: individuals who receive a higher number of nominations are considered to be more influential and act as role models within their communities (Valente & Davis, 1999; Rogers, 2003). Table 2b presents the distribution of the number of nominations within and across gender. On average, men and women receive a similar number of nominations in the mercury discussion network. However, there is a significant variation between individuals. Men received up to 13 nominations, while one woman received as high

Table 3: Gender specific multivariate logistic regression models showing likelihood of adoption of new diet behavior to reduce mercury exposure by individual-level and mercury discussion network characteristics

		Women (n=89)	Men (n=69)
	Characteristics	Odds Ratio	Odds Ratio
Model 1	Socio-economic level	1.1	1.0
	Education	1.5**	1.1
	Age	1.0	1.0
Adjusted Model 2	Total number of discussion partners	3.5***	1.3**
Adjusted Model 3	Number of women as discussion partners	3.2***	2.4*
	Number of men as discussion partners	5.0*	1.2
Adjusted Model 4	Number of nomination	4.6 ***	1.2
Adjusted Model 5	Number of nomination from women	3.9**	1.9
	Number of nomination from men	7.8**	1.1

Model 1 includes the three individual-level variables.
Models 2 to 5 are adjusted for the individual-level variables included in model 1.
*p<0.05, ** p<0.01, *** p<0.001

as 34 nominations. Furthermore, men and women are opinion leaders mostly in their own gender group, as indicated by the high number of nominations received within each gender group (79% and 81%, respectively).

In the Adjusted Models 4 and 5 of Table 3, we examined the relations between the number of nominations in the discussion network and adoption of new diet behavior to reduce mercury exposure. Women, but not men, who receive a higher number of nominations in the discussion network, are more likely to have adopted the diet modification (Adjusted

Model 4). When the number of nominations is computed for men and women separately, the association is again statistically significant for women but not for men (Adjusted Model 5).

Adoption and mercury discussion between spouses

Since, fish consumption depends both on fishing activities, usually carried out by husbands, and meal preparation, usually a wife's task, discussion on mercury issues between spouses might be an important factor associated with the adoption of a new diet behavior at the household level. Table 4 shows the percentage of adoption for men and women for the 50 couples of our sample as a function of interpersonal communication on mercury with their spouse. The percentages of adoption are significantly higher among both men and women who discuss mercury issues with their spouse.

Table 4: Percentage of adoption as a function of interpersonal communication between spouses (n= 50)

	Women		Men	
	n	% of adoption	n	% of adoption
Spouses are discussion partners	25	84*	25	76**
Spouses are not discussion partners	25	56	25	36

Chi Square statistical tests were conducted, separately for men and women, to assess the potential differences between the individuals who discuss or not mercury issues with spouse (* $p<0.05$, ** $p<0.01$).

Discussion

Participatory research and interpersonal communication

The participation of over 84% of the villagers in the discussion network illustrates how the problem of mercury contamination was an important issue for the members of the Brasília Legal community in 2001, nine years after the community began to participate in the CARUSO project. The results suggest that the involvement of the villagers in the participatory research process had contributed to the generation of mercury interpersonal discussion in the community, the cross-sectional nature of our data does not allow us to establish a causal relationship? Furthermore, since people from the Tapajós region worked in artisanal gold mining during the Amazonian gold rush, during the last two decades of the 20th century, and since the use of mercury to amalgamate gold was a well known process among villagers, it is possible that mercury was an actively discussed issue among the Tapajós communities independently of their participation in the CARUSO project. To shed some light on the question, we mapped the mercury discussion network of another fishing community of the Tapajós region, which has similar size, cultural and social conditions, São Luiz do Tapajós, but which had been involved in the CARUSO project for only one year at the time of the study. The structural analysis of the São Luiz do Tapajós mercury discussion network, mapped in 2003 among 169 individuals, showed that a much lower proportion of the villagers are involved in discussion on mercury issues than in the BL community, as revealed by the comparison of network's densities - the total number of ties divided by the total number of possible ties - (0.004 for SLT versus 0.013 for BL). Furthermore the high level of fragmentation of the São Luiz do Tapajós discussion network indicated that the circulation of information regarding mercury issues is limited (51 individual are connected in the main component, 41 individuals take parts is 10 small connected groups with size ranging from 2 to 11 and 77 individuals are isolated and do not discuss mercury issues). This comparison strongly suggests that longer and deeper involvement in the participatory research process contributes significantly to interpersonal discussion on mercury issues.

Interpersonal communication and adoption

Adoption in the Brasilia Legal community can be considered to have reach high levels, especially if we take into consideration that the innovation has perceived attributes that seem to offer little advantage. Furthermore, there is evidence that change in fish diet can be effective to reduce mercury exposure in the community. Colleagues from the CARUSO project conducted a longitudinal evaluation of mercury exposure, using hair mercury levels as an indicator, with a sample of the Brasilia Legal population (n=47). Comparison of diet and exposure of the same persons in 1995 and in 2000 showed that although they continued to eat the same quantity of fish, they had preferentially included less contaminated herbivorous fish in their diet (Mergler et al. 2001). Consequently, hair mercury levels among the tested population decreased by approximately 35%. In this sample, among the 28 individuals who participated in our interviews and declared to have adopted dietary change, 26 (93%) showed a decrease in hair mercury levels.

Results show a significant association between individual change in diet behavior and the involvement in discussion on mercury issues. However, the community is not a homogeneous entity and the degree of participation in the discussions is highly variable between the villagers. Furthermore, although the percentages of adoption are similar in men and women's groups, the analysis of individual-level characteristics and discussion patterns within and across gender suggests that different factors are involved in the adoption process for men and women and that each gender group plays different roles in the diffusion process. Although discussion among same gender individuals is much more frequent than discussion between men and women, our results showed that across gender discussion is especially important for the diffusion process.

Mercury discussion within gender groups and adoption

Women's adoption of new diet behavior is associated with discussion about mercury issues with other women as well as with opinion leadership within their gender group. One of the key participatory activities in the Caruso project involved a group of women and provides

a likely explanation for these observations. A prospective survey was carried out with 26 adult women who used a daily food diary, for over one year between March 1999 and February 2000, to analyze the relationship between consumption of different types of food and mercury exposure (Passos et al., 2003). These women organized daily meetings to discuss the relationships between diet and mercury. Of the 24 of these women who were also part of the present sample, 23 adopted dietary changes. These 24 women also have a higher level of education than the rest of the women in the village (6.6 versus 4.1 years of schooling, $p<0.0001$, ANOVA). Furthermore, these women received a mean number of nominations in the mercury discussion network which was much higher than those who did not participate in the diet survey (4.7 versus 1.6 nominations, $p<0.0001$, ANOVA). This participatory activity may have played an important role in fostering the emergence of a group of adopting, educated and opinion leader women actively discussing mercury issues and promoting the change in diet behavior to reduce mercury exposure among other women in the community.

In contrast, men's adoption of diet changes is not associated with discussion on mercury issues with other men, nor to opinion leadership within their gender group. Differences in women's and men's norms regarding fish consumption may explain the distinctive role of both groups in the diffusion process. Indeed, it is likely that the innovation conflicts with men's norms since it is based on the association between the negative health effects of mercury exposure and fishing which is their main subsistence activity. On the contrary, women's norms, based on their main role in child care and family health, may favor the adoption of the innovation.

Mercury discussion across gender groups and adoption

Women's and men's adoption of the innovation is associated with discussion about mercury with individuals of the opposite gender group as well as with their spouse. Adopting women are also opinion leaders among men. The key role of discussion about mercury issues across gender, both at the community and household level, might be associated with the interdependent roles of men and women in defining which fish species enter into the composition of the household diet. Indeed, men and women play differentiated roles and

responsibilities in activities as well as issues related to diet and fishing. The choice of fish for consumption depends both on how men orient their fishing activities and choices related to which fish to keep and which to sell to other households and on how women select the fish included in the preparation of the daily meals, usually brought home by their husband, but also sometimes provided by other men from the community.

Network approach to participatory research

This case study also show how researchers can take advantage of social network analysis to adapt and improve participatory research approaches. Indeed results were further integrated in a new cycle of participatory research aimed at strengthening the diffusion process, through the involvement of men opinion leaders and through the promotion of interpersonal communication across gender. Women who were opinion leaders among men were adopters and were likely to favor adoption among men. However, opinion leadership on mercury issues among men was not correlated with adoption. This result indicates that, although men are as active as women in the discussion network, non-adopting, male opinion leaders may not transmit messages or act as role models promoting the adoption of healthy diet behavior. In order to support their role in the promotion of solutions to reduce mercury exposure in the community, several men identified as opinion leaders were invited to organize a workshop, in collaboration with the researchers, to discuss the linkages between health issues and diet, fishing and agricultural practices. This strategy of co-organization stimulated a high level of participation among fishermen who discussed alternative fishing practices to favor the availability of the less contaminated fish for community consumption, as well as among farmers who debated the development of new agricultural systems in order to decrease mercury mobilization toward aquatic ecosystems. To address the effectiveness of this strategy, the change in the role of male opinion leaders in the community will be evaluated in a future study. Participatory activities were also carried out to promote mercury discussion across gender, which is much less frequent than within gender, but is nevertheless key to the adoption process in the community. Among these activities, a workshop, aimed at promoting discussion between spouses, was conducted with young couples who were invited to debate health risks for the fetus and young children in relation to mercury exposure. We

hope that the present study will stimulate other initiatives based on the integration of social network analysis into participatory approaches to empower communities to build integrated solutions allowing them to improve their environment and health.

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CHAPITRE 3

A NETWORK APPROACH FOR ANALYSING AND PROMOTING EQUITY IN PARTICIPATORY ECOHEALTH RESEARCH

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Abstract

Effective involvement and equity in participation between men and women and the various community groups are likely to influence the equity in the sharing of the development outcomes of any participatory research project. The CARUSO project, a participatory research based on the ecosystem approach to human health, showed that the inhabitants from Brasília Legal, a small village located on the river banks of the Tapajós river in the Brazilian Amazon, are exposed to mercury through fish consumption; a subsequent participatory intervention based on dietary changes was effective in reducing mercury exposure of the population. In the present study, we focus on equity in participation and analyse the discussion network about mercury and health to measure individual and group involvement in the community. Participation in the discussion network is associated with the awareness of the critical information necessary to allow the individual to change dietary habits toward the preferential consumption of the less contaminated fish species. Our network analysis shows that gender, age, religion, education, subsistence activities and spatial distribution of the houses are key elements affecting the involvement of the population in discussions about mercury and health. Based on these results, we propose strategies for integrating the research results and the knowledge of the villagers in a new cycle of participatory research in order to address the lack of involvement of some groups and to promote equitable participation and benefit sharing.

Introduction

In recent years participatory research has become a fervently advocated concept and a tool for many development programs. Based on a cyclical process of inquiry, reflection and action, participatory research aims at offering an opportunity for local people to exercise their voice, to interpret their situation and to choose their own way of development through action (Cornwall & Jewkes, 1995; Probst & Hagmann, 2003). The outcome of participatory research is affected by how local people are involved and by whom amongst these people is involved (Cornwall & Jewkes, 1995; Cornwall, 2003; Parkes & Panelli, 2003). Several studies have shown that participatory research programs that fail to take the sociocultural diversity of the community into account with a view to promoting the effective participation of men, women and of various social groups affected by the problem may actually increase the inequalities, widening the gap between the elite and lower socioeconomic status groups, although they may have a globally positive impact on the living conditions of the community (Röling et al., 1976; Rogers, 1976; Shingi & Modi, 1976; Mayoux, 1995; Cornwall, 2003). To incorporate the equity dimension in participatory projects, it is essential to develop methods that allow for disaggregated analyses of the data relating to the different social groups and to explore how the barriers to participation faced by some segments of the community might be overcome (Mosse, 1994; Forget & Lebel, 2001; Probst & Hagmann, 2003).

The main goal of the ecosystem approach to human health – ecohealth approach - is to improve human health and well-being while simultaneously maintaining a healthy ecosystem (Forget & Lebel, 2001; Lebel, 2003). Transdisciplinarity, participation and equity are its three essential methodological components. Here, we address equity in community participation in a ecohealth project on mercury exposure in the Brazilian Amazon. The analysis of the discussion network about mercury and health, that allows for a disaggregated analysis of the involvement of the men, women and the various social groups in the community, is used to identify the axes of difference that may affect participation. We also propose guidelines for incorporating these results into a cyclical on-going process of inquiry, reflection and action to promote equitable participation involving all segments of the community.

Background and context of the CARUSO project

Brazilian and Canadian researchers teamed up in 1994 to explore mercury environmental contamination and human exposure of riverside populations in the Tapajós region. The project, called CARUSO provided a new understanding regarding the environmental dynamics and the health effects of mercury for local communities and allowed to initiate actions to reduce human exposure and improve well being. In the present article, we focus on the participatory process involving the inhabitants of Brasília Legal, a small community on the banks of the Tapajós river where most of the CARUSO studies have been carried out.

A summary of the modes of participation in Brasília Legal

From the onset, a participatory approach was chosen by the researchers of the CARUSO project as an appropriate methodology to investigate the complex links between human and environmental factors associated with the mercury contamination of the aquatic ecosystems and with the health and well-being of the communities living on the banks of the Tapajós River. From the first contact with the community in 1994 to the undertaking of a successful pilot project to reduce mercury exposure, the participatory research has gone through a number of stages associated with different types of participation of the villagers, as the researchers recognized the need to integrate local knowledge and experiences in an increasingly collaborative process. Although these stages were not chronologically linear – one beginning as another finishes – but exhibited significant overlap, they follow a trend of progressively deeper involvement of the communities in the participatory process. Table 1 presents the main characteristics of the different phases of the CARUSO project in Brasília Legal, emphasizing the cyclical process of inquiry, reflection and action. These phases have been distinguished according to the modes of participation of the villagers that in many ways parallel the classification proposed by Biggs (1989).

The previous phases of the CARUSO project, carried out from 1994 to 2000, highlight how approaches with different modes of participation fulfill different tasks, from the generation of scientific knowledge to the adoption of new diet behaviors to reduce mercury exposure. Although the results of the pilot project clearly reveal the emergence of a process of change in the community, they raise two important questions that have been left unanswered: how deep did the process of change spread among community members? Have all the different social groups been equally involved in this process? To answer these questions a fourth phase of participatory research has been initiated in 2001 and is the subject of the present study (table 1).

Equity in participatory research

Participatory research emerged in the 1970s, but for a long time, perceptions and problems and the differing experiences of women were not taken into consideration (Cornwall & Jewkes, 1995; Mayoux, 1995; de Koning and Martin, 1996). As a consequence, women have been largely excluded from many participatory projects where knowledge was both provided and produced by men (Mosse, 1994). Feminist theories and practices have contributed to identify the barriers to women's participation and to address the role of women in community development issues (Frieze et al., 1978; Maguire, 1987; Mayoux, 1995). However the initial focus on women in development gradually shifted to a greater concern with gender relations and socio-economic inequality (Cornwall, 2003; Lebel, 2003). Several authors concluded that, in order to promote an equitable development, participatory research projects need to address the issues of differences in terms of an inclusive approach to gender relations, taking into account the heterogeneity both among women and men (de Koning & Martin, 1996; Chant, 2000; Cornwall, 2003).

Table 1: phases of participatory research in Brasília Legal

Phases of Participatory research	**Research focus**	**Modes of participation** [a]	**Inquiry** **Main results**	**Reflection** **New research questions**	**Action**
The previous phases					
Phase 1 1994-1997	Biogeochemical studies of mercury in soil, sediments and water	Contractual: Members of the community were contracted by the researchers to provide services for fieldwork with no decision power.	Deforestation causes intensive erosion of soils rich in naturally occurring mercury, contributing significantly to the contamination of waterways [b].	Are the fish-eating population of Brasília Legal exposed to mercury? What are the health impacts of mercury exposure?	Organize a community workshop to discuss mercury contamination with the villagers and invite them to participate in a study about mercury exposure and human health.
Phase 2 1995-1997	Analysis of mercury in fish and evaluation of fish diet, mercury exposure and health effects	Consultative: Opinions of the villagers were sought as input for research and actions which are under the control of the researchers	The population is exposed to mercury through fish consumption [c]. Mercury exposure results in dose related adverse health effects [d].	How to build solutions to reduce human mercury exposure while maintaining fish consumption?	Long-term collaboration between researchers and the population to search for and implement solutions to reduce human mercury exposure.

Phase 3 1998-2000	Pilot project based on dietary changes to reduce mercury exposure	Collaborative: Villagers participated in all stages of the pilot project and shared some of the responsibilities with the researchers.	The participatory intervention based on dietary changes was effective in reducing mercury exposure of the individuals who participated in the pilot project [e].	How deep did the process of change spread among community members? Have all the different social groups been equally involved in this process?	Using a network approach, collaborate with the whole population to analyse community involvement and equity in participation.
The phase which is the object of the present study					
Phase 4 2001-2004	Network study for analysing equity	Collaborative: Villagers participated in all stages of the network study and shared some of the responsibilities with the researchers.	The analysis of the discussion network about mercury and health revealed unequal involvement of social groups in the participatory process.	How to promote community involvement and equity in participation?	Using a network participatory intervention, promote community involvement and equity in participation.

The next phase		
Phase 5	Network	Collegiate:
2005-	participatory intervention for promoting equity	Toward a more collegial mode of participation.

[a] Adapted from Biggs, 1989, who distinguishes four modes of participation: 1. contractual, where members of the local communities are contracted in the projects of the researchers to take part in their experiments with no decision power; 2. consultative, where local people are asked for their opinions as input for research and actions which are under the control of the researchers; 3. collaborative, where community members work together with researchers to determine priorities but responsibility remains with researchers for directing the process; and 4. collegiate, where local people and researchers share their knowledge to create new understandings and work together to form action plans under the control of local people.
[b] Guimarães et al. 2000 ; Roulet et al., 1999; Roulet et al., 2000
[c] Lebel et al., 1997
[d] Amorim et al., 2000 ; Lebel et al., 1998
[e] Mergler et al., 2001

The most straightforward way to measure the participation of the community members is to build indicators based on their involvement in the various activities carried out during the research. Correlation between participation in research activities and individual social variables can be used to identify the factors that are associated with the degree of involvement of the community members in the participatory process. However this atomistic approach does not take into consideration the involvement of the community members beyond their direct participation in the activities promoted by the researchers and does not allow to capture the systemic nature of community development since social interactions between the individuals are not taken in account. Indeed, many studies have highlighted that establishing the usefulness and relevance of the information generated by the participatory process as a basis for action, as well as promoting its diffusion, involves complex negotiations through a rich web of social ties based on relation between all the stakeholders affected by the problem (Rogers & Kincaid, 1981; Valente et al., 1997; Boulay & Valente, 1999; Lebel, 2003; Levy-Storm & Wallace, 2003). As a useful tool for disaggregated analyses of the social interactions between the social groups, in the present study we use social network analysis to inquire into equity in participation at the community level.

Social network analysis: a tool for analysing equity in participation

Social network analysis studies the interactions between the behavior of the individual at the micro level and the pattern of relationships between the individuals at the macro level (Wasserman & Faust, 1994; Wellman, 1988). To reach their goal of uncovering the patterns of people's interaction and the structuration emerging from these interactions, social network analysts have created tools and methods for the gathering and analysis of relational data (Wasserman & Faust, 1994). These tools and methods were used for the study of many fields of human communication among which are organisational behavior, social capital, health, social support, small world phenomenon, innovation diffusion and social inequalities (Saint-Charles & Mongeau, 2005).

Numerous studies have shown that structure of social networks affects the transmission of information and the diffusion of new practices in social groups and communities (Boulay & Valente, 1999; Kincaid, 2000; Rogers & Kincaid, 1981; Rogers, 1995; Valente, 1995; Valente et al, 1997; Watts, 2003). Social network analysis has also allowed for a better understanding of how the most isolated people of a community can be reached (Boulay & Valente, 1999; Kincaid, 2004; Rogers, 1995; Saint-Charles & Mongeau, 2005; Valente, 1995; Watts, 2003) and has been used for targeted health interventions through the identification and involvement of individuals indigenous to a community who are able to promote the diffusion of information and changes in health behaviour in their social networks (Ball et al. 1998, Kegler et al. 2003; Valente et al. 2003). Although – to our knowledge – social network analysis has not been used in the context of participative research per se, the "actor linkage matrix" proposed by Biggs in his holistic approach for strengthening research and development capabilities in natural resources systems, has strong parallels with social network analysis (Biggs & Matsaert, 1999). The matrix illustrates the relationships and the flows of information between key actors and is used as a tool for project evaluation to promote learning and replanning through the creation of alternative scenarios, actions and interventions.

In the present study, we use social network analysis as an alternative method to measure who is involved in the community and to identify equity in participation, in which social interactions as well as key elements in community diversity are taken into account. We analyse the participation in discussions about mercury issues, as an indicator of the effective involvement of men, women and the various social groups of the Brasília Legal community in the participatory process. Through the analysis of the discussion patterns between the villagers, we identify the axes of difference, such a gender, age, religion, education, socioeconomical status, subsistence activities and spatial distribution of the houses, that may facilitate or act as a barrier to the actual involvement of the local population in the discussions about mercury at the level of the entire community.

Material and methods

Population

The study was carried out in the village of Brasília Legal, situated on the banks of the Tapajós River, a major tributary of the Amazon River, Brazil. A map of the study region is available on the CARUSO project web site: http://www.unites.uqam.ca/gmf/caruso/caruso.htm. In September 2001, a meeting was held in the Brasilia Legal community to invite the villagers to participate in the network study. A complete mapping of the community, done in collaboration with the villagers, revealed that the village had a total of 110 households. Data were collected using semi-structured face-to-face interviews that were conducted by the principal investigator privately at the home of the participants in October 2001. The interviews covered standard demographic characteristics, knowledge about mercury accumulation in fish, and network questions. In order to increase the likelihood to find people at home and to maximize de size of our sample, each household was visited several times at different times of the day to invite the household heads (usually a couple) to participate in the interview. If the household heads were repeatedly absent after several visits, another person in the house was interviewed. This strategy allowed us to conduct the interview with a total of 158 persons (89 women and 69 men), from a total of 96 different households. People from the remaining 14 households could not be encountered either because they are not permanent members of the community, had moved recently or were temporarily absent for health or professional reasons.

Variables used to differentiate the villagers

The main variables used in this analysis to reveal axes of difference between the villagers of Brasília Legal were gender, age, socioeconomic status, education, house location, religious affiliation and subsistence activities. Socioeconomic status was measured as an interval variable that is the sum of the presence in the house of a radio, a television set, a TV parabolic receptor, a well for drinking water, a sanitary inside the house and an electric generator. Education level is the number of years attending school. Religious affiliation and

subsistence activities were recorded using open-ended questions and categories were defined a posteriori (see results).

Knowledge about mercury accumulation in fish

The pilot study to reduce mercury exposure of the Brasília Legal population was based on a key information: herbivorous fish usually have the lowest mercury levels while the carnivorous fish exhibit the highest (Lebel et al., 1997). To be able to orient their fish consumption to the less contaminated fish species, villagers must be aware of this information. Knowledge about mercury accumulation in fish was measured as a dichotomous variable as whether the respondent was aware of the difference in mercury accumulation between herbivorous and piscivorous fish and able to distinguish between these two groups by identifying correctly at least one species in each category, among the fish living in the Tapajós region.

Discussion network on mercury

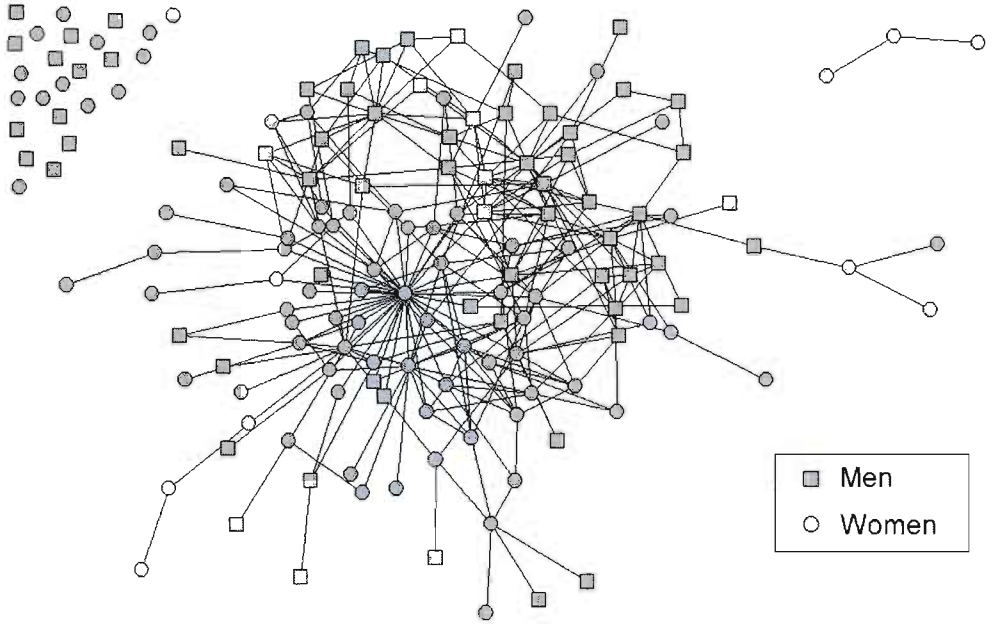
Interpersonal communication regarding the mercury issue was assessed by asking the respondents to name the individuals with whom they usually discuss about mercury issues, whether in the context of health, diet or fishing. Our intention with the phrasing of the question was to preferentially select network partners with whom the respondent had substantial conversation about mercury (strong ties) and not merely casual talks. From a total of 363 nominations directed at individuals living in the village, 322 (89 %) were directed at individuals who had been interviewed and 41 (11 %) were directed at individuals who were not included in our sample. From these 322 nominations, 39 were reciprocal. Network ties with individuals who could not be interviewed were dropped from the analysis since no information was available for these network partners. For the purpose of the analysis, two individuals were considered as discussion partners if either person mentioned the other. Accordingly, we obtain a discussion network including 283 reciprocal relationships, giving a total of 566 discussion partners.

Network data were stored as an actor-by-actor matrix using the UCINET software (Borgatti et al, 2002) and then exported to the Netdraw software (Borgatti, 2002) to visualize the structure of the discussion network as presented in figure 1. The grouping of community members sharing selected characteristics was done using the collapse function of the UCINET program, which allows for the calculation of the mean number of discussion partners within and between groups. Significant difference in the mean number of discussion partners between groups was assessed using variance analysis (ANOVA).

Results

Figure 1 presents the discussion network about mercury in the Brasília Legal village. The nodes depicted as square in the graph represent men, while circles represent women. Two nodes are connected by a line if one or both individuals reported discussing with the other about mercury issues. The most striking characteristic of the discussion network is that the majority of the respondents belong to one main and relatively dense component comprising 130 members, including 73 women and 57 men. This observation shows that mercury is a discussion topic between most of the community members. However a significant portion of villagers seem not to be actively involved in discussion about mercury. The network analysis revealed one small component comprised of three women, as well as 25 isolates, 12 men and 13 women. Furthermore the main component is far from being homogeneous. Some individuals are linked to the main component through only one discussion partner, while others exhibit numerous connections with a wide set of individuals. The individual number of discussion partners ranges between 0 and 40 and is used as a variable to measure the involvement in the discussions about mercury. The mean number of discussion partners (MNDP) for the whole network is 3.6.

Figure 1



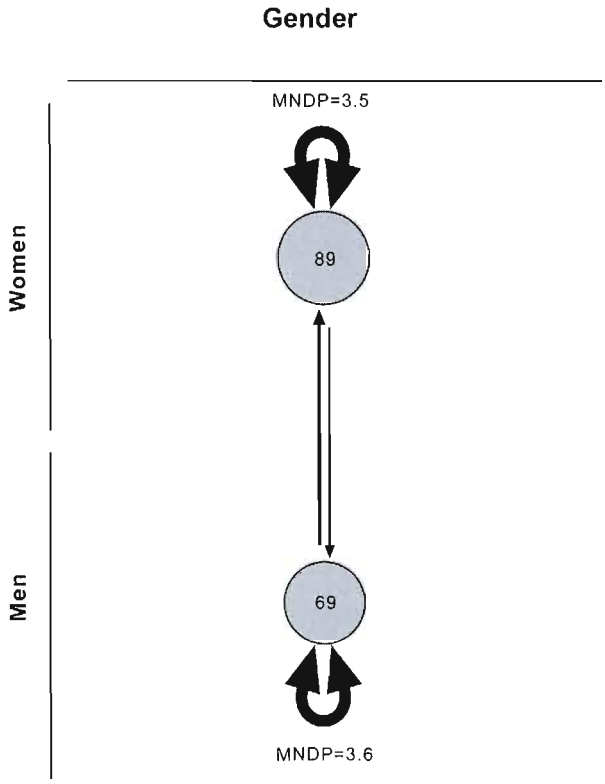
Discussion network on mercury between the villagers of Brasília Legal (n=158).

In order to examine if there is an association between personal attributes of the villagers and their involvement in the discussions about mercury, community members sharing selected characteristics were grouped together and MNDPs were analysed within each group and between them. In figures 2 to 9, groups are represented by circles whose area is proportional to the number of individuals – indicated within the circle - in the respective groups. The MNDP for each group, with all the other groups including itself , is indicated in the legend of the figures. MNDP within each group is indicated using a reflexive arrow, while MNDP from one group to another is indicated by an arrow directed from the former to the latter. The thickness of an arrow is proportional to the MNDP value. MNDP values within and between groups are available for figures 2 to 9 in the supporting online material, at http://www.unites.uqam.ca/gmf/fm/data/supporting_online_material_mertens_et_al.htm

Gender

Figure 2 shows how discussion about mercury is distributed within and between men and women's groups. The MNDP is 3.5 and 3.6 respectively for women and men. As the thickness of the reflexive arrows indicates, most of the discussion about mercury occurs within same sex groups. Respectively 76% of the men and 81% of the women discuss mercury issues with same sex members. This result prompted us to use gender as an additional grouping variable in the subsequent networks analysis.

Figure 2

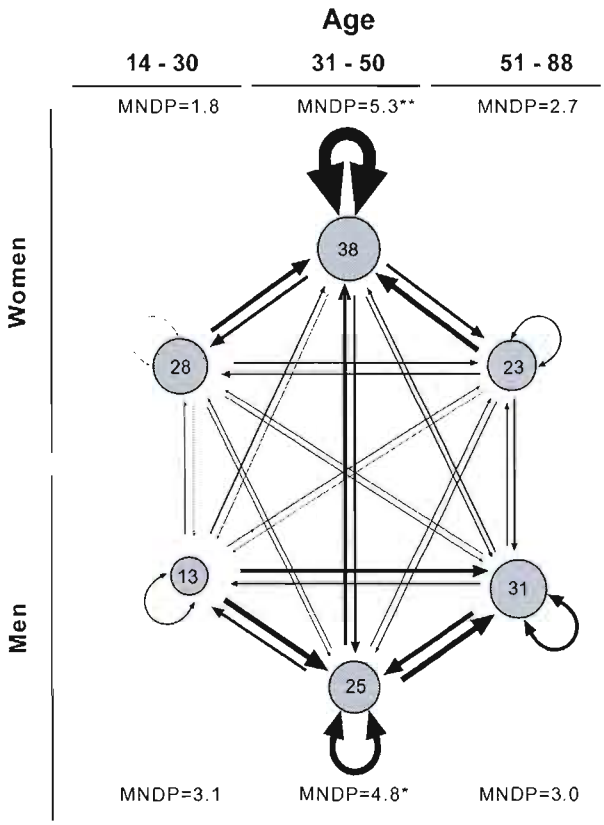


Discussion network on mercury within and between men and women's groups

Age

Age from the villagers who participated in the study ranges from 14 to 88 years. The population was divided in three age groups, arbitrarily defined in order to minimize the difference in size between them: 14 to 30, 31 to 50 and 51 to 88 years old (Fig. 3). People who are between 31 and 50 years old have significantly more discussion partners about mercury than people from the two other age groups. This difference is statistically significant for both men and women (ANOVA, $p<0.05$ and $p<0.01$ between the 31-50 and the two other groups, respectively for men and women). Younger men and women have very few discussion partners both among people of their own group and with individuals belonging to the 14 to 30 years old group of the opposite sex.

Figure 3

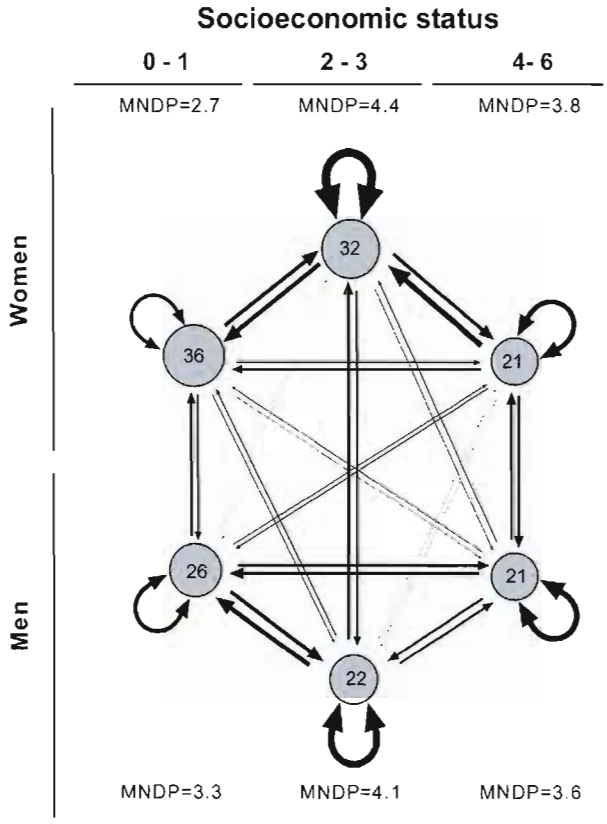


Discussion network on mercury within and between age groups, by gender (* $p<0.05$, ** $p<0.01$).

Socioeconomic status

Figure 4 shows that for both men and women discussion about mercury is rather evenly spread within and between groups established according to the socioeconomic status of the individual.

Figure 4



Discussion network on mercury within and between groups defined according to socioeconomical status, by gender.

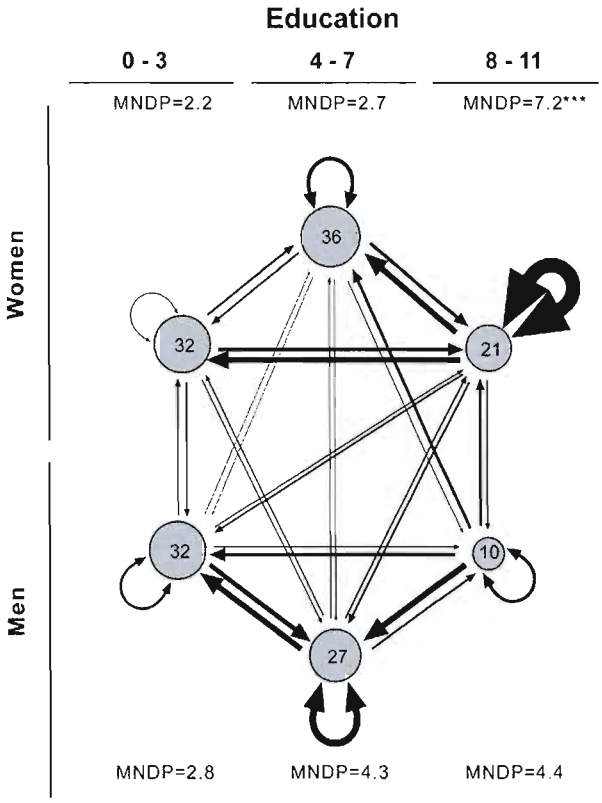
Education

The analysis of the discussion patterns between groups of different education levels, 0 to 3, 4 to 7 or 8 to 11 years of schooling respectively, reveals that the discussion pattern is markedly different between men and women (Fig. 5). On the average, women with 8 to 11 years of schooling discuss mercury issues with 7.2 villagers, in contrast with women with lesser years of schooling who have an average of only 2.2 and 2.7 discussion partners respectively (ANOVA, $p<0.001$, between the women's group with 8-11 years of schooling and the two other groups). Furthermore, most of the discussion involving women from the group with the highest level of education takes place with members of their own group. A different picture emerges from the analysis of discussion about mercury for men's groups defined according to their education level. Discussions are much more evenly distributed between the three men's groups and there is no significant difference in the MNDPs between them.

Spatial distribution of the houses

The 110 houses of Brasilia Legal are uniformly spread along the left bank of the Tapajos river, on a North-South axis. A main line of 56 houses, approximately 800 meters long, front straight onto the river. Behind this line, the other houses of the village are distributed into two shorter rows also parallel to the river. Since no clear natural boundary defining distinct neighborhood could be identified, the village was arbitrarily divided into three areas on the North-South axis, with approximately the same number of houses. Although Brasilia Legal is a very small community where everybody knows everybody, figure 6 clearly shows that discussions about mercury are spatially concentrated, occurring preferentially between close neighbors than between people living in distant areas.

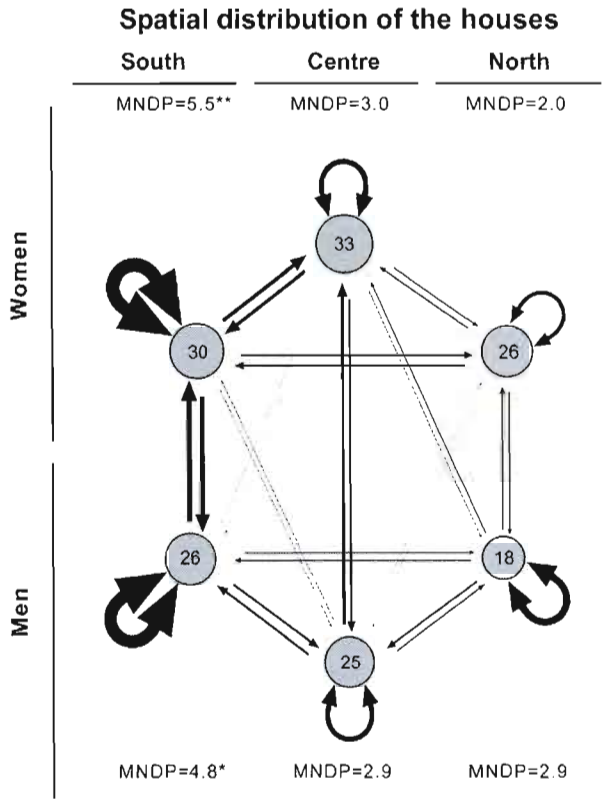
Figure 5



Discussion network on mercury within and between groups defined according to education levels, by gender (*** $p<0.001$).

Respectively 80, 63 and 64 % of the inhabitants of the Southern, Central and Northern areas of the village discuss mercury with people living in their own area. For both men and women, the intensity of discussion is significantly higher between the inhabitants of the Southern area than between those who live in the other two areas (ANOVA, $p<0.05$ and $p<0.01$, respectively for men and women). Considering men and women together, the MNDPs of the inhabitants of decrease from 5.2 in the Southern area to 3.0 and 2.3 in the Central and Northern areas respectively.

Figure 6



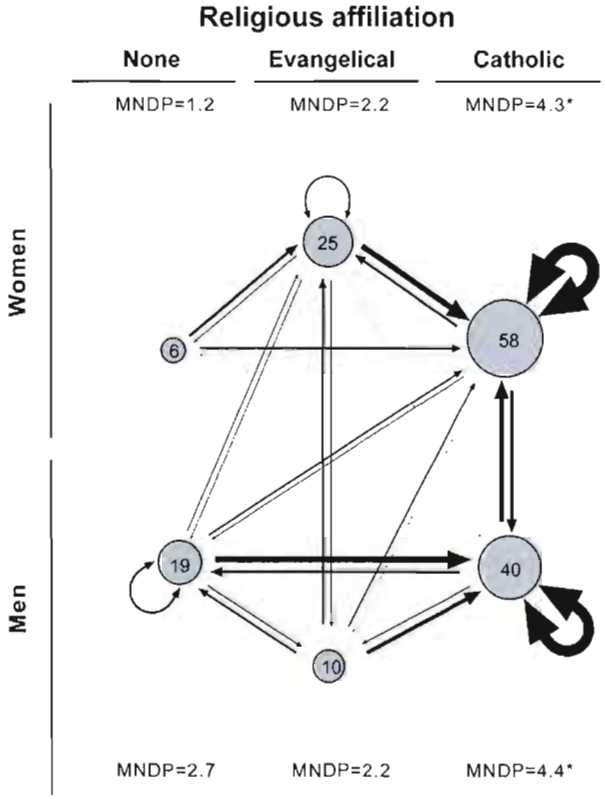
Discussion network on mercury within and between groups defined according to the spatial distribution of the house, by gender (*p<0.05 and **p<0.01).

Religious affiliation

Five churches are present in the Brasília Legal community. The majority of the villagers interviewed reported attending the Catholic church (58 and 65 % of men and women respectively). Only 7 % of the women did not attend any church, against 28 % of the men. Church attendance of the remaining population is distributed between 4 evangelical churches (Assembly of God, Presbyterian, Baptist and Christian Congregation). Since there were very few members in each of the evangelical affiliation groups, individuals were pooled into one evangelical group to allow comparison with the Catholic affiliation group and with

the group of people who do not attend any church. Results presented in figure 7 show that discussion about mercury between the villagers is associated with their religious affiliation. A similar pattern, showing a deep involvement of the catholic community in discussion about mercury, is observed for men and women. Men and women attending the Catholic church have on the average significantly more discussion partners than men and women with evangelical or no religious affiliation, respectively (ANOVA, $p<0.05$, between the Catholics and the other two groups). Furthermore, the thickness of the reflexive arrows for both Catholic groups indicates that men and women discuss mercury issues much more frequently within their own religious group than with individuals with evangelical or no religious affiliation.

Figure 7



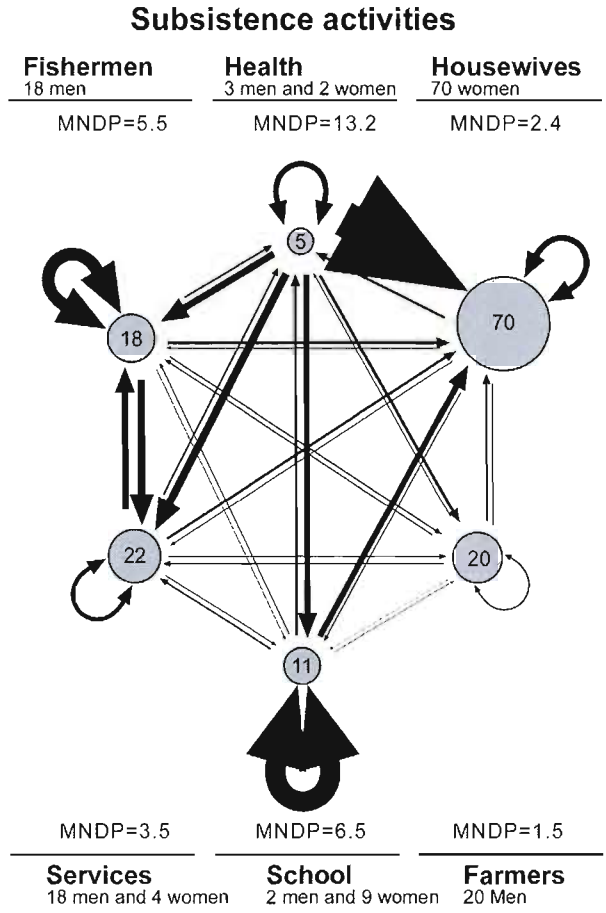
Discussion network on mercury within and between groups defined according to religious affiliation, by gender (*$p<0.05$).

Subsistence activities

In figure 8, villagers were aggregated into groups according to their main subsistence activities. The housewives group consist of 70 women whose main activities are to take care of children, prepare the meals for the family and clean the house. However many of them add to these daily task other activities like working with their husband in fishing or agricultural activities, taking care of a vegetable garden, or producing and selling handcraft. Seven men who worked in boat transportation, four as public servants, five in small grocery stores and two in house construction as well as two women who worked as domestic servants and two as public servants were included in the service group. Agriculture was the main subsistence activity for 20 men. Among men, 18 reported to be professional fishermen. Seven teachers (6 women and 1 man) and 4 public servants (3 women and 1 man) were working at the local public school. Five persons were working in the health sector: three men (one was selling pharmaceuticals, one was the community health worker and one is a nurse assistant) and two women (the midwife and a nurse). Four female students and 8 retired men were not considered for this analysis, to avoid cluttering the diagram with too many groups.

The intensity of involvement in discussion about mercury as well as the structure of the discussion network differs markedly between groups with different subsistence activities (ANOVA, $p<0.001$, between the six groups). The health workers' group is the one with the highest MNDP. On the average each member of the group discusses mercury issues with 13.2 villagers in our sample. Their involvement in these discussions is clearly directed to the other groups of the community with strong variations in intensity depending on the group involved.

Figure 8



Discussion network on mercury within and between groups defined according to subsistence activities.

Their MNDP with the other groups ranges from only 0.6 with the farmers' group to as much as 7.2 with the housewives' group. The local school workers' group discuss mercury issues with 6.5 villagers on the average. In sharp contrast with the health workers' group most of their discussion occurs with members of their own group with very little involvement with the other groups, except with the housewives group. Fishermen have a MNDP of 5.5. Their discussion partners belong mostly to their own group and to the service group, composed predominantly of men. Members of the service group have an average of 3.5 discussion

partners and direct most of their discussion to individuals belonging to their own group or to the fishermen's group. Each housewife discusses mercury issues with only 2.4 persons on the average and most of their discussion partner are women of their own group or health workers. The participation of the farmers in discussions about mercury is the lowest among all groups, with a MNDP of only 1.5.

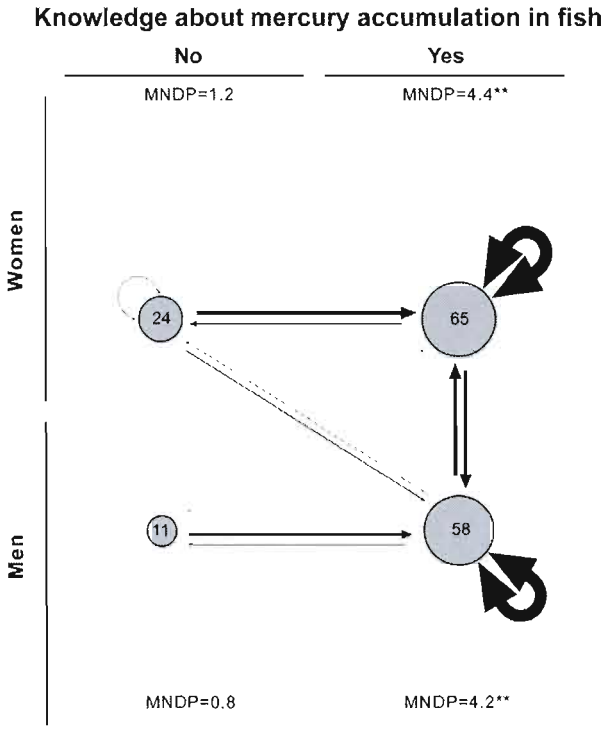
Knowledge about mercury accumulation in fish

The analysis presented in figure 9 addresses the possible link between discussion about mercury and the diffusion of the critical information necessary to allow the individual to change dietary habits toward the preferential consumption of the less contaminated fish species. Results show that both men and women who know the difference in mercury accumulation between herbivorous and piscivorous fish discuss mercury issues with a much higher number of partners on the average than people who are not aware of this information (ANOVA, $p<0.01$ between the two groups, for both women and men).

Discussion

The analysis of the discussion network on mercury illustrates how the problem of mercury contamination is now an important issue for the members of the Brasília Legal community. Association between discussion about mercury and knowledge of the critical information necessary to effectively reduce mercury exposure, while maintaining fish consumption, highlight the role of interpersonal communication between the villagers as one of the essential component in the process of change toward an improved health. However, a causal relationship cannot be assumed from these results and at least two alternative possibilities may contribute to the strong association between discussion about mercury and awareness. Discussion about mercury might be an efficient interpersonal channel for information exchange, contributing to awareness and extending the reach of the information about mercury issues beyond the individuals who were directly involved in the participatory

Figure 9



Discussion network on mercury within and between groups defined according to knowlegde about mercury accumulation in fish, by gender (**p<0.01).

process. Alternatively, it is also possible that people who are aware of the difference in mercury accumulation between herbivorous and piscivorous fish are more motivated to get involved in discussion about mercury.

Results show that the community is not an homogeneous entity and that the degree of participation in the discussions is highly variable between the villagers. Gender was shown to be only one of the dimensions of difference associated with discussion about mercury, indicating that the participation of particular men or women in the discussion should not be taken as representative of men or women in general in the community. The factors which may facilitate or constrain the involvement of the villagers in the discussion about mercury

were best revealed by performing analysis of disaggregated network data using gender combined with other axes of difference. We build on these results, which have been discussed with the villagers in a community workshop held in October 2004, to propose strategies for targeting excluded groups and for stimulating new roles of key actors in the community. These strategies are intended to provide guidance in a new cycle of participatory research (table 1: phase 5).

Strategies for targeting excluded groups in the new phase of participatory research

The data presented here allowed us to identify the groups of men and women who have significantly fewer discussion partners than the other groups according to specific axes of difference and who can be targeted for adapted participatory approaches to promote their effective involvement around mercury issues. For instance, farmers may be less involved in discussion about mercury issues because they frequently leave the village for several days for farm work in remote locations and may not feel much concerned by a problem centered around fishing practices and fish consumption. Promotion of their involvement in discussion about mercury issues should take into account the barriers specific to this group and the results of both health studies which have shown that farmers are among the community members with the highest hair mercury level (Passos, unpublished data), and biogeochemical studies which have highlighted the important relationships between slash-and-burn farming practices and mercury contamination of the ecosystems (Roulet et al., 1999).

Furthermore, the analysis of network structure allows to go beyond the identification of less involved people and may contribute to achieve a deeper understanding about how the various axes of difference may affect the involvement in discussion about mercury. Three examples illustrate how to take advantage of this understanding to promote participation in the next phase of the project.

The most obvious characteristics of the discussion network is that men discuss preferentially with other men and women with other women. The low level of discussion across gender may have some implications because men and women share responsibilities in

family nutrition that may influence mercury exposure of the whole family. The choice of fish for family consumption might be the subject of negotiation between men and women since it depends both on how men (in Brasilia Legal, more than 80 % of the adult men fish for family consumption) orient their fishing activities and choose the fish to be brought home and on how housewives select the fish to be included in the preparation of the daily meals. Consequently, the future phase of participatory research in Brasília Legal should simulate discussion between spouses as a strategy to promote family-level consensus allowing for the preferential consumption of the less contaminated fish.

Discussion patterns involving men's and women's groups attending the evangelical churches show that they discuss very little about mercury issues with other people of the same religious affiliation. This observation suggests that the evangelical churches do not provide an arena for debate and information exchange about mercury in Brasília Legal. To increase the degree of involvement of the evangelical church leaders in the CARUSO activities could be a significant step to put mercury higher on the agenda of these groups.

A striking characteristic of the discussion pattern between age groups is the very low level of interaction between the people 30 years old or younger. This observation calls for a specific approach with younger people because most of the pregnancies are likely to occur within this age group and it is well known that the health of foetus and young children is especially at risk in relation to mercury exposure (Grandjean et al., 1997, 1999).

Strategies for stimulating new roles of key actors in the new phase of participatory research

Up to now we have mainly focused on strategies for targeting groups relatively isolated in the discussion network about mercury. However, researchers should also take advantage of potentially influential groups who are highly involved in discussion about mercury and may play a critical role regarding health and development issues in the community. People working at the local school is one of these groups. Teachers and local school public servants are among the people with the highest level of education in Brasilia

Legal and are recognized as well-informed people and as a source of advice by many of the inhabitants of the village. They participated actively in CARUSO health studies and are keenly aware of the many aspects of the mercury problem in the Tapajos region. They have organized classroom activities about mercury issues with their pupils that are important for the future of the community. However, it remains to be assessed whether these initiatives have been able to promote discussion on mercury at the family level and whether they have had an impact on diet behaviors. Although it is one of the most active group in the debates about mercury, the analysis of the discussion network structure revealed that schoolworkers limit most of their interaction to members of their own group. Given their social position, if they broaden their range of discussion partners outside of their group, school workers could greatly contribute to the diffusion of the information and recommendations which are critical to allow the villagers to lower their exposure to mercury. Consequently, researchers could stimulate schoolworkers to share their knowledge more broadly within the community.

Study limitations and implications for future research

Our study is based on a snapshot of the discussion network and does not reveal how the involvement of the villagers in the CARUSO project has changed through time and how social interactions have contributed to the process that allowed mercury to gradually become an issue on the agenda of the community. In order to capture the evolution of the participation of the various groups in the discussion network regarding mercury issues, a follow-up network study will be conducted in the next phase of participatory research.

By using the MNDPs to assess groups' involvement in the discussion about mercury, we do not take into consideration the intra-group variability. This limitation is partially overcome by disaggregating the network data according to several axes of difference, which allowed us to build and compare a wide range of different groups. However, another limitation of our study is that the variables used to disaggregate the discussion network data were externally-defined and may fail to match with other dimensions of difference based on the community power structures which may contribute to shape interpersonal relations between the villagers. In the next phase of participatory research, we will involve the

villagers in the definition of the variables to be used to measure the dimensions of difference in order to build social categories which are relevant to them and better reflect local diversity. We could also use blockmodeling techniques (Wasseman & Faust, 1994) in order to look for groups sharing similar patterns of interaction within the network.

Conclusion

Network participatory intervention for promoting equity

In the next phase of participatory research in Brasília Legal (table 1: phase 5), targeted activities involving farmers, people under 30 years old or younger, people attending evangelical churches and school teachers will be organized to promote debates centered around the specific role of each group in the building of solutions to reduce the environmental and social impact of mercury contamination. These activities will provide an opportunity for the participants to discuss their specific preocupations and to formulate recommendations which may not have emerged before in the participatory process and will be included in the new cycle of inquiry, reflexion and action. By involving previously excluded social groups and by stimulating new roles for key actors of the community, we believe that the integration of the network approach in the cycle the participatory research in Brasília Legal will result in a significantly stronger role of the villagers in the guidance of the research project, which provides an important step toward collegial participation.

The present study suggests that social network analysis is a useful approach to take in consideration how men, women, and the various social groups differ in their involvement with environmental and health issues, according to their repective role in the community. Although this network approach is presented in the specific context of the Caruso study, it has a much more general appeal and we believe it may be applied to integrate community participation and equity in the research framework of the ecosystem approach to human health, in a broad range of projects.

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CHAPITRE 4

EMERGENCE AND ROBUSTNESS OF A COMMUNITY DISCUSSION NETWORK ON MERCURY CONTAMINATION AND HEALTH IN THE BRAZILIAN AMAZON

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Abstract

Information exchanges, debates and negotiations through community social networks are essential to ensure the sustainability of the development process initiated in a participatory research and to allow the population to adapt their actions to the evolution of the environmental and social contexts. Here, we analyze the structural properties and robustness of the discussion network about mercury issues in a community from the Brazilian Amazon involved in a participatory research whose objectives are to study the dynamics of the pollutant in ecosystems, evaluate health effects and reduce exposure. Most of the villagers are connected in a large network, where they are, on average, separated from any other individuals by few intermediaries. Furthermore, the structure of the discussion network displays resilience to the random elimination of villagers, but shows vulnerability to the removal of one villager who has been a long-term collaborator of the project. Although the network exhibits a structure likely to favor an efficient flow of information regarding mercury issues in the village, these results show that, in order to ensure the sustainability of the communication process, specific actions should be taken to stimulate the emergence of a pool of opinion leaders and increase the redundancy of discussion channels.

Introduction

Participatory research has increasingly emerged as an important approach to promote development while taking into consideration the complex links between the health of the human population and the sustainability of the ecosystems upon which human welfare depends (Forget & Lebel, 2001). This approach offers an opportunity for local people and researchers to share their knowledge, to create new understandings and to work together to form and implement action plans (Cornwall & Jewkes, 1995). Participation of communities in the research process is essential to ensure local ownership of the research results and build solutions that are adapted to sociocultural contexts and meet population needs.

A successful participatory research program should allow the community to engage in a long-lasting process of development after the research program has ended and to adapt their actions to the evolution of the environmental and social contexts. Information exchanges, debates and negotiations between the community members are key to promoting the sustainability of this process by allowing them to continuously interpret their situation through taking into account new information to promote adaptative development strategies. At the level of the entire community, the collection of individuals involved in information sharing and discussion forms a network that can be studied using the concepts and tools of social network analysis. In the present article, we analyze the structural properties and robustness of a discussion network in the context of changing socio-environmental conditions, to inquire into the process of communication between the members of a community, which has been involved in a participatory research project.

Background of the Caruso project

Since 1994, the Caruso project, a participatory research based on the ecosystem approach to human health, has been exploring the links between the impact of human activities on the ecosystem, mercury environmental contamination and the health effect of human exposure among riverside populations in the Tapajós region, in the Brazilian Amazon. Biogeochemical studies showed that deforestation resulting from ''slash-and-burn''

agricultural practices has caused intensive erosion of soils rich in naturally occurring mercury, contributing significantly to the contamination of waterways (Lucotte, Davidson, Mergler, Saint-Charles, & Guimarães, 2004) and that climatic conditions and aquatic vegetation in many of the Tapajós ecosystems are optimal for mercury methylation, speeding up the process of the incorporation of mercury into the aquatic food chain, up to humans (Lucotte et al., 2004). Wide intra- and inter-species variations in mercury concentrations were observed in the aquatic fauna of the Tapajós region, the highest mercury levels being consistently found in piscivorous species, and the lowest in herbivorous species (Lebel, Roulet, Mergler, Lucotte, & Larribe, 1997).

Because the nervous system is a prime target for methylmercury, the populations exposed to methyl mercury through fish consumption are placed at a disadvantage with respect to adequate development of intellectual and physical capacities due to nervous system deficits. Neurofunctional testing conducted with the inhabitants of Brasilia Legal, a small village located on the banks of the Tapajós river, to determine the health impacts of mercury exposure through fish consumption, showed significant declines in motor coordination, certain visual functions as well as cytogenetic properties (Amorim et al., 2000; Lebel et al., 1998). In 1998, Caruso researchers invited the villagers to participate in a pilot project based on dietary changes which sought to reduce human mercury exposure while maintaining fish consumption. The consensus reached by the researchers and the community favored a recommendation where all fish can be eaten, but where diet was directed towards more frequent consumption of less contaminated fish species. Comparison of diet and exposure of the same persons in 1995 and in 2000 (n=47) showed that they continued to eat the same quantity of fish, but modified the relative proportions of piscivorous and herbivorous fish. Consequently, hair mercury levels among the tested population decreased by approximately 35% (Mergler et al., 2001).

Sustainable solutions to reduce mercury exposure in changing social and environmental conditions

The Tapajós region is a very active colonization frontier, with changing social and environmental conditions which may have a significant impact on mercury dynamics in the ecosystems as well as on human exposure to the contaminant (Lucotte et al., 2004). Changes in the villagers' fishing practices in response to the opening of new markets or to the reduction in the availability of the most-valued fish species as the result of overfishing by commercial fleets are likely to affect fish consumption and mercury exposure. Mercury contamination of the aquatic ecosystems of the Tapajós is also very likely to increase as the consequence of growing deforestation rates associated to the rapid expansion of the soybean agricultural frontier (Fearnside, 2001). Current land and fire use practices by the local farmers are also likely to create positive feedbacks in future fire susceptibility, fuel loading, and fire intensity which may amplify the impacts of agriculture on deforestation and mercury mobilization into aquatic ecosystems (Cochrane et al., 1999). Furthermore, these rapid environmental changes are associated with intense migratory movements both locally and regionally (Perz, 2002).

Tangible results from the pilot project carried out in Brasilia Legal highlight how the participatory approach has been successessful in initiating a process of change in the community to reduce mercury exposure. It remains however to be assessed whether the project has reached a sufficient level of autonomy to become independent from the outside project initiators. It is indeed essential for the community, on the longer term, to gain empowerment in order to respond to changing socio-environmental conditions and to further develop and adapt their actions to sustain efficient solutions in regard with mercury contamination.

From 1994 to 2001, community meetings, face to face interviews as well as informal discussion have provided numerous opportunities for information sharing between researchers and many villagers. The interactions between researchers and community members were important to collectively discuss the research results and build strategies to

reduce mercury sources and exposure. Equally important to the diffusion are the discussions and debates regarding mercury issues which may have emerged between the villagers themselves, in the course of seven years of participatory research in the community. Indeed these discussions may extend the reach of the information about mercury issues beyond the individuals who were directly involved in the research and allow the diverse social groups to share their concern and to make sense of the available information as a basis for action.

In order to evaluate if continuous long-term information sharing between the villagers are likely to be efficient in allowing new information regarding mercury issues to reach most people of the community, we investigated the structural characteristics and robustness of the discussion network about mercury issues in the Brasília Legal community.

Social network analysis as a tool to investigate the pattern of information exchanges about mercury issues

A network is a set of items, which are called nodes, with connections between them, called links. A social network is a collection of individuals, each of whom is connected with some subset of the others, through specific social ties (Wasserman & Faust, 1994). Social network analysis studies the relationships between the behavior of the individual at the micro level and the pattern of interactions between the individuals at the macro level (Wasserman & Faust, 1994). These relationships are explored by measuring composition variables which are defined at the level of the individual, like gender, age, economic activities, religious affiliations or place of birth and structural variables which are defined for pairs of individuals and describe ties of a specific kind (Wasserman & Faust, 1994). Structural variables are the cornerstone of social network data sets and are used to reveal the patterns of people's interactions. Friendships (Fararo & Sunshine, 1964), scientific collaborations (Newman, 2001), sexual relationships (Bearman, Moody, & Stovel, 2002; Liljeros, Edling, Amaral, Stanley, & Aberg, 2001), E-mail communications (Ebel, Mielsch, & Bornholdt, 2002), advice in organizations (Saint-Charles & Mongeau, 2005) and acquaintance relationships (Bernard, Kilworth, Evans, McCarty, & Selley, 1988; Csányi & Szendroi, 2003) illustrate the

wide variety of social interactions which have been studied from a social networks perspective.

Network properties and efficiency of the communication process

Three properties are especially relevant to assess the communication potential of a network, i.e., the possibility that an information can reach most individuals composing the network : the level of fragmentation of the network associated to the existence of distinct components, the degree distribution, and the average distance (Wasserman & Faust, 1994).

For an idea or an information pertaining to an individual to reach another, the two have to be connected, either directly or through some other people. If there is a path between every pair of individuals in the information exchange network, it is said to be connected and messages can flow between all pairs of individuals. Alternatively, if the network is composed of several distinct subsets in which there is no path between the individuals of the different subsets, it is said to be disconnected. These subsets are called components and information can circulate only between the individuals belonging to the same component, but not between the individuals belonging to different components (Wasserman & Faust, 1994).

The degree of a node, k, is the number of links the node has to other nodes. The degree distribution, defined as the fraction of nodes in the network that have degree k, is obtained by counting the number of nodes with k = 1, 2, 3... links and dividing by the total number of nodes. Different classes of social networks can be distinguished according to their degree distribution (Albert & Barabási, 2002). Single-scale networks are characterized by a degree distribution exhibiting a fast decaying tail, such as exponential or Gaussian, and there are no highly connected nodes (Amaral, Scala, Barthélémy, & Stanley, 2000). By contrast, scale-free networks are characterized by a degree distribution with a tail that decays very slowly, such as a power law, which indicates that the huge majority of the nodes have a small degree, while a few nodes have a very high number of links and are responsible for the overall connectivity of the network (Amaral et al., 2000; Barabási & Albert, 1999). Single-scale degree distribution has been frequently found in social networks build upon

relationships which require face to face interaction, because investment in time and energy necessarily imposes a severe limitation on the number of social ties an individual may possess (White & Houseman, 2003). Friendship and acquaintance networks (Amaral et al., 2000; Bernard et al., 1988; Fararo & Sunshine, 1964) as well as an adolescent romantic and sexual network in a high school in the United States (Bearman et al., 2002) are examples of single-scale social networks. The web of human sexual contact is a notable exception. Indeed Liljeros et al. (2001) showed that the cumulative distribution of the number of different sexual partners in one year decays as a scale-free power law. In information sharing networks, the degree of a node is the number of discussion partners of the individual and the analysis of the degree distribution provides information about the involvement in the debates at the community level.

The ability of an information to be transmitted from one individual to another is also dependent of the distance between them in the discussion network. The distance between two nodes is defined as the number of links in the shortest path between them (Wasserman & Faust, 1994). The average distance - the average of the distances between every pair of nodes in the network - is a global measure of separation and can be used to assess the efficiency of the communication process at the level of the entire network. Short average distance in social network is believed to promote efficient communication, allowing information to be transmitted between any two individuals with only a small number of intermediaries. Numerous authors have identified short average distances between individuals in a variety of social networks: film-actor collaborations (Watts et Strogatz, 1998), scientific collaborations (Newman, 2001), E-mail exchanges (Ebel et al., 2002), online acquaintance relationships (Csányi & Szendroi, 2003) and friendship on the web (Adamic & Adar, 2003).

Network robustness and sustainability of the communication process

A key feature of networks is their topological robustness, which refers to their ability to respond to changes in the external conditions or internal organization while maintaining relatively normal behavior (Albert & Barabási, 2000). Robustness of networks to sustain efficient communication between all nodes of a given network has been evaluated, using

computer simulations, by analyzing fragmentation of the network into small isolated components and increase in the average distance, in response to the successive removal of selected nodes. Computer simulations used to evaluate network robustness can be compared with empirical longitudinal network data and are useful to develop models of network dynamics according to a variety of scenarios. Scale-free networks appear very sensitive to losing the rare highly connected nodes, while relatively robust to randomly losing the more highly abundant less connected nodes (Albert & Barabási, 2000). In contrast, single-scale networks, in which nodes have similar numbers of connections, display similar responses to the loss of highly connected and random nodes (Albert & Barabási, 2000).

The main objectives of the present study are to analyze the structure of the mercury discussion network involving the villagers of the Brasilia Legal community after seven years of participatory research, in order to identify individuals who may play a distinctive role in the information flow and to assess the robustness of the discussion network to sustain information exchanges even if a significant fraction of the community members cease to get involved in the discussion about mercury.

Methods

The study was carried out in the village of Brasília Legal, situated on the banks of the Tapajós River, a major tributary of the Amazon River, Brazil. A map of the study region is available on the Caruso project web site: http://www.unites.uqam.ca/gmf/caruso/caruso.htm. In September 2001, a meeting was held in the Brasilia Legal community to invite the villagers to participate in the network study. A complete mapping of the community, done in collaboration with the villagers, revealed that the village had a total of 110 households. Data were collected using semi-structured face-to-face interviews that were conducted by the principal investigator privately at the respective homes of the participants in October 2001. Since households are mostly represented by nuclear families, our strategy, in order to maximize de size of our sample, was to visit each household several times at different times of the day to invite the household heads (usually a couple) to participate in the interview. If

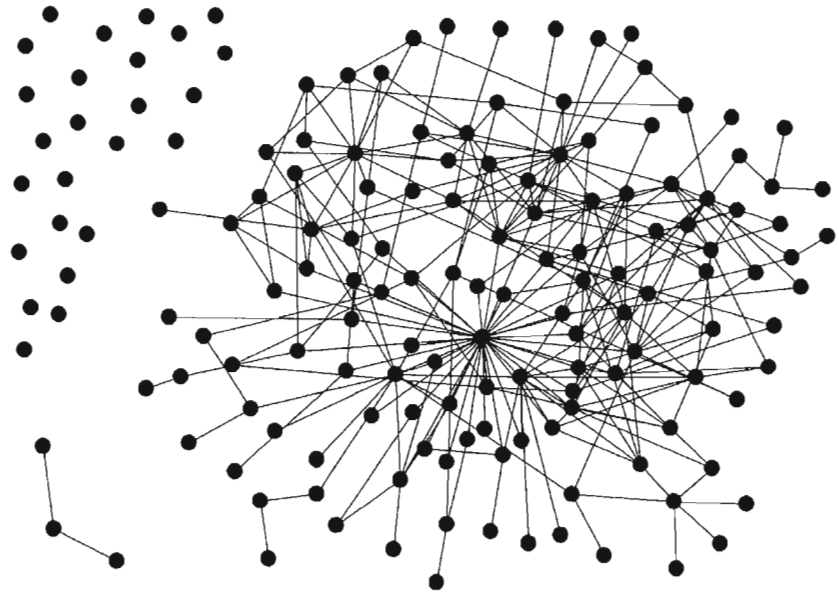
the household heads were repeatedly absent after several visits, another person in the house was interviewed. This strategy allowed us to conduct the interview with a total of 158 persons, from a total of 96 households. People from the remaining 14 households could not be encountered, either because they were not permanent members of the community, had moved recently or were temporarily absent for health or professional reasons.

Interpersonal communication on the mercury issue was assessed by asking the respondents to name the individuals with whom they usually discuss about the subject, whether in the context of health, diet or fishing. Our intention with the phrasing of the question was to preferentially select network partners with whom the respondent had substantial conversation about mercury and not merely casual talks. From a total of 363 nominations directed at individuals living in the village, including those living in the same household, 322 (89 %) were directed at individuals who had been interviewed and 41 (11 %) were directed at individuals who were not included in our sample. Network ties with individuals who could not be interviewed were dropped from the analysis since no information was available for these network partners. In order to obtain the most complete picture possible of the network, two individuals were considered as discussion partners if either person mentioned the other. Network data were stored as an actor-by-actor matrix using the UCINET software (Borgatti, Everett, & Freeman, 2002) and then exported to the Netdraw software (Borgatti, 2002) to visualize the structure of the discussion network as presented in figure 1. The distance matrix between all pairs of nodes belonging to the main component was obtained using the UCINET software (Borgatti et al, 2002). Computer simulations were performed to test the robustness of the main component of the mercury discussion network by randomly removing, 2, 5, 10 and 20 % percents of the nodes, as well as all the links attached to them. The networks obtained in 10 independent experiments for each percentage of randomly removed nodes were analyzed using the UCINET program to calculate the number of nodes and the average distance in the largest component.

Results

Figure 1 presents the discussion network about mercury in the Brasília Legal village. The nodes are depicted as circles. Two nodes are connected by a line if one or both individuals reported discussing with the other about mercury issues. The network analysis revealed one small component linking three individuals, as well as 25 isolates who did not participate in the discussions about mercury. However, the most striking characteristic of the network is that the majority of the respondents belong to one main and relatively dense component comprising 130 members linked together by 281 discussion relationships. These villagers are probably not aware that they belong to a large discussion network, which emerges as a macro-structure resulting from the integration of the individual interactions. However, this component defines both the boundaries and the preferential channels for potential circulation of the information about mercury and will be examined in the next sections of the article.

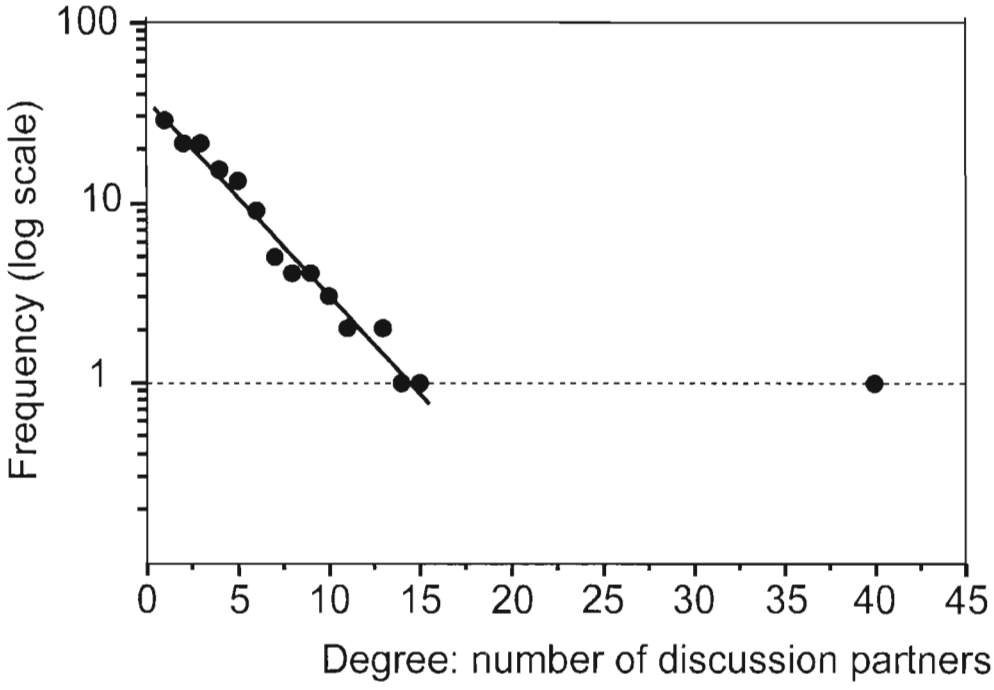
Figure 1



The discussion network about mercury issues between the villagers of Brasília Legal (n=158).

Fig. 2 shows a linear-log plot of the distribution of the number of discussion partners for the main component of the network. The degree distribution is well approximated by exponential decays, consistent with a single scale for the connectivities. However one villager has a very high number of discussion partners and emerges as an outlier to the exponential distribution. This person has been – since the beginning of the Caruso project – involved in many research activities and will be thereafter referred to as the Caruso collaborator.

Figure 2



Linear – log plot of the distribution of the numbers of discussion partners for the main component of the mercury discussion network. The full line is a guide for the eye of what an exponential decay would be.

To further evaluate the role played by participation in the Caruso project, villagers were divided into 3 groups according to the year of their first participation in the project. The average number of discussion partners of the villagers who participated for the first time in 1995 (n=36), 2000 (n=31) and 2001 (n=90) decreases from 4.6 to 4.1 and 2.5, respectively (the Caruso collaborator has been removed from this analysis).

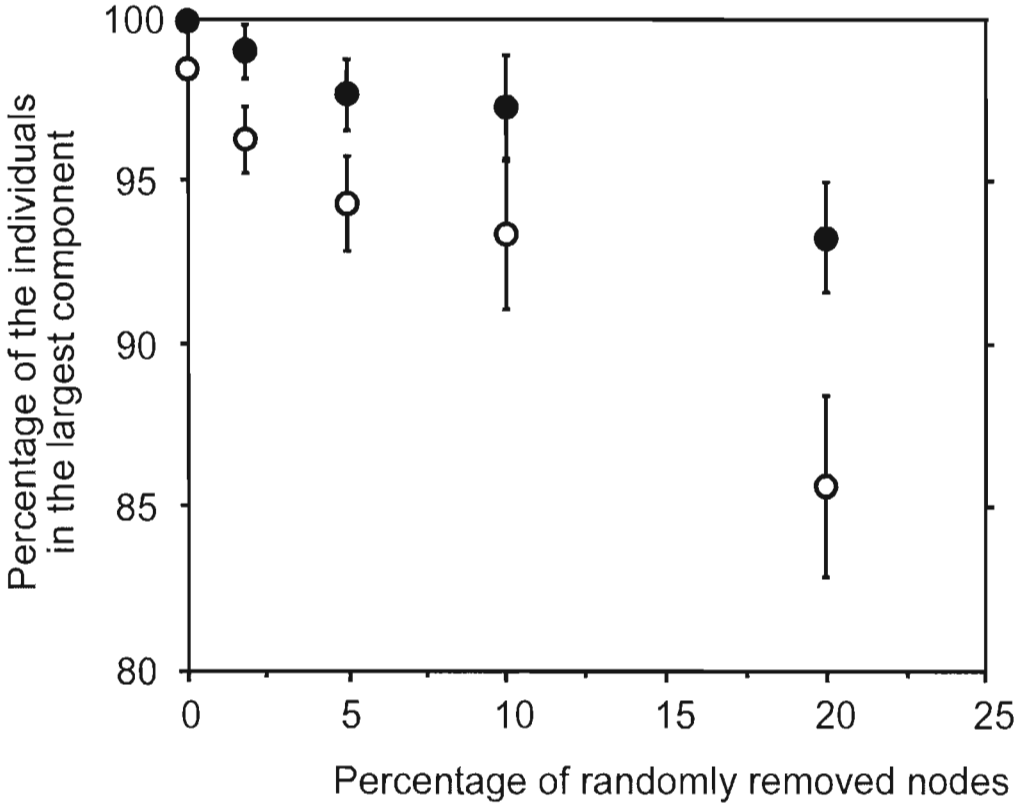
The average distance between villagers belonging to the main component of the mercury discussion network is 3.4, which means that on the average, people are separated by only 2.4 intermediaries. The distribution of distances is homogeneous, peaks around a value of 3 and exhibits a tail that decays even faster that what would be expected for an exponential function (data not shown).

Each year, some individuals will stop to be involved in discussion about mercury, mainly as the result of migration out of the village. As a consequence some paths that contribute to the system's interconnectedness will be eliminated, affecting the circulation of information in the community. Two potentially negative effects are the fragmentation of the network in small non-communicating components and the increase in the communication distance between villagers. The robustness of the main component of the mercury discussion network to sustain information exchanges between community members can be tested by randomly removing a increasing percentage of the nodes through computer simulations and by analyzing the impacts on network fragmentation and on the average distance.

Changes in the percentage of the individuals who remain connected in the largest component of the discussion network and in the average distance between individuals in this component are presented as the function of the random removal of 2, 5, 10 and 20 % of the nodes. The Caruso collaborator was excluded from the set of nodes that could be targeted for random removal from the network. However, in order to evaluate specifically the role of this person in the robustness of the network two sets of simulations have been performed, either in the presence (filled circles) or alternatively in the absence (empty circles) of this individual from the network.

Data in figure 3 show that, in the presence of the Caruso collaborator, most of the individuals (93%) remain connected in a large component even if up to 20% of the nodes are randomly removed. The selective removal of the Caruso collaborator alone does not lead to a significant fragmentation of the network and 98% of the individuals remain connected. However, in the absence of the Caruso collaborator, the discussion network become much more vulnerable to the random elimination of a fraction of the individuals and we observe a synergistic effect on the fragmentation of the network as more individuals are randomly removed. Nevertheless, a large component, connecting 86% of the individuals on the average, persists even if both the Caruso collaborator and 20 % of the individuals are eliminated.

Figure 3



Percentage of individuals remaining connected in the largest component of the mercury discussion network as a function of the percentage of randomly removed nodes, in the presence (filled circles) or absence (empty circles) of the Caruso collaborator. Error bars represent one standard deviation above or below the mean value of ten simulations.

The average distance between the individuals who remain connected in the largest component of the discussion network increases significantly, from 3.4 to 4.1, as a consequence of the removal of the Caruso collaborator from the network (data not shown). Average distance is however little affected by the random removal of up to 20% of the nodes from the network, either in the presence (3.5) or the absence (4.3) of the Caruso collaborator.

Discussion

The structural analysis of the discussion network about mercury in the Brasília Legal community revealed that most of the inhabitants of the village are connected in a large component, where they are on average separated from any other individuals by very few intermediaries. In a previous study, we have shown that information exchanges about mercury between the members of the community are likely to influence the actions to undertaken by the villagers to reduce exposure (Mertens, Saint-Charles, Mergler, Passos, & Lucotte, 2005). Indeed, participation in the mercury discussion network was found to be associated with the awareness of the critical information necessary to allow the individual to change dietary habits toward the preferential consumption of the less contaminated fish species. A short average distance in the discussion network is likely to favor an efficient flow of critical information regarding mercury issues in the village and to be important to create a common understanding of health problem associated with mercury contamination. This property of the discussion network may have contributed to the success of the pilot project in reducing mercury exposure, while maintaining fish consumption.

Although the discussion network has been built using data from one unique time point (2001), the present study shed some light on the possible dynamics of information exchanges about mercury in the village. On the one side, the analysis of the structural properties of the discussion network provides insights about the past processes that allowed mercury to gradually become an issue on the agenda of the community. On the other side, the results from computer simulations allow us to test possible scenarios about the future evolution of the discussion network in response to a changing environment.

How mercury became an issue on the agenda of the community

The discussion network on mercury illustrates how the problem of mercury contamination is now an important issue for the members of the Brasília Legal community. Since the participation in discussions about mercury has probably been a progressive process, paralleling the gradual involvement of the community in the participatory research, it is likely that the discussion network we have described using data collected in 2001, is the result of a growing process. The degree distribution of the main component of the discussion network, that decays exponentially, is compatible with a random growing network model (Alberts & Barabási, 2002). This model starts with a small number of nodes, add a new node to the network at every time step and assume that new nodes connect with equal probability to the nodes already present in the network. According to this model older nodes in the network will, on the average, have a higher number of links than new ones. Data showing that individuals who became involved earlier in the Caruso studies have, on the average, a higher number of partners in the mercury discussion network, provides further support to the random growing network model.

However, the very high degree of the Caruso collaborator suggests that a mechanism of targeted preferential attachment directed toward this person was also at play in the growing process. The central role of the Caruso collaborator in the discussion network may have emerged progressively both as a consequence of his distinctive role in the participatory research and because villagers have increasingly recognized this individual as a key resource person to turn to for reliable information about mercury issues.

The evolution of the discussion network in a changing environment

The discussion network displays resilience to the random elimination of discussion partners, which suggests that the community will be able to sustain a communication process about mercury involving most of the villagers even if a relatively high fraction of the individuals stop being involved in discussion about mercury. However data show that the vulnerability of information exchanges at the community level is likely to increase

significantly if the Caruso collaborator is no longer participating in the discussion network. This observation strongly suggests that circulation of information in the community is overly reliant on the Caruso collaborator and would be at risk in a situation where this person would either leave the village or loose interest in being intensely involved in mercury issues.

Study limitations and implications for future research

The focus of the analyses has been on the main component of the discussion network. However, any initiative to promote the diffusion of information in the community as well as equity in the involvement around mercury issues also need to take into account the individuals who are disconnected from this component and can presumably not be reached by the main flow of information about mercury.

Furthermore, the individuals position in the network and their number of discussion partners have revealed unequal involvement around mercury issues between the different social groups of the community, as well as between men and women within households (Mertens et al., 2005; Mertens et al., 2006). A network intervention, aimed at promoting equitable participation of all villagers in the debates and actions to reduce both mercury sources and human exposure, is currently being carried out, integrating the information from the purely mathematical approach based on random deletion to evaluate the network robustness and the involvement of the villagers in the discussion according to their social characteristics (Mertens et al., 2005).

Our simulations are based on the random removal of individuals from the network. However, the dynamics of the discussion network are likely to involve both non-random elimination of discussion partners and the addition of new individuals and links. Indeed several members of the same family may leave the village simultaneously and the consequences of these group migrations out of the village remain to be addressed. Furthermore, each year, new individuals arrive and settle in Brasília Legal. They are likely to progressively get involved in the discussion about mercury, contributing to new links in the network, which may offer alternative channels of communication and compensate for the loss

of connectivity resulting from migration out of the village. However, newcomers may also draw the villagers away from their involvement around mercury issues by diffusing opinions bringing discredit on them or by establishing diverging agendas for the community. A longitudinal analysis is currently being carried out to inquire into the dynamics of the formation and dissolution of the links in the mercury discussion network and to investigate the role of potential underlying factors like changes in the involvement and interest of the individuals and social groups in mercury issues and migrations in and out of the village.

The longitudinal study will also allow us to investigate possible changes in the structural configuration in the discussion network as the community engages in further stages in the diffusion process, from the creation to the maintenance of a common understanding of mercury-related health problems. The mapping of the types (kinship, friendship, occupational) and strength (reciprocal and/or multiplex) of the social ties which are associated with information exchanges on mercury will also provide valuable information regarding the social processes taking place in the community associated to the different stages of the diffusion process. Using these data, we will refine our simulations and modeling approaches to be able to adapt our strategies to promote the appropriation of information about mercury to other communities of the Tapajós region.

Implications for practice: a two step network approach for health promotion work

Participatory health promotion projects face two simultaneous challenges: achieve effective improvement in community health and guarantee a sufficient level of autonomy of the community in sustaining a better health status in a changing social and environmental context, independently from the work of the outside project initiators. Since it is usually not possible to carry out long term longitudinal study to monitor the sustainability of health promotion work, there is a need to develop methods that provide the basis to design intervention that will maximize the conditions of long lasting health improvement. We propose a two step network approach that can be used first as a method to better understand the success and difficulties associated to health promotion work by analysing how the relevant information circulates in the community and by identifying the key persons

involved, and, as a second step, to evaluate the potential for sustainability of the results of the health promotion work by analysing the robustness of the information exchange network in the community. The first step of this approach has been applied in numerous studies (see for example: Bond, Valente & Kendall, 1999; Stoebenau & Valente, 2003) and can be used to examine the extent to which health promotion agents have reached the community and to assess the degree to which communication with the agents has affected health. The second step of this approach is illustrated in the present article and in Mertens et al. (2006) and can be used to carry out interventions to increase the robustness of the network by designing and implementing specific participatory activities to stimulate either the emergence of a pool of opinion leaders able to reach the various social groups or a reorganization in the network in order to promote connectivity and increase redundancy of channels through which information could flow. This two step methodology can be applied in a variety of health promotion contexts and, as an example, it has been successfully used to evaluate the structural properties and robustness of the information exchange and collaboration networks between the members of the civil society and health workers in a national occupational and environmental health program carried out by the Ministry of Health of Brasil (Mertens et al. unpublished).

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CHAPITRE 5

STRONG-TIE SMALL-WORLD NETWORK REVEALED BY INTEGRATING MULTIPLE SOCIAL DIMENSIONS

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Abstract

Empirical and theoretical studies of social networks have suggested that the small-world structure is unlikely to be found in networks composed exclusively of strong ties. However, these studies analyzed networks using only one social relationship. Using community and intra-organizational network data, we show that although the strong-tie small-world structure was not found in single social dimension networks, this topology can emerge by integrating several social dimensions. We provide arguments to propose that the multiple social dimension strong-tie small-world structure can be used as an indicator of social capital at the community level.

Introduction

Small-world social networks

Small-world networks refers to a class of networks sharing two structural properties: local clustering much higher than in random networks and small average distance between nodes similar to what is found in random networks (e.g., Watts and Strogatz, 1998). Studies focusing on the simultaneous presence of these two properties in complex systems flourished after the discovery that this topology is shared among many real social, informational, technological and biological networks (e.g., Watts, 2004).

Social networks involving different kinds of interactions have been shown to belong to the class of small-world networks: film-actor co-participation (e.g., Watts and Strogatz, 1998; Barabási and Albert, 1999; Amaral et al., 2000), scientific collaboration (e.g., Newman, 2001), email communications (e.g., Ebel et al., 2002), friends and neighbors on the Web (e.g., Adamic and Adar, 2003), acquaintance relationships (e.g., Csányi and Szendroi, 2004). Several functional properties and underlying social principles, associated with high clustering and small average distance, are shared among small-world social networks. High clustering, characterized by a high frequency of connected triads, leads to redundancy in the local topology of the network, promotes robustness to resist fragmentation and provides a faster and more reliable diffusion in the network, as transmission may follow several alternate paths resulting in multiple exposure of the individual (e.g., Moody and White, 2003; Rogers, 2003). High clustering is believed to reflect local ordering principles like homophily - the tendency of individuals to interact with others who are similar in certain attributes (e.g., McPherson, 2001) - and triadic closure or transitivity - the higher probability of two individuals to be connected if they share a connection with a third individual than if they do not (e.g., Rapoport, 1953; Watts, 1999; Kossinets and Watts, 2006). Small average distance between individuals promotes communication efficiency and diffusion across the diverse areas of the network, as well as accessibility to resources (e.g., Watts, 2004; Moody and White, 2003). In small-world social networks, small average distance has been attributed to the existence of shortcuts acting as bridges between the densely connected clusters (e.g.,

Watts and Strogatz, 1998) or to the existence of nodes with unusually large numbers of connections (e.g., Barabási and Albert, 1999).

Tie strength and small-world properties

Tie strength can be defined as a combination of the amount of time, the emotional intensity, the intimacy and the reciprocal services associated to the relationship (e.g., Granovetter, 1973). Several lines of evidence suggest that strong ties tend to be more transitive than weak ties (e.g., Kossinets and Watts, 2006; Granovetter, 1973; Granovetter, 1983; Friedkin, 1980). Indeed a person's close friends are probably also each other's friends, while acquaintances are much less likely to know each other. Furthermore, the high social investment associated with strong ties imposes constraints on the number of these ties an individual is able to maintain active simultaneously (e.g., White and Houseman, 2003). Based on the combined effects of these two properties, several authors have argued that strong ties tend to fragment networks into small disconnected groups, each of which composed of individuals with many ties to each other (e.g., Watts, 1999; Granovetter, 1973; Friedkin, 1980). Weak ties, however, have been shown to connect people from distant social circles, favoring access to more diverse types of resources and diffusion of new information (e.g., Rogers, 2003; Granovetter, 1973; Granovetter, 1983; Burt, 1992; Hansen, 1999; Wegener, 1991). It has been proposed that weak ties act as bridges among dense clusters, connecting them into larger networks and reducing drastically the average distance between individuals (e.g., Watts, 2004; Granovetter, 1973 ; Granovetter, 1983; Dodds et al., 2003). There is indeed a close analogy between Granovetter's weak tie local bridges and Watts & Strogatz's shortcuts (e.g., Watts, D.J, and Strogatz, 1998; Granovetter, 1973). In some social networks, short average distance between individuals is associated with the ability of a small fraction of nodes, with a very high number of ties, to efficiently link nodes from diverse regions of the network (e.g., Barabási and Albert, 1999; Ebel et al., 2002). Because of the limitation in the number of strong ties an individual may be able to sustain simultaneously, the majority of links associated to hubs are probably also weak ties.

The evidence presented above supports the idea that strong and weak ties contribute differently to the structural properties of small-world networks and that both types of ties are needed for the emergence of this topology in social networks. Consequently, small-world topology would be an unlikely structure to be found in social networks composed exclusively of strong ties, because the latter would either be fragmented in small groups or exhibit long average distance among individuals.

The above conclusions, which depict the social world as a set of clusters connected by weak ties, are based on analyses of social networks which take into consideration only one dimension of social life, such as electronic communication, occupation or friendship. However, social life involves complex relational processes, in which individuals interact with each other on a variety of social dimensions simultaneously (e.g., Wellman and Wortley, 1990; Burt, 2005; Lazega, 2001; Saint-Charles and Mongeau, 2005). Indeed, many studies may have failed to reveal alternative network structures because they did not take into account the ability of individuals to connect different social groups, based on their multiple activities and affiliations. For instance, two individuals who belong to two different kin groups and have different occupations can be linked by a third who has a family tie with the first one - shares group membership according to the kinship social dimension - and works in the same company as the second – i.e. shares group membership according to the occupation social dimension. Watts et al. (2002) have recently proposed a model that shows that structural properties, like small-world topology, as well as functional properties, like searchability, may emerge in networks built by taking into consideration several social dimensions. In this model, networks are highly clustered in each social dimension because ties tend to be transitive among individuals who share a set of attributes. However, short average distance among individuals emerges because individuals interact on more than one social dimension, establishing connections among the different social groups.

The objective of the present paper is to use empirical network data to examine the structural and functional properties of strong-tie social networks built on single and multiple social dimensions. More specifically, we focus on the following question: Could the strong-tie small-world structure, which is not present when the single social is considered, be

revealed if several social dimensions are taken into consideration simultaneously? Furthermore, if the answer to the above question is yes, what are the relationships between the patterns of connection of the individuals at the local level and the emergence of this network structure at the global level and what are the possible implications regarding functional properties of social networks?

To answer these questions, we use network data on different social relationships collected in the community of Brasília Legal, a village situated on the banks of the Tapajós River, a major tributary of the Amazon River, Brazil. A map of the study region is available on the CARUSO project web site: http://www.unites.uqam.ca/gmf/caruso/caruso_home.htm. The census of the population revealed that the village had a total population of 557 people in 118 households among which 347 - those aged at least 14 - were invited to participate in the study. Data were collected for a total of 336 individuals; 11 could not be interviewed because of severe health problems or because they were temporarily living outside of the village. Semi-structured face-to-face interviews covering standard demographic characteristics and network questions were conducted privately at the home of each participant in October and November of 2004. People were asked about network partners living in the village, based on three different social dimensions: friendship, occupation and kinship. Reciprocity of the social relationship, which has been used to identify strong ties in several previous studies (e.g., Rogers, 2003; Kossinets and Watts, 2006; Granovetter, 1973; Marsden and Campbell, 1984; Haythornthwaite, 1996), is used here to build the village strong-tie friendship and occupation networks. To build the strong-tie kinship network of the village, only close kin relationships were included: between parents and children, brothers and sisters or between spouses. Network data were stored as actor-by-actor matrixes using the UCINET software (e.g., Borgatti et al., 2002) and then exported to the Netdraw software (e.g., Borgatti, 2002) to visualize the structure of networks.

Results

Strong-tie networks build on a single social dimension

Tables 1 and 2 show the main structural characteristics of the friendship, occupation and kinship strong-tie networks. None of these three one-dimensional networks are small-worlds. The friendship and occupation networks lack any component large enough to probe for small-world properties. They indeed share high levels of fragmentation into numerous isolates, respectively 126 and 169, and into small components, with a size ranging from 2 to 29 for the friendship network and 2 to 30 for the occupation network. Although the kinship network also exhibits a significant level of fragmentation (18 isolates and 23 small components), it has a major component which links close to 50% of the individuals and deserves structural analysis for small-world properties. Because households' family members form fully connected groups, the main component of the kinship network has a clustering coefficient much higher than the one calculated for a random network with the same number of nodes and ties (Table 3). However, the component has a tree-like structure which contributes to increasing in the average distance (7.5), which is more than twice the value of what is found in a random network. The structural properties of the kinship network demonstrate that it is not a small-world network because 50 % of the individuals are either isolates or belong to small components and the other 50%, although they are linked together, are separated, on the average, by a much greater distance than would be the case in a random network.

Strong-tie network integrating multiple social dimensions

The analysis of the three networks built using a single social dimension is in agreement with previous theoretical arguments and empirical observations, supporting the idea that strong-tie networks tend to be fragmented and do not have the small-world topology. A multiple social dimension (MSD) network was built by integrating the

Table 1: Main structural characteristics of friendship, occupation, kinship and MSD networks

Network	Friendship	Occupation	Kinship	MSD
Nodes	336	336	336	336
Links	177	167	571	793
Mean number of links per individual	1.1	1.0	3.4	4.7
Range of the number of links per individual	0-5	0-9	0-12	0-16
Isolates	126	169	18	3
Small components	42	42	27	1

Table 2: Distribution of components size in friendship, occupation, kinship and MSD networks

	Networks			
Component size	Friendship	Occupation	Kinship	MSD
330	0	0	0	1
167	0	0	1	0
30	0	1	0	0
29	1	1	0	0
23	0	0	1	0
18	1	0	0	0
16	0	0	1	0
15	1	0	1	0
14	1	0	0	0
13	0	0	1	0
11	1	0	1	0
8	1	0	2	0
7	3	0	0	0
6	1	1	0	0
5	3	2	2	0
4	5	4	3	0
3	5	10	5	1
2	19	23	10	0
1	126	169	18	3

Table 3 : Structural properties of the main component of the kinship and MSD networks

Structural properties	Kinship	MSD
Nodes	167	330
Size as a percentage	50	98
Links	362	790
Mean number of links per individual (<k>)	4.3	4.8
Range of the number of links per node	1-12	1-16
Maximum distance	22	15
Mean distance between nodes (D)	7.5	5.2
D random	3,5	3.7
D/D random	2.1	1.4
Clustering coefficient (C)	0.68	0.45
C random	0.026	0.015
C/C random	25	31

The average distance in a network, D, is the average of the distances between every pair of nodes (32). The clustering coefficient, c, (also called ego-network density, 32), defined for node i, which has n neighbors, is the ratio of the number of links between node i's neighbors that actually exist to the maximum possible number of links between these neighbors if they were all connected. The clustering coefficient of the network, C, is the average of the clustering coefficient for all nodes. These two measures, D and C, are used to probe the structure of small-world topology in real networks by comparing their value to those obtained in random graphs with the same number of nodes and links. In random graphs, D is approximately equal to ln(N)/ln<k> where N is the total number of nodes and <k> is the average degree, while C is approximately equal <k>/N (1).

friendship, occupation and kinship relationships, as shown in Figure 1. Individuals are connected by lines of different colors and sizes according to the type of relation and the number of social dimensions simultaneously involved. Since 9 links include simultaneously the three social dimensions, while 104 include two of them, the number of links of the MSD network is only 793, while the sum of the number of links of the three one-dimensional networks is 915 (Table1).

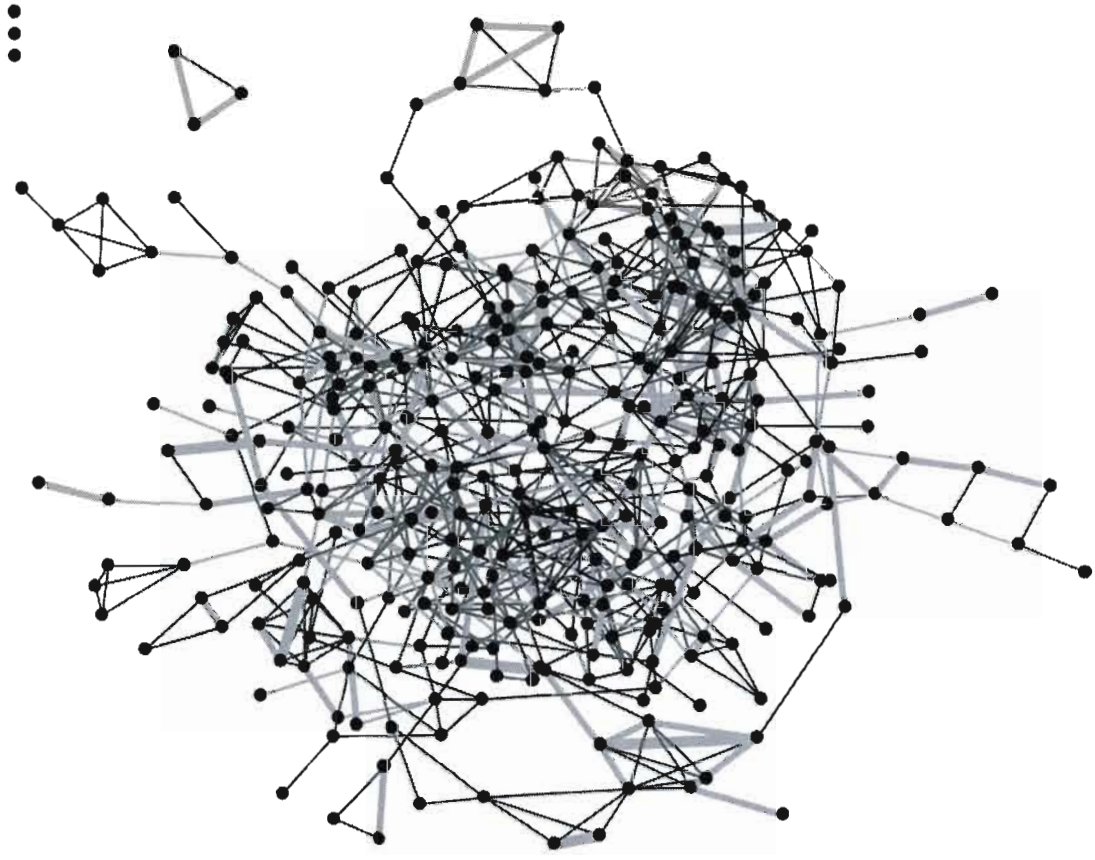
The most striking characteristic of the MSD network is that 98% of the individuals are connected in one single giant component (Table 3 and Figure 1). Only three individuals are isolated and there is only one small component consisting of a connected triad. The clustering coefficient of the main component of the MSD network is much higher than the one calculated for a random network with the same number of nodes and links (Table 3). The average distance between nodes is only 5.2, close to the corresponding value for the random network (3.7).

The above results show that, although neither the friendship, occupation nor kinship networks are small-world, the integration of the three social dimensions reveals that almost all individuals of the village are connected in a strong-tie small-world network, showing the properties of high clustering and short average distance.

Interdimensional connectors and the emergence of the strong-tie small-world structure

In order to analyze the processes involved in the emergence of the strong-tie small-world topology, based on multiple social dimensions, we analyzed the relationship between the pattern of connection of the individuals at the local level and the overall pattern of connectivity of the MSD network at the global level.

Figure 1



Friendship, occupation, kinship and multiple relations are respectively shown in green, blue, red and grey. Links involving two and three social dimensions are, respectively, twice and three times as large as the links involving only one.

The distribution of the number of links for the main component of the MSD network peaks around its mean value (4.7) and then declines exponentially, indicating that no individuals have a very high number of ties and that the short distance observed is not associated with the existence of hubs in the MSD network (data not shown).

Another likely explanation for the emergence of the MSD giant component is that individuals who have ties in more than one social dimension with different individuals could

act as connectors between friendship, kinship and occupation clusters. To test this hypothesis, we focused on two network measures that are able to differentiate between individuals based on their role as connectors: clustering coefficient and betweeness centrality (1, 33). Connectors are expected to have lower clustering coefficients than other individuals in the network because they link individuals who have no (or a few) ties between them. They are also expected to lie more frequently on the shortest path between pairs of individuals and consequently to have a higher betweeness than the other individuals in the network.

In table 4, non-parametric tests are used to compare clustering coefficient and betweeness among the three sets of individuals who have ties along 1, 2 or 3 social dimension(s) with different individuals in the main component of the MSD network. This analysis reveals highly significant differences in mean rank among the three groups for both measures. Individuals who have ties in only one social dimension tend to have high clustering coefficients, while individuals with ties in two and three social dimensions tend to have intermediate and low clustering coefficients, respectively. Furthermore, on the average, individual betweeness increases among groups with ties in one, two or three social dimensions. Since individuals who have ties in more than one social dimension have more ties on the average and since both clustering coefficient and betweeness are correlated to the number of ties, we repeated the analysis for sets of individuals who have the same number of ties in the MSD network. Individuals with degree 5 or higher were grouped because there were too few individuals in each category to allow for statistical analysis. As shown for the whole population, clustering coefficients decrease while betweeness increases significantly between the sets of individuals who have the same number of ties but have ties in 1, 2 or 3 social dimension(s) respectively. These results show that individuals who link friendship, kinship and occupation groups because they have strong ties along distinct social dimensions at the local level act as inter-dimensional connectors and favor the emergence of the giant component in the MSD network at the global level.

Table 4: Clustering coefficient and betweeness comparison in the main component of the MSD network

	Number of social dimensions with different individuals			
Number of ties in MSD network	1	2	3	p
2-16				
Number of individuals	55	162	88	
Mean rank for clustering coefficient	234	145	118	<0.0001
Mean rank for betweeness	76	148	210	<0.0001
2				
Number of individuals	16	23		
Mean rank for clustering coefficient	28	15		<0.001
Mean rank for betweeness	13	25		<0.01
3				
Number of individuals	14	40	8	
Mean rank for clustering coefficient	49	28	21	<0.0001
Mean rank for betweeness	18	36	34	<0.01
4				
Number of individuals	13	23	15	
Mean rank for clustering coefficient	39	27	13	<0.0001
Mean rank for betweeness	14	26	37	<0.001

5-16				
Number of individuals	12	76	65	
Mean rank for clustering coefficient	104	86	61	<0.001
Mean rank for betweeness	44	68	94	<0.0001

Non-parametric statistical tests (Mann-Whitney and Kruskal-Wallis) were conducted to assess the potential differences in the distribution of clustering coefficient and betweeness among the sets of individuals who have ties along 1, 2 or 3 social dimension(s) with different individuals in the main component of the MSD network. Non-parametric tests were chosen since normality cannot be assumed for either distribution. Mean rank is presented for each set of individuals. For each individual, clustering coefficient and betweeness were measured using Watts & Strogatz (1) and Freeman (32) measures respectively. Individuals with degree one were removed from the analysis because no clustering coefficient can be calculated for them and because their betweeness is equal to zero.

Functional properties of the MSD strong-tie small-world structure

The functional implication of the strong-tie small-world structure integrating multiple social dimensions was investigated by relating its distinctive properties and the social processes identified in the Brasilia Legal community to ensure food security, promote collective health and modify behavioral practices to reduce exposure to mercury, a toxic substance that accumulates in fish (e.g., Mergler et al., 2007).

The villagers depend on fish for a major part of their diet and the majority of men fish on a regular basis (e.g., Lebel et al., 1997). Fishermen usually fish in small groups and catch is shared among group members. There is a large diversity of fish species (e.g., Sampaio da Silva et al., 2005) and collective management of fish stocks is ensured by distributing fishing activities among the diverse locations surrounding the village and the wide diversity of fishing practices. The catch serves primarily for family consumption. Alternatively, fish can be sold at local markets to contribute to household earnings, but they are also frequently provided at no cost to other villagers who lack access to this resource, including single mothers or older individuals. Fish can thus be considered as a resource made

available by the collaborative work among fishermen (occupation ties) and made accessible to both household members (kinship ties) and people in need (friendship ties). Assuming that stronger ties favor these collaboration and exchange processes, it is likely that food security at the level of the entire community can be achieved because the Brasilia Legal community takes advantage of its social network both in terms of structure and tie strength to promote access to essential resource and its mobilization.

Due to the lack of health services in the community, health is mainly a collective endeavor based on traditional medicine through the growing and exchange of medicinal plants. In 2001, we conducted a study on the availability and exchanges of medicinal plants among families which revealed that more than 90% of the households have their own backyard where, on the average, 10 different medicinal plant species are grown, with numbers ranging from 2 to 38 (Mertens F., unpublished). The mapping of the exchange network of medicinal plants between households identified 59% of the backyards as a source of medicinal plants and revealed that 85% of households benefit from this shared resource. Since exchange relationships might preferentially be associated to strong ties, it is likely that the strong-tie small-world structure of the community favors access to the plant species used in traditional medicine and contributes significantly to collective health.

People from the community are exposed to mercury, a toxic substance with demonstrated adverse health effects, through fish consumption (e.g., Lebel et al., 1997). In 1998, we initiated a participatory pilot project in the village in order to reduce mercury exposure through a change in dietary behavior (e.g., Mertens et al., 2005). Our strategy was based on the very high fish biodiversity in the Amazon region that allows the population to choose among many different fish species for consumption, as well as on the discovery that mercury concentrations vary widely among fish species, the highest mercury levels being consistently found in carnivorous species and the lowest in herbivorous species (e.g., Lebel et al., 1997). The recommendation was that all fish can be eaten, but diet should be directed towards more frequent consumption of fish species with less contamination. To be able to modify their fish consumption to the less contaminated fish species, villagers have to know about the patterns of mercury accumulation in fish. Contact with the researchers,

participation in pilot project workshops and information exchanges through weak ties may all contribute to the awareness of the villagers (e.g., Mertens et al., 2005). However, for information to be trustworthy and form the basis for action, such as modifying fish consumption patterns, we postulate that strong ties need to be especially important.

To test this hypothesis, we compared the mean number of strong ties in the MSD network among the villagers who are at the unawareness, awareness or action stage regarding change in diet behavior to reduce mercury exposure. Awareness was measured as a dichotomous variable as whether the respondent knew about the difference in mercury accumulation between herbivorous and carnivorous fish and was able to distinguish between these two groups by identifying correctly at least one species in each category, among the fish found in the Tapajós region. Action was measured as a dichotomous variable as whether the respondent said that he/she has modified his/her fish consumption with the objective to reduce mercury exposure and was able to explain how this change was achieved. The mean number of strong tie increases significantly (ANOVA, $p<0.0001$) among the individuals who are at the unawareness (4.1), awareness (4.8) and action stage (6.2), respectively, suggesting an important role of strong ties in mediating circulation of informational resources to favor the adoption of healthy diet behavior.

The three examples illustrate how the strong-tie small-world structure integrating multiple social dimensions could contribute significantly to enhance the ability of the villagers to take advantage of the available resources embedded into the community social network to improve their quality of life. Indeed, the distinctive structural properties of the network can be linked to availability, access and mobilization of resources. The multiplicity of social dimensions integrated in the network forms the basis for source availability. Increased diversity of resources can be made available through the multiple social groups that are linked together in the network. Resource access is likely to be associated to the short average distance in the network. This property allows all members of the network to have access to resources, which can potentially be shared at the community level, rather than be restricted to small isolated groups. Mobilization of resources can be made effective because all individuals are linked through strong ties. Relations of trust associated to strong ties,

ensuring reciprocity and exchanges, can enhance the motivation to share resources at the community level. Altogether, these results regarding the relationships between network structure and the processes of resources availability, access and mobilization suggest that the identification of the strong-tie small-world topology can be used as an indicator of social capital in the community (38).

The above discussion emphasizes positive consequences that can be associated with a high level of social capital mediated through the strong-tie small-world structure. However, the same strong-ties structure that brings benefits to members of a community can also have less desirable effects, by contributing to the group's isolation and thus limiting its opportunities to take advantage of potential links to and resources from outsiders (e.g., Portes, 1998). In Brasilia Legal, community closure associated to strong ties may prevent success in the villagers' social, environmental, economical or political initiatives (Mertens F, unpublished data). At the social level, small-world networks linking all inhabitants together through strong ties in several social dimensions may intensify the capacity for mutual monitoring and strong enforcement of local norms, leading to restriction in personal freedoms, privacy and autonomy of individuals. Villagers also frequently ask for assistance and privileged access to resources from the main entrepreneurs of the community, whose economical activities might be hindered. Furthermore, members of the community have little control over the drastic environmental changes occurring rapidly at the regional level, like deforestation or exhaustion of fish stocks, which are mainly done by outsiders. Finally, at the political level, villagers have few interactions with the municipality where they have no political representative and achieve only limited success in obtaining resources from government institutions to improve community infrastructure and services.

MSD strong-tie small-world structure in diverse social contexts

In order to test whether the integration of different social dimensions may reveal the small-world strong-tie structure in other social contexts, we analyzed data from a network intra-organizational study carried out in a Canadian public institution where data have been collected for 5 different relationships among 25 individuals (Saint-Charles, unpublished

data). For each relationship, strong ties were defined by using a combination of a tie strength measure and reciprocity. As shown in table 5, single dimensional networks are fragmented into isolated (40-56% of the nodes), small components (8-28% of the nodes), while the largest components include at most a little above half of the nodes (28-52% of the nodes). By integrating all 5 types of relationships, the intra-organizational structure that emerges is a small-world network of people interacting through strong ties, including 88% of the nodes in a main component characterized by a small average distance (D = 2.1; D/D random = 0.9) and a high clustering coefficient (C = 0.48; C/C random = 2.8). Although this network has small size, this example illustrates that complex human interactions which simultaneously integrate multiple social dimensions might be a general principle underlying the widespread occurrence of the strong-tie small-world structure.

Conclusions

We argue that strong-tie small-world network structure could have been greatly overlooked in social networks because of the usual bias toward measuring network relations in separated social dimensions. We hope that the present study will stimulate the search for the strong-tie small-world structure in diverse social contexts where strong ties and multiple social dimensions have been shown to play in important role, like organizations (e.g., Hansen, 1999; Krackhardt and Stern, 1998; Nelson, 1989), ethnic business enclaves and niches (e.g., Portes, 1998), communities (e.g., Granovetter, 1983) and computer-supported social networks (e.g., Wellman et al., 1996).

Table 5: Structural properties and distribution of components size of the intra-organizational networks

	Friendship	Advice	Influence	Interaction	Support	MSD
Nodes	25	25	25	25	25	25
Links	22	32	24	26	28	82
Mean number of links per individual	0.9	1.3	1.0	1.0	1.1	3.3
Range of the number of links per individual	0-3	0-5	0-7	0-5	0-6	0-13
Isolates	11	10	14	11	12	3
Component size						
22	0	0	0	0	0	1
13	0	1	0	0	0	0
12	0	0	0	1	0	0
11	0	0	1	0	0	0
10	0	0	0	0	1	0
7	1	0	0	0	0	0
5	1	0	0	0	0	0
3	0	0	0	0	1	0
2	1	1	0	1	0	0
1	11	10	14	11	12	3

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CONCLUSION GÉNÉRALE

Les recherches menées dans le cadre de la présente thèse montrent l'importance des réseaux sociaux dans la circulation des informations et dans la mise en place de solutions participatives pour améliorer la santé humaine et la qualité de vie au niveau d'une communauté d'Amazonie brésilienne dont les habitants sont exposés au mercure en conséquence de l'utilisation traditionnelle des sols pour l'agriculture de subsistance. Les résultats convergent en montrant comment les concepts théoriques et méthodologiques de l'analyse des réseaux sociaux permettent une analyse approfondie des relations sociales au sein des processus participatifs qui sont au cœur de l'approche écosystémique à la santé.

Les résultats révèlent la diversité et les spécificités des processus sociaux associés à la participation communautaire au sein d'un projet de recherche qui s'appuie sur les approches écosystémiques à la santé humaine. Ils ont aussi permis de mettre en évidence une structure de réseau social, qui pourrait avoir une ample portée et être appliquée à divers contextes, en jetant la lumière sur les relations entre structure sociale, capital social et cohésion sociale au sein des communautés.

1. La diversité des processus sociaux associés à la participation communautaire : défis et opportunités pour une stratégie d'intervention

Les différents articles de la thèse mettent en évidence des processus sociaux distincts associés à la mise en place d'initiatives pour améliorer la qualité de vie et la santé du village de Brasilia Legal. Ils suscitent une importante interrogation : Comment intégrer la diversité de ces processus au sein d'une vision cohérente afin de construire une stratégie d'intervention participative locale et régionale face au problème de la contamination par le mercure?

Un ensemble de résultats pointent dans une direction commune afin de dresser une stratégie de recherche participative à l'échelle de la communauté : privilégier une approche participative collective par rapport à une intervention basée sur le rôle d'un petit nombre de personnes clé (leaders d'opinion) qui pourraient jouer un rôle multiplicateur et prendraient le relai des chercheurs dans la mise en place d'initiatives pour améliorer les conditions de vie de

la communauté. En effet, les processus de diffusion des changements alimentaires pour diminuer l'exposition au mercure semblent plus efficaces quand la communication est horizontale et implique le plus grand nombre de villageois et villageoises, que dans le cas où les informations atteignent les membres de la communauté par l'entremise de leaders d'opinion (chapitre I). De plus, il est important d'impliquer l'ensemble des familles au sein du processus participatif dans la mesure où la discussion entre les époux au sein de chacun des nombreux ménages est essentielle dans le choix des espèces de poissons les moins contaminées (chapitre II). Les résultats du chapitre III montrent qu'il existe des barrières qui affectent la participation des divers groupes sociaux et que des actions spécifiques sont nécessaires auprès de chacun de ceux-ci pour assurer l'implication de l'ensemble de la communauté autour de la question du mercure. Dans le même ordre d'idée, un processus de diffusion qui se baserait sur un nombre limité de personnes clé rend la durabilité des solutions mises en place vulnérable aux changements sociaux et environnementaux (Chapitre IV). De nouveaux résultats appuient ces conclusions. En effet, une étude récente a montré que les personnes de Brasilia Legal qui jouent un rôle prépondérant aux niveaux économiques et politiques et qui seraient des candidats potentiels sur lesquels les chercheurs pourraient penser s'appuyer, n'étaient pas impliquées significativement dans la promotion des solutions pour diminuer l'exposition au mercure (Demeda et Mertens, en préparation). L'approche collective n'exclut cependant pas de reconnaitre et de prendre en compte le rôle clé que peuvent jouer certains membres du village dans la promotion de la santé communautaire. Les résultats du chapitre III mettent d'ailleurs en évidence le rôle des femmes leaders d'opinion au niveau des processus de diffusion des changements alimentaires pour diminuer l'exposition au mercure. Il est important de s'appuyer sur leur capacité de mobilisation, même si leur rôle sera limité par la diversité des groupes sociaux et familiaux qui existent dans la communauté et qui ne seront probablement pas tous rejoints par leurs actions.

L'approche communautaire, même si elle permet de développer des solutions locales à court terme basé sur les changements alimentaires, fait cependant face à certaines limitations. En effet, le problème de la contamination par le mercure possède des causes environnementales et sociales régionales, à l'échelle du bassin versant. Les solutions mises en œuvre doivent tenir compte des facteurs environnementaux, politiques, sociaux et

économiques régionaux et impliquer l'ensemble des acteurs qui jouent un rôle au niveau des diverses questions qui s'articulent autour de la problématique.

En parallèle avec les études de réseaux menées à l'échelle avec la communauté de Brasilia Legal, nous avons entrepris une analyse des relations sociales entre les communautés riveraines du Tapajós impliquées dans la Phase régionale du projet Caruso. Les résultats préliminaires de cette étude ont montré que les relations entre les communautés étaient très peu développées et n'étaient pas associées à un processus d'organisation sociale qui pourrait déboucher vers la mise en place d'initiatives régionales en relation avec la problématique du mercure.

De plus, au-delà de l'importance de la participation des populations touchées par le problème, il est nécessaire de prendre en considération le rôle des autres catégories d'acteurs qui peuvent jouer un rôle face aux problèmes de santé associé à la contamination des écosystèmes par le mercure. L'implication des gestionnaires politiques, des organisations de la société civile et des secteurs économiques est une nouvelle priorité qui a été établie dans les projets de recherche qui ont fait suite au projet Caruso. Le projet PLUPH - Poor land use and poor health: primary prevention of human health through sound land-use for small-scale farmers of the humid tropics, 2007-2011 , financé par le Programme de partenariat Teasdale-Corti de recherché, en santé mondiale en est un exemple. Au sein de ce projet, l'analyse des réseaux sociaux est mise à profit pour cartographier les canaux de communication et de représentativité des communautés aux différents niveaux politiques, incluant les municipalités, l'état du Pará, le gouvernement fédéral et les instances internationales, qui tous jouent un rôle dans les questions de développement régional au niveau du bassin versant de la rivière Tapajós. Cette étude permettra d'identifier les barrières et les opportunités de collaborations entre échelles et entre secteurs pour viabiliser un processus participatif à la fois dans la construction et dans l'implémentation des projets de développement régionaux et des politiques publiques. Ces résultats pourront être utilisés pour mettre en place des solutions régionales qui vont au-delà des changements au niveau des habitudes alimentaires, mais qui s'attaquent aux sources environnementales et sociales de la contamination des écosystèmes amazoniens par le mercure.

2. La mise en évidence d'une nouvelle structure de réseau social : pistes de recherche sur les relations entre structure sociale, capital social et cohésion sociale au sein des communautés.

Les résultats du chapitre V révèlent une structure de réseau social qui n'avait pas été mise en évidence jusqu'ici : un petit monde de lien fort basé sur l'intégration de diverses relations sociales. Cette découverte a permis de lancer de nouvelles questions de recherche sur les relations entre la structure et la fonction des réseaux sociaux.

2.1. Le petit monde de liens forts rencontré au niveau du village de Brasília Legal en intégrant diverses relations sociales est-elle une structure atypique caractéristique de cette communauté ou au contraire une structure partagée par des communautés de différentes natures : villages, communautés scientifiques, organisations publiques et privées, etc.?

Pour répondre à cette question, il sera nécessaire de recueillir des données empiriques sur les relations existantes entre les membres de diverses communautés. De telles données ont été récemment recueillies pour une communauté régionale dans le cadre du projet Diálogos – construction d'un consensus autour de l'accès aux ressources naturelles en Amazonie brésilienne. Six mois de patient travail de terrain ont abouti au recensement des acteurs de la société civile, du secteur public et du secteur productif impliqués dans les actions de développement durable au niveau du Portail de l'Amazonie, un territoire de plusieurs dizaines de milliers de km^2 et qui englobe 16 municipalités situées à la frontière sud de l'Amazonie brésilienne (http://www.dialogos.org.br). Au total, 583 acteurs ont été identifiés et ont participé aux entrevues qui ont permis de recueillir des données de réseaux relatives à quatre dimensions : le dialogue, l'alliance, la confiance et le pouvoir en relation avec le thème du développement régional durable (Menezes et al, 2007). L'analyse de la structure des réseaux de cette communauté régionale est en cours.

2.2. Est-ce qu'une structure de liens interpersonnels forts de différents types formant un réseau en petit-monde, pourrait contribuer à expliquer l'émergence et le maintien de la cohésion sociale d'une communauté ?

La cohésion sociale peut être définie comme une volonté des gens de coopérer et de s'engager dans des partenariats avec leurs pairs (Jackson et al, 2000). Au-delà de cette définition globale, différentes définitions plus élaborées ont été proposées, les unes mettant l'accent sur la solidarité sociale (réduction des disparités, de l'exclusion, partage de valeurs et de défis, etc.) et les autres sur le capital social (accès à différentes ressources disponibles par l'entremise des relations sociales) (Berger-Schmitt, 2000). Pour répondre à cette question, il sera nécessaire d'analyser les propriétés structurelles et fonctionnelles des réseaux sociaux de liens forts établis selon des dimensions relationnelles uniques et multiples au sein de différentes communautés. Les propriétés structurelles des différents réseaux seront mises en relation avec des indicateurs macroéconomiques ou macrosociaux de cohésion sociale. Les caractéristiques et objectifs collectifs des diverses communautés étudiées (communautés locales de villageois, communauté régionale d'acteurs articulée autour d'objectifs communs, communautés de savoirs partagés par des chercheuses et chercheurs, organisations publiques et privées) pourraient guider le choix des dimensions relationnelles qui seront analysées et intégrées au sein des réseaux multidimensionnels ainsi que des indicateurs macroéconomiques ou macrosociaux de cohésion sociale.

2.3. La structure du petit monde de lien fort peut-elle être considérée comme une mesure intégratrice du capital social?

Mesurer le capital social demeure un défi qui est reflété par la grande diversité d'indicateurs qui ont été proposés pour mesurer les différentes dimensions du concept aux niveaux individuel et communautaire. (Portes, 1998). En tant que caractéristique d'un individu, le capital social est lié à l'accès et l'utilisation des ressources disponibles au niveau des réseaux sociaux auxquels l'individu est lié (Burt, 1992, Lin, 1999). En tant que caractéristique des communautés, le capital social est une propriété qui augmente la qualité de vie des membres du groupe, facilite l'action collective et la collaboration (Lin 1999; Putnam, 1995; Pretty, 2003; Pretty et Ward, 2001). Borgatti et al. (1998) ont proposé une série de mesures du capital social basée sur ces deux niveaux, incluant le nombre de connections pondérées par la force des liens et l'hétérogénéité des relations sociales au niveau individuel et la densité des liens et la faible distance moyenne entre les individus au niveau de la communauté. Ces diverses mesures du capital social sont maximisées au niveau

d'un réseau où les individus, en fonctions de leurs relations de différents types, sont connectés à d'autres qui appartiennent à divers groupes sociaux et séparés de ceux-ci par de courtes distances en moyenne. Dans la mesure où le petit monde de liens forts basé sur plusieurs dimensions sociales capture simultanément diverses mesures aux niveaux individuel et communautaire, il apparait important de tester si cette structure particulière peut être considérée comme un indicateur intégré associé à un niveau élevé de capital social? Afin de répondre à cette question, il est nécessaire de comparer la structure sociale de diverses communautés (villages, organisations, communautés de pratiques, groupes d'acteurs impliqués dans un projet collectifs, etc.) et d'analyser la possible relation entre les structures mises en évidence et l'accès et la mobilisation des ressources disponibles par l'entremise des relations sociales aux niveaux individuel et communautaire.

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